Good energy management in farm livestock buildings

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Good energy management in farm livestock buildings

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CONVERSION FACTORS

Metric units	Approximate conversion factors	Results in:
LINEAR		
millimetre (mm)	x 0.04	inch
centimetre (cm)	x 0.39	inch
metre (m)	x 3.28	feet
kilometre (km)	x 0.62	mile
AREA		
square centimetre (cm^2)	x 0.15	square inch
square metre (m^2)	x 1.2	square yard
square kilometre (km^2)	x 0.39	square mile
hectare (ha)	x 2.5	acres
VOLUME		
cubic centimetre (cm^3)	x 0.06	cubic inch
cubic metre (m^3)	x 35.31	cubic feet
	x 1.31	cubic yard
CAPACITY		
litre (L)	x 0.035	cubic feet
hectolitre (hL)	x 22	gallons
	x 2.5	bushels
WEIGHT		
gram (g)	x 0.04	oz avdp
kilogram (kg)	x 2.2	lb avdp
tonne (t)	x 1.1	short ton
AGRICULTURAL		
litres per hectare (L/ha)	x 0.089	gallons per acre
	x 0.357	quarts per acre
	x 0.71	pints per acre
millilitres per hectare (mL/ha)	x 0.014	fl. oz per acre
tonnes per hectare (t/ha)	x 0.45	tons per acre
kilograms per hectare (kg/ha)	x 0.89	lb per acre
grams per hectare (g/ha)	x 0.014	oz avdp per acre
plants per hectare (plants/ha)	x 0.405	plants per acre

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CONTENTS

PREFACE

We hope that this publication will be of assistance to you. Whether you are planning to erect a new building or are just looking for energy-saving ideas, attention to construction details and equipment selection, and some operating tips can save you money now.

We would especially like to thank Marcel Levesque, who acted as scientific adviser, and John Turnbull, both from the Engineering and Statistical Research Institute, Research Branch, Agriculture Canada, for their valued constructive criticisms and assistance during the preparation and writing of this publication.

In addition, we owe a debt of gratitude to representatives from almost every province who took the time to give us their valued suggestions for improvements of the draft. Most of them have been included.

Ralph G. Winfield, P. Eng.

INTRODUCTION

Energy use and, more particularly, energy cost are concerns of meat, milk, and egg producers across Canada. The monthly or quarterly energy bills often seem excessively high—and, indeed, in some instances they are higher than necessary. This publication is intended to point out inefficient energy uses and, it is hoped, to provide techniques or suggestions to reduce consumption by making more efficient use of conventional energy (electricity, oil, liquified petroleum gas (LPG),* or natural gas). This could include improving system designs and/or management; changing systems; or reusing energy that has been dumped, a common practice when energy was inexpensive.

The troubleshooting tables at the end of this publication should be of particular interest. If air quality or high heating costs are of concern, pinpointing the cause(s) and possible solutions is likely to be the first step in using the detailed information in this publication effectively.

New technology such as solar preheating of ventilation air, that is, or soon will be, cost effective, as conventional energy costs continue to increase, is discussed. Research and field trials are ongoing; thus any reference list quickly becomes outdated. However, the references listed in this publication, including the Canada Service Plan (CSP) plans, as well as more recent test reports and updated literature, should be available through all provincial agricultural extension offices.

ENERGY USES

Electrical energy is the one form of energy used in almost every animal and poultry housing unit because of its versatility. It is used for lighting, product cooling, feed processing, materials handling, and forced ventilation, and it can also be used for space and water heating. Oil, LPG, and natural gas are also used but primarily for heating; one exception to this is the use of an internal combustion engine, primarily the farm tractor, to process feed on the farmstead.

Energy for lighting is usually minimized by the use of windows, where practical, for example in the tie-stall dairy barn. Time clocks and dimmer switches can be used in swine-breeding buildings and poultry laying units where photoperiod is critical, and rate of gain can be regulated by adjusting the feeding time or frequency. When feed, which requires energy to produce, can be saved, the relative cost of electricity for controlled lighting is often minimal.

Energy for feed processing is a small part of the total feed cost. A field survey by Weeden and Norrish (1980) of electric-powered blender-grinders showed that energy used for feed processing ranged from 0.8 to 8.7 kWh/t. Most feed was processed with less than 5 kWh/t and, at $0.05/kWh, the cost was only $0.25/t. Although reductions are possible by using good mill maintenance and the largest screen hole size practical, potential energy savings are relatively small.

Materials handling, by augers, conveyors, silo unloaders, pumps, and so forth, is perceived by many to be a large energy user. This is not true of most Canadian farms. Relatively large motors are only operated for short time periods one to three times a day; thus, although electrical demand (kilowatts) and resultant size of service (amperage) might be large, the daily energy (kilowatt hours) usage could be small. Most farms are charged only for energy (kilowatt hours) and not for demand (kilowatts). If a demand charge is included, the peak demand can often be reduced by staggering the load use time. This might require completing feeding or manure removal operations before starting the milking equipment, or vice versa—a good management technique. When one considers that a silo unloader can be operated to handle a tonne of silage in minutes for a few cents, climbing the silo and forking is not a desirable alternative.

Space (air) and water heaters, continuous fan ventilators, and milk/egg coolers are the largest users of energy. A 270-L water heater emptied and reheated twice a day, 365 days a year, to sanitize milking equipment, may use 19 194 kWh/year, assuming 20% standby losses. At $0.05/kWh, the cost for this energy is $959.70. Heat removed from the milk could be used to replace a portion of that energy or steps could be taken to reduce hot water usage (wastage) or standby losses.

Similarly, a small (0.2 kW) exhaust fan operating continuously uses about 2628 kWh/year at a cost of $131.40, whereas a 5-kW electric fan-forced heater uses up to 120 kWh/day in the winter at a cost of $6.00. Again, an electrical energy cost of $0.05/kWh has been assumed.

Milk and eggs must be farm cooled to retain quality. Many young animals and birds require a controlled environment to survive in Canada's harsh winter climate and, at the same time, to gain weight at maximum rate with a near-minimum amount of feed. If certain animals or poultry are kept in a colder than optimum environment they will increase the feed requirement to reach market weight. Because feed costs represent about 65% of total production costs, the effects can be financially disastrous to the producer. To illustrate the "energy" cost of feed versus fuel, consider a well-insulated grower-finisher barn for 1000 hogs. To maintain a good gain rate of 0.8 kg/day, it is estimated that the extra feed consumed

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* Commonly referred to as propane.

by hogs for each 1 C° (Celsius degree) below the optimum temperature of 20°C, would be 0.02 kg/day for each kilogram of gain.

First, assume that the ventilation thermostats, or controllers, are set to maintain the barn air temperature at 8°C, without any supplemental heat. The barn temperature, therefore, is 20–8 = 12 C° below the optimum temperature (20°C), and the extra feed, priced at $250/t (or $0.25/kg), would cost:

1000 hogs × 12 C° × 0.02 × 0.8 kg/day × $0.25/kg = $48/day

Second, assume that the controllers in the barn are set for 20°C, and enough supplemental electric heat is supplied (0.02 kW per pig) to maintain a healthy indoor environment when it is -15°C outdoors. The extra heating, priced at $0.05/kWh, would cost:

1000 hogs × 24 hours per day × 0.02 kW per pig × $0.05/kWh = $24/day

The above examples are oversimplified, but even though the extra heating at $0.05/kWh is cheaper, they show that with electrical heat either feed energy or heat energy can be used to heat animals. Remember, of course, that social animals such as pigs, penned in groups and given access to enough dry bedding, can create their own microenvironment. This allows the manager to operate the building at a lower temperature, thus saving both heat and feed energy.

To a great extent, the energy and cost of maintaining a good environment in animal and poultry buildings can be controlled by the producer. An understanding of the objectives and of the system and its operation can, in many instances, save significant amounts of energy as well as dollars in reduced mortality and herd health costs. The primary purpose of this publication is to suggest ways of obtaining better environmental control in animal or poultry housing units with less conventional energy: in other words, to suggest ways of using energy wisely rather than wastefully.

HEAT BALANCES IN BUILDINGS

The heat balance of a building intended for environment control is like a bank account. The outflow of heat cannot exceed the inflow: if it does there will be a penalty. The penalty may be in the form of death losses due to an undesirable environment.

Heat losses

To insure comfort, health, and productivity of some animals and poultry a constant minimum air temperature within the building must be maintained—for example 21°C. If the outside air temperature is -20°C, a 41 C° temperature difference will be forcing heat to flow out of the building through the walls, ceiling, and concrete perimeter. This is one reason, and the most obvious, for insulating walls, ceiling, and perimeter—to stop *conduction* heat losses (Fig. 1).

Another equally important reason for insulating the building is to prevent *convection* and *radiation* heat losses. Convection losses are caused by warm building air giving up heat to cold wall surfaces. The heavier cooled air then moves down the wall surfaces and is replaced by more warm air at the top. This air circulation by convection causes undesirable drafts on animals penned near walls, particularly if they are on the floor.

The radiation heat loss is the direct radiation loss caused by a warm body, that of either the animal or the bird, radiating heat to a "visible" cold body, namely a poorly insulated outside wall or ceiling. When you sit near a campfire on a cold evening, one side of you absorbs the radiant heat from the fire, whereas the other side loses heat to the cold dark sky until you turn around (which you inevitably will do).

With most animal and poultry buildings the major heat loss is caused by air exchange from the building. Ventilation, or planned air exchange, is essential, but undesired air exchange above the minimum rate required in cold weather is expensive and wastes energy.

A well-insulated building is also highly desirable in very hot weather when animals are confined. It minimizes solar gain and temperature rise within the controlled environment area. A well-insulated confinement building is easier and cheaper to ventilate in summertime.

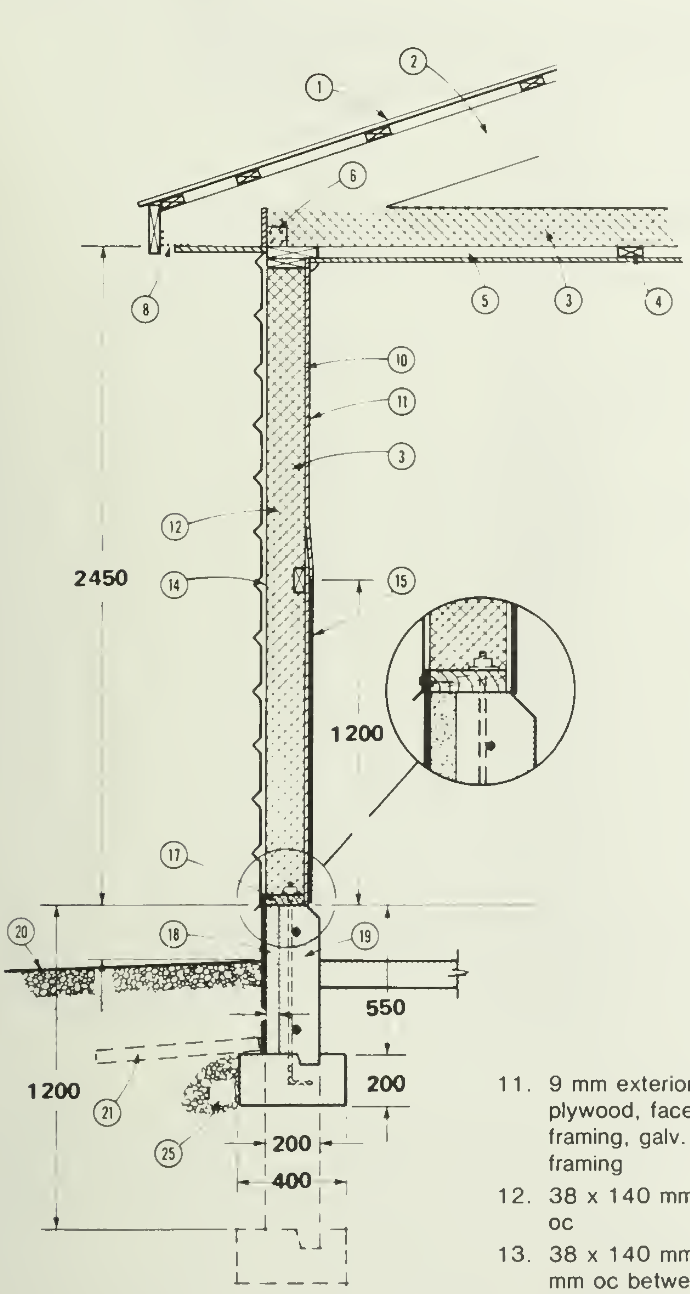
Heat gains

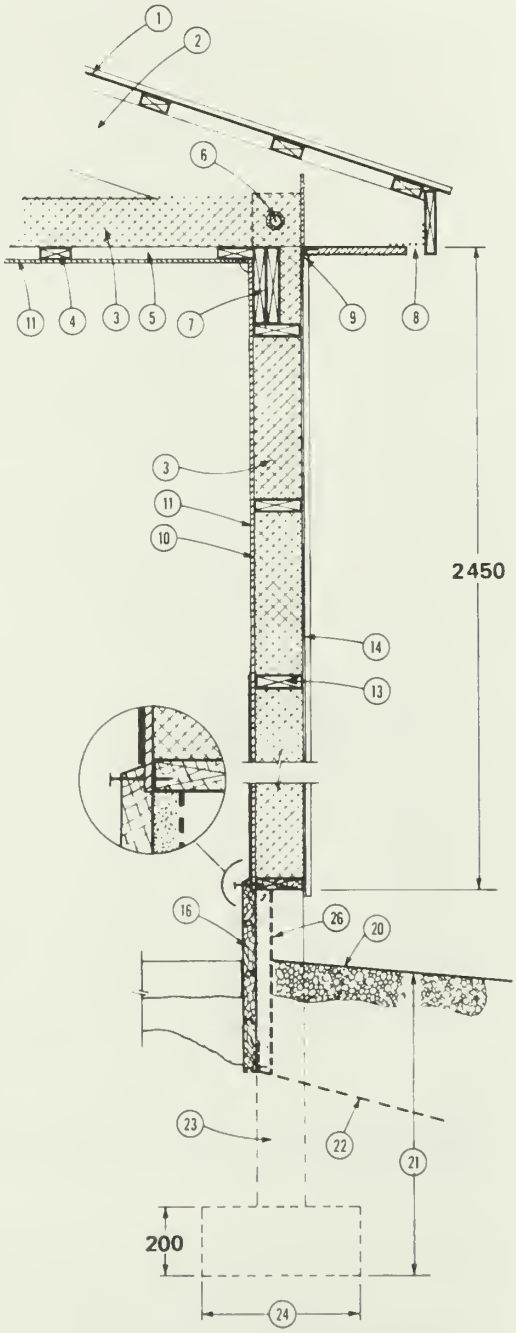
All animals and birds produce dry body heat, which can be felt and is referred to as sensible heat. This heat is available to warm the air in a confinement building, but its output is directly proportional to the activity level of the animals or birds. When inactive at night, the building heat requirement is higher because of the colder night temperature and lack of solar heat gain. Also, electrical equipment such as motors, lights, and radiant heating machinery produce additional heat while being operated.

In addition, animals and birds respire and give off moist or latent heat contained in the moisture vapor of their breath. It is this moisture, as well as some from waterers, manure, and wet floors, that must be removed continuously from confinement buildings, even in cold weather. Thus, ventilation or air exchange is required to bring in cold outside air, which must then be heated to the desired building temperature (e.g., 21°C), and to remove the moisture-laden air.

If the animals, birds, and equipment do not produce sufficient heat to match heat losses, then recovered or supplemental heat must be provided to balance the account, otherwise environmental conditions will deteriorate. Control of supplemental heat is the key to success in saving energy and money.

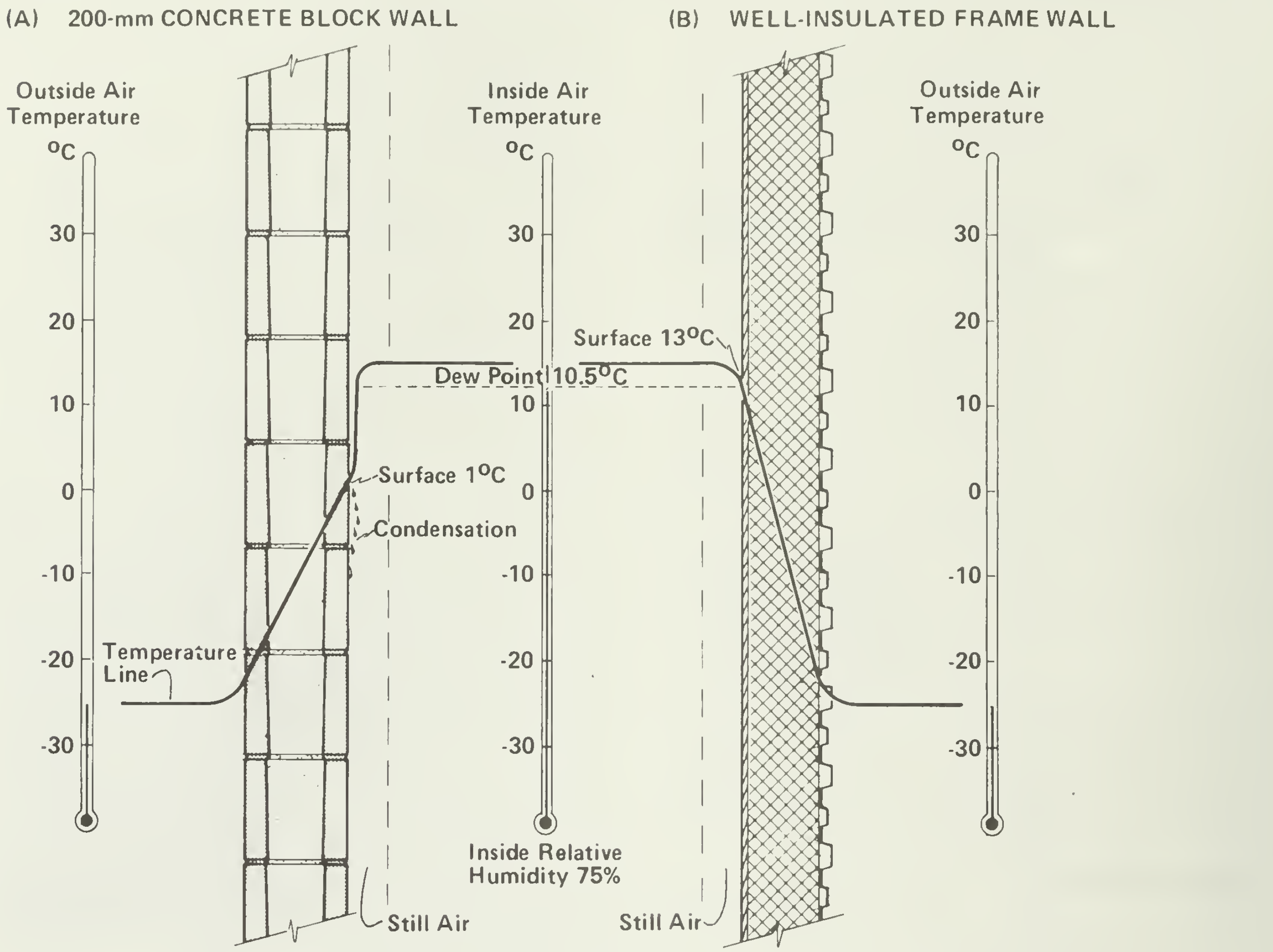
Fig. 1 Desired insulation systems for stud and pole frame wall construction.





1. roofing system to suit truss spacing (2)
2. roof trusses @ 600 or 1200 mm oc, depending on roof snow load and truss design
3. friction-fit glass fiber insulation, RSI-3.5 or better
4. 38 x 89 mm ceiling girts @ 1200 mm oc
5. 38 x 64 mm filler blocking between girts (4) at trusses
6. M12 bolt, truss to pole; or galv. steel nailing anchor, truss to plate
7. notch poles for 2-38 x 235 x 4800 mm plate beam, joints staggered 2400 mm at poles (23)
8. 50 mm vent slot, galv. bird screen, for attic ventilation
9. angle flashing 50 x 50 mm, bent from galv. steel
10. polyethylene vapor barrier
11. 9 mm exterior select sheathing plywood, face grain across framing, galv. roofing nails to framing
12. 38 x 140 mm studs @ 600 mm oc
13. 38 x 140 mm girts fitted @ 600 mm oc between poles (23), bottom girt CCA-pressure-treated
14. asphalt felt windproofing; sheet metal exterior cladding with corrugations across the framing, nailed or screwed beside the ribs
15. in pen areas 5 mm recompressed high-density cement asbestos board over plywood (11), pre-drill holes for galv. nails, caulk all edges
16. 38 x 140 x 4800 mm CCA-pressure-treated tongue and groove planking, end joints staggered 2400 mm at (23)
17. 38 x 140 mm CCA-treated sill
18. 50 mm polystyrene tacked with finishing nails to concrete form before placing concrete; after stripping forms, cover with 5 mm recompressed high-density cement-asbestos board nailed to sill (17) under siding (14)
19. concrete foundation, 15M rebars continuous top and bottom, M12 anchor bolts @ 1200 mm oc
20. gravel perimeter, or use eavestroughing
21. below frost, or add horizontal perimeter insulation with shallow footing and heat continuously
22. rodent stop, galv. hardware cloth nailed to (16)
23. 89 x 140 mm pressure-treated sawn wood pole @ 2400 mm oc
24. 400 mm diam. concrete footing under poles (23), increase diam. for wider building spans and softer soils
25. 100 mm footing drain tile or tubing to outlet, if drainage is poor
26. optional perimeter insulation and asbestos board

Fig. 2 Prevention of moisture vapor condensation on wall surface by insulation.



HOW ENVIRONMENTAL CONTROL IS ACHIEVED

For young animals and birds requiring a constant minimum temperature, for example 21°C, a well-insulated building is essential. It will minimize heat losses by conduction, convection, and radiation, thus providing the opportunity for a warm, dry, and draft-free environment. But respired moisture as well as gases and dust must be removed; therefore, ventilation is essential to change the air. In cold weather the rate of change is dictated by the relative humidity (RH) of the room air. If the building is well insulated, RH can rise to 80% of the saturation capacity of the air before the air feels damp and before condensation begins to appear on cold building surfaces. Fig. 2 illustrates the principle of air being cooled to its dew point or saturation temperature at a cold wall surface. If condensation occurs, convection drafts will also occur, and building deterioration will be accelerated by water on and in the structural components.

An alternative to a well-insulated building is to lower the RH by increasing the ventilation rate while maintaining building temperature. This alternative is very energy expensive and should not be used except for a short time or in an emergency. Even with a well-insulated building, ventilation heat loss greatly exceeds the building shell or conducted heat losses (Fig. 3). In cold weather (-18°C), a well-insulated pig weaner room at 21°C requires 15.6 times as much energy to replace ventilation heat losses as to replace building heat losses. With the minimum ventilation needed for moisture control, weaner pigs are able to supply 58% of the heat energy required. Because the heat deficit is already 16 kW with 80% RH air, any further RH depression by overventilation would have to be supplied (100%) with purchased or recovered heat energy.

Fig. 3 Ventilation heat losses in cold weather exceed building heat losses in well-insulated swine facilities to maintain inside relative humidities just below 80%.

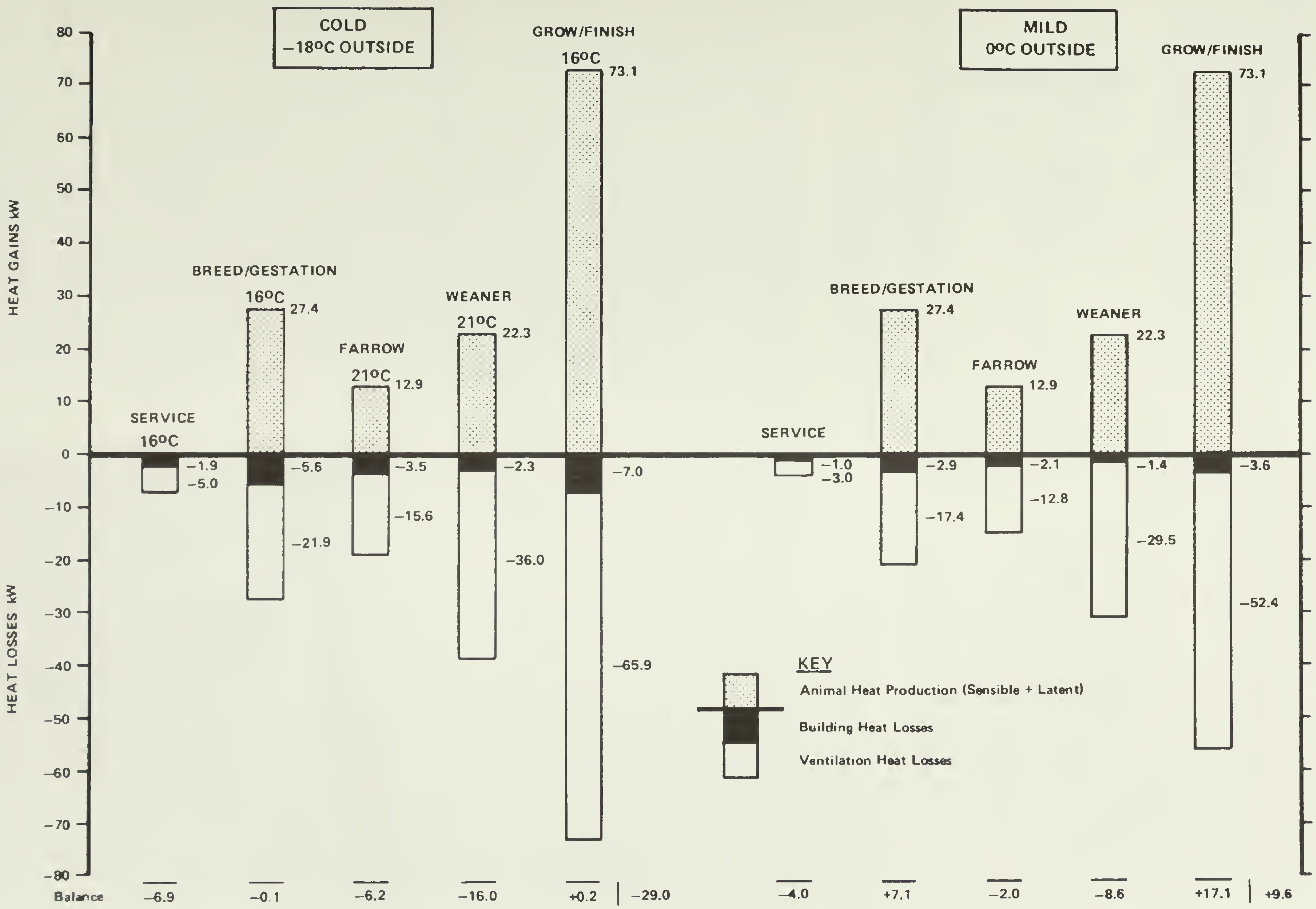
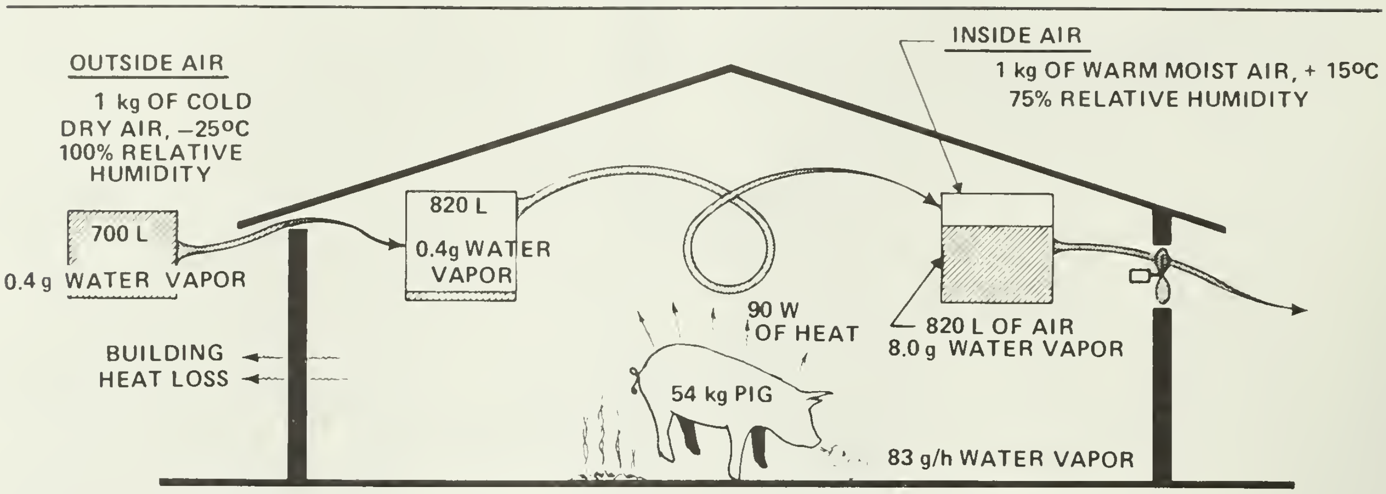


Fig. 4 Cold winter air when warmed can carry a significant quantity of moisture vapor produced by animals or birds.



Winter removal of moisture

When cold, nearly saturated, outside air is heated to room temperature, it has a much greater capacity to carry moisture vapor (Fig. 4). One kilogram of cold air, or 700 L, carries only 0.4 g of water vapor at saturation—100% RH. When heated from -25° to +15°C, the now expanded 820 L of air can carry 8.0 g of water vapor when only 75% saturated. The pickup potential is 7.6 g of water per 820 L of air exhausted. When room air is exhausted back into the cold outside air and cooled, moisture vapor condenses outside, creating extensive visible fog around fan hoods on clear bright mornings (Fig. 5). A great deal of heat is discharged in this exhaust air and heat reclaimers are being used to recapture some of it.

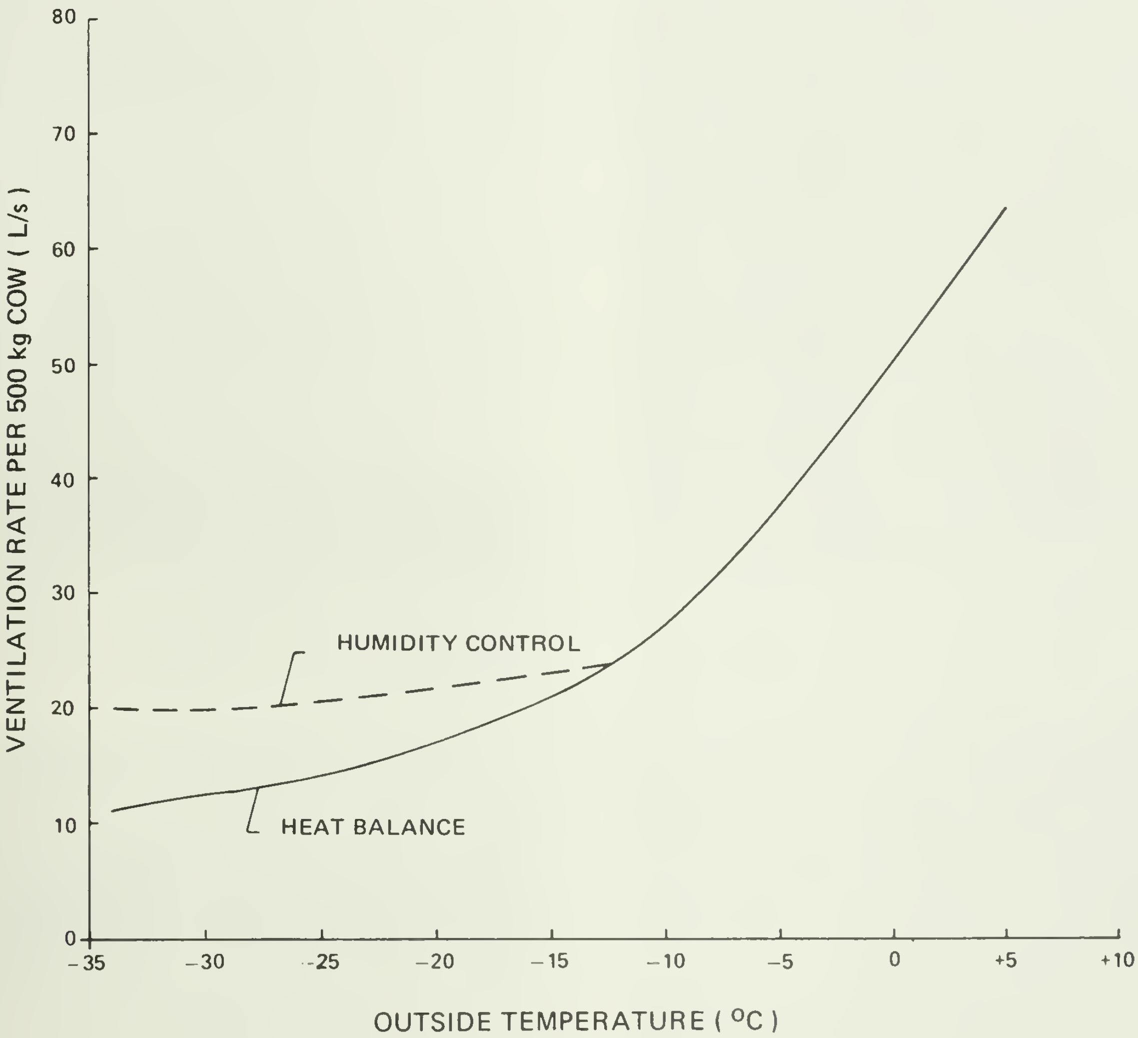
Fig. 5 Exhaust air is saturated when discharged into cold outside air.

Removal of heat

At a specific outside temperature, depending on the housing unit, animal or bird size, and building space per animal, a point is reached where excess heat, not moisture, becomes the factor determining air exchange or ventilation rate. This temperature is commonly referred to as the critical (or heat deficit) temperature, below which supplemental heat may be required. Fig. 6 illustrates a typical example for a tie-stall dairy barn. When temperature is below -12°C, a dilemma occurs. One can either underventilate by maintaining building temperature (heat balance) and allowing moisture vapor to accumulate—an acceptable temporary practice, for example for one or two cold nights—or add supplemental heat to force moisture or humidity control ventilation, which is expensive for a dairy barn. A better alternative is to reduce building temperature (highly desirable in many dairy barns), as long as the temperature stays a few degrees above freezing, at 7°C for instance. Milk production with Holsteins will not be significantly affected and the air will be fresher, for example, and less humid. Most mature animals are capable of adapting to lower housing temperatures and will, in fact, compensate by producing more sensible (dry body) heat and less latent heat. This same philosophy *cannot* be applied to a brooding or farrowing/weaning application. Below the heat deficit temperature, supplemental heat or heat recovery should be added. Proper heating equipment sizing and control can insure the desired moisture control ventilation without wasting heat energy.

Above the heat deficit temperature, excess animal or bird heat must be removed by increasing the ventilation rate by at least two or three levels as the outside temperature increases. This can be achieved with a combination of variable speed, two-speed, and/or multiple exhaust fans designed for the number and size of animals or birds present. In some instances, increased summer ventilation rates can also be achieved with natural (no fan) ventilation.

Fig. 6 Ventilation rates for heat balance and humidity control in a tie-stall dairy barn.



THE ENERGY COST OF ENVIRONMENTAL CONTROL

As discussed earlier, overventilation with supplemental heat remaining on causes a waste of heat energy and money.

Overventilation can occur as a result of any one of the following situations:

a) To reduce RH in a building that is poorly insulated.
b) A building that is not properly closed up, permitting the infiltration of outside air.
c) Ventilation fans that are improperly sized or rated (continuous or moisture control).
d) Thermostatic controls that are inaccurate or dirty.
e) Thermostatic controls that are not properly located (a heater control in a cool draft will force overventilation).
f) Thermostatic controls that are on higher-capacity (e.g., temperature control) fan(s) set too low or inaccurately calibrated.

If overventilation in cold weather continues for any reason the cost will be high. For example, in a building that has an overventilation rate of 500 L/s when the outside temperature is -18°C and the inside temperature is +21°C, the excess, or wasted, supplemental heat could be as much as 574 kWh, or $28.70/day, based on a cost of $0.05/kWh. This is assuming the supplemental heating equipment is large enough to provide that heat, which it often is, because of oversized heating units having been installed for safety margin.

For the weaner barn listed in Fig. 3, it is possible that under the same temperature conditions as quoted in the foregoing example, 384 kWh (16 kW × 24 hours), costing $19.20/day, based on a cost of $0.05/kWh, might be required. But if the overventilation cost of $28.70 is added, the heating energy cost could be $47.90, or almost two and one-half times that required. The same increase would apply regardless of the type of fuel used for heating.

Based on a feed cost of $250.00/t, $19.20 represents a feed equivalent of 77 kg, whereas $47.90 represents 192 kg of feed. The $19.20 is better spent on heat energy than on feed energy; however, the energy wastage by overventilation from $19.20 to $47.90/day is not likely to bring about a feed savings of 115 kg/day when temperature and RH control are already near optimum.

Gaining control of air exchange

Obtaining the desired cold weather exhaust rates is not always easy. To date, no standardized agricultural fan-testing program is mandatory in Canada. Work is being done on this essential need and should be encouraged. The testing of 450-mm exhaust fans by Huffman and Pegg (1981) indicated significant flow rate variations, particularly at low speeds. The power efficiency also varied markedly from one manufacturer to another; that is, litres per second of fan output per watt of power input.

At present, the best recommendation is to insure that the critical winter ventilation range is bracketed, which means that two ventilation rates are available, one just below the required rate and the other just above it, to allow for maximum rate flexibility. This is particularly critical in buildings where animal or bird weight, or density, is variable, for example a swine-finishing unit or a poultry brooding unit. Bracketing can be illustrated by using the graph in Fig. 6. A low continuous exhaust rate of 10 L/s per 500-kg cow should be available with provision to increase to just over 20 L/s. This can often be done with one or more two-speed fans, or two small fans, depending on the size and shape of the building space. Two or three additional temperature control ventilation levels should be available to increase the total ventilation rate in steps as the outside temperature increases above -12°C. The maximum summer rate will be dependent on the housing system desired. In some instances, natural ventilation can be used during the summer period if adequate building openings such as windows, doors, and tilt panels are available.

The actual rate of moisture production by animals or birds is variable, depending on factors such as housing system, manure handling/storage system, and feed. Field-scale tests in Alberta by Clark et al. (1980) and Smith et al. (1980), in swine feeder barns and dairy barns showed significant variations in required moisture removal rates, and thus in required air exchange rates. These management factors make a flexible ventilation system design by bracketing an essential requirement, particularly for winter conditions, to minimize supplemental heat energy while maintaining a nearly ideal environment.

Power efficiency of fans is important but should not be overemphasized to the detriment of the year-round system. It is a well-known fact that large diameter, slow-speed fans are more energy efficient. They produce more airflow (litres per second) per watt of power input and should be used for high airflow summer ventilation. However, a serious energy error can occur if these fans are used for constant-temperature winter ventilation. Except for very large production units, for example caged laying hens, these larger fans may cause overventilation, which is energy expensive if supplemental heat is added, or they may cause erratic (on-off) ventilation. On-off low-level winter ventilation, using a cycling time clock control, should not be used except when necessary in small areas, e.g., small farrowing units. Even short-term ammonia and moisture buildup creates an undesirable environment and accelerates building deterioration. Some fan manufacturers are supplying small, low flow rate fans for small production units. These fans should be used even if their power efficiency is low. For example, the potential savings of supplemental heat energy greatly exceed the fan energy savings in small farrowing rooms or heated calf nurseries.

The totally controlled natural ventilation concept to minimize air-moving energy is gaining in popularity in some regions of Canada. It is being used successfully in modified environment barns for dairy and beef animals—where minimum temperature control is not critical—and even for swine feeder barns in warmer regions.

ENERGY CONSUMPTION CAN BE REDUCED—WITH EXISTING TECHNOLOGY

Getting air into a building effectively and efficiently

Getting air into a building effectively is important. Most controlled-environment animal and poultry housing units in Canada are ventilated by the negative pressure system. Exhaust fans create a slight negative pressure within the building as they push air out (Fig. 7). With this system, the difference in static pressure can be measured in millimetres of water column, or pascals, using a U-tube manometer. A more practical unit is a slant-tube manometer, which measures the slight differences in static pressure more accurately (Fig. 8). The "high" column should be extended to the ventilated attic, at outside pressure, to eliminate wind effect. The "low" column should be turned down to keep dust and so forth, out of the special gauge oil. The manometer is an effective guide for adjusting slot-type air inlets (Fig. 9).

Fig. 7 Exhaust fans create a slight negative pressure within the building, causing air to enter by inlets or cracks. This air must then be uniformly distributed.

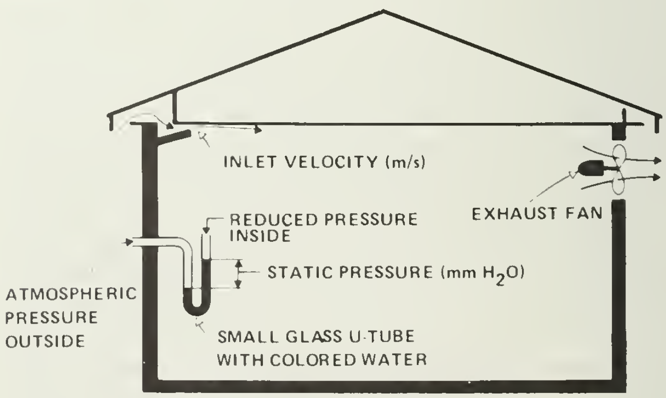


Fig. 8 A slant-tube manometer is used to measure negative pressure for accurate air inlet adjustment to insure jetting.

Fig. 10 A slot-type air inlet complete with a small boat winch for adjustment.

Fig. 9 Air inlet slots must be adjusted properly to insure air mixing without drafts.

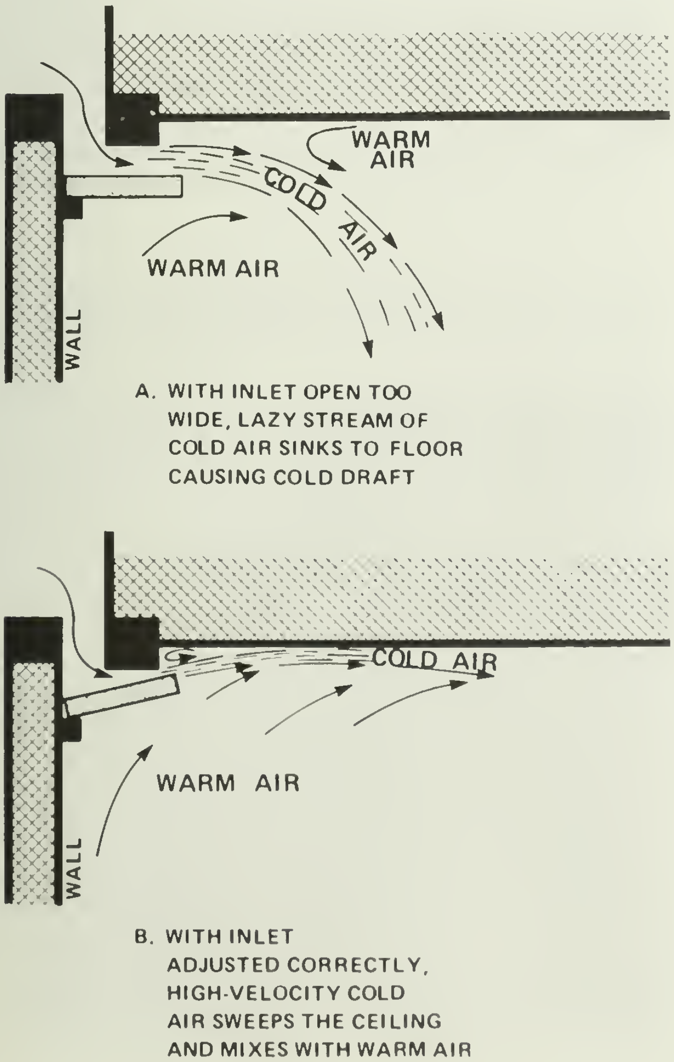


Fig. 10 shows a slot-type air inlet complete with a small boat winch for adjustment. The air inlet location determines the distribution of fresh air within the room. The adjustment determines the extent of air mixing to provide the animals or birds with fresh air without drafts. Fig. 9 illustrates the mixing concept. Air inlet velocity should be at least 4 m/s to provide good mixing and circulation within the building, but it should be limited to about 5 m/s to prevent overloading the exhaust fans, reducing their output, energy efficiency, and motor life.

Getting air into a building efficiently is also important. The *air intake* (or delivery section to the air inlet) must be properly sized and located. The intake can have various configurations but application of some basic principles are essential.

1. The *intake area* must be large enough to meet summer ventilation requirements. Many systems fail to be effective or efficient because they cannot meet the demands required of them. If the intake area, usually in the soffit, is too small, the exhaust fans will be overloaded and less efficient, hot attic air might be drawn down, and air from the inlet will not jet properly to provide air circulation within the building space. Typical solutions to this hot weather problem are to open one, or more, doors or to add more exhaust fans to provide relief from heat stress. Neither of these solutions should be necessary; extra fans add to energy usage, whereas open doors make some animals or birds comfortable at the expense of others not fortunate enough to be penned in front of the doorway(s).

The summer intake area should permit air to pass at a speed, or velocity (V), of not more than 2 m/s, if straight, and not more than 1–1.5 m/s, around sharp bends; the air can then be accelerated to 4 m/s at the

Fig. 11 It is essential that an air intake slot be of sufficient width, set out from the vertical wall, and screened to prevent bird entry.

Fig. 12 This air intake has small (fly) screening, which fills with dust, and a roller door track, which restricts intake airflow. Both of these situations are undesirable.

air inlet slot by the exhaust fans. If air friction losses are too high on the way to the inlet slot, the inlet will be ineffective and will not initiate good air circulation within the building space, particularly at the level of the animals or birds.

Sizing the intake is relatively simple, since 1 L equals 0.001 m^3. For example, if a building has a summer ventilation requirement (Q) of 6000 L/s, the minimum *air intake area* (A) leading to the inlet slot should be at least:

$$A = \frac{Q}{V} = \frac{m^3/s}{m/s} = m^2 = \frac{6000\ L/s \times 0.001\ m^3 L}{2\ m/s} = 3\ m^2$$

During hot weather operation, the *inlet slot* should provide a total opening of only 1.5 m^2 for this example to maintain the 4 m/s air-jetting velocity. Inlet velocity is easily determined by a slant-tube manometer (Fig. 8) providing a water reading of 1.3 mm, or 13 Pa. If the reading is up and the air does not jet properly, look for an inadequate or restricted air intake. Air intakes should be screened to keep out wild birds and rodents (Fig. 11). A coarse screen (6 × 6 mm mesh) is most suitable for this purpose; a finer screen will also keep out insects, but it tends to plug with dust and other material too frequently, restricting air intake (Fig. 12). Flies and other insects always attempt to avoid a fast-moving airstream.

2. Air intakes must be protected from wind and snow. If the intake is in the soffit, it should be located next to the face board; it should *not* be adjacent to the vertical building wall where snow can be blown in (Fig. 13). Also, wind can create a positive pressure at the air intake, causing undesirable overventilation in cold weather. With long buildings that are not protected from wind by trees or other buildings, wind blowing at an angle on a poorly located and poorly protected air intake can cause reverse airflow by creating a negative pressure at the prevailing, or upwind, end of the air intake, and a positive pressure at the leeward, or downwind, end. This situation can cause severe temperature and ventilation differences along the building. Wind problems are often more serious if a silo, milk house, or other attachment is sited along the

Fig. 13 This screened air intake has sufficient width for summer ventilation, is located away from the vertical wall, and has a door to further reduce wind and snow effects during winter operation.

building. Such buildings become wind-stops and create a high-pressure zone on the upwind side and a negative-pressure zone on the downwind side.

A screened air intake just behind the face board usually eliminates most problems. For many buildings, a narrower-than-opening hinged door as shown in Fig. 13 is a worthwhile addition, and can be closed all winter, because cracks along the door will provide adequate winter air intake. Some winter ventilation air can also be drawn from the attic if the air intake is over-the-plate; this is not detrimental providing continuous ventilation is assured to prevent backdrafting.

If the intake system is through-the-wall, for example in multistory broiler houses, the opening should be hooded, with the hood extending below the wall opening, and having the back flange set out from the wall face by at least 100 mm (Figs. 19–22). Where a problem exists, it can often be eliminated or minimized by attaching a galvanized or painted metal air scoop to the wall at the air intake entrance, thus redirecting the air coming up the wall as a result of wind. It is essential that the air intake area not be restricted to less than the desired size by the wind diverter.

For long one-room buildings with temperature variation occurring along the length due to wind effect, intermittent blocking to section the air intake/inlet system is often a practical solution. Sectioning prevents pressure variation along a continuous air inlet system. Some temporary relief has been achieved by cross wiring the continuous winter ventilation fans, but this is not the most desirable long-term solution. By cross wiring, if the building runs north-south, the north fan is operated by the south thermostat, and vice versa.

Efficient air intake and inlet design with wind and snow protection is an essential part of a workable ventilation system.

Proper attic ventilation

Attic space above controlled environment areas must be well ventilated for the following reasons: (*1*) to prevent condensation, and (*2*) to reduce summer heat load.

Regardless of the care taken by the building contractor, some moisture vapor will permeate the ceiling. Even with a good vapor barrier in place, ceiling fasteners will puncture it, allowing moisture vapor to enter the attic space. If moisture vapor is not removed by air exchange it will condense, causing wet insulation, reduced R value, and structural deterioration. This need for air exchange is greatly increased when a porous ceiling is used as a winter air inlet (see Agric. Can. Publ. 1714, *Tie-stall dairy cattle housing*).

From another energy viewpoint, the attic must be well ventilated to reduce summer heat load. Unventilated attic temperature can rise to over 50°C on a bright summer day. The best arrangement is a continuous-screened eave slot to permit air entry and either gable or ridge ventilators to allow warmed air to escape (Figs. 14, 15). If ventilation openings are adequate, fan-powered attic ventilation should not be required.

Whenever possible, the roof sheathing should be a light color, for example white or aluminum. Some people will argue that a dark roof acts as a solar collector in the winter time; this might be a factor, but a 1:3 sloped roof is a poor winter solar collector in Canada's northerly latitudes (above 40°). The dark

Fig. 14 This perforated soffit is adequate for attic ventilation air intake only, and should not be used for summer building air intake. The open area provides only a fraction of the requirement.

Fig. 15 This gable-end louvre permits discharge of hot attic air in summer. Larger gable-end louvres can also be used as air intakes for center air inlet systems.

roof, as a bare-plate collector, reradiates heat to a clear night sky and causes the attic temperature to go *below* outside air temperature when this heat is needed most—at night (Winfield and Munroe 1980).

The continuous eave air slot can be part of the building air intake system (for over-the-plate systems), to reduce construction labor. With such an arrangement it is essential that blocking be placed between the trusses, leaving only a narrow slot at the top for attic ventilation air to pass. This blocking holds and/or prevents the ceiling insulation from being moved by wind or from falling into the air inlet. In addition, and more importantly, from an energy/environment standpoint during the summer, blocking will minimize the amount of warm attic air drawn to the air inlet. In many buildings *with inadequate summer air intake area* under the eaves, ventilation air is drawn from the attic space via ridge or gable openings. This can cause severe overheating unless some insulation has been placed under the roofing to minimize solar heat gain. The exhaust fan system capacity is often considered the cause of increased room temperature; increasing the fan capacity increases this effect and the fan energy cost as well. The solution is to increase the air intake area.

Fan-forced air circulation/recirculation

Many package systems are available commercially or can be fabricated. Using fans to introduce, circulate, or recirculate air for a controlled-environment building adds to the electrical energy consumption. However, this should not be a major winter concern, because the energy becomes available indirectly as supplemental heat, if it is required in the building during cold weather operation.

For older buildings being converted for controlled environment, these package systems often provide the most practical and cost effective means of getting air distributed within the building space. Barns with thick masonry walls, excessive width, and other obstacles such as solid walls for multi-room farrowing all come into this grouping.

Forced-air distribution units also help to distribute warmed air from heat exchangers (reclaimers) that provide point source air inlets. This air must be distributed to all animals or birds within the building to avoid dead air spots.

Air recirculation used for controlled environment buildings with high or cathedral-type ceilings, can also save energy by preventing temperature stratification, or layering, at low winter ventilation rates. The only concerns with air recirculation are as follows: (*1*) the potential for airborne disease organisms (pathogens) to be spread more quickly to all animals or birds, and (*2*) the potential for drafts to be created if high-velocity air jets are deflected onto the animals or birds by obstacles in the air path.

The external configuration of packaged intake/exhaust systems, which provide recirculation, should also be considered. If cooled winter exhaust air carrying water droplets (see Fig. 5), are redirected by wind back into the intake, the water droplets must be revaporized, which requires a significant amount of heat energy. In a heat deficit situation, which is likely in very cold weather, the relative humidity in the building will rise, even though an adequate exhaust rate is maintained. The end result can be either a high heating bill to force overventilation or very moist conditions inside the building. Baffles to separate exhaust from intake airflows (or other external wind protection such as fan hoods), will usually solve the problem.

Ventilation without fans

From a purchased energy standpoint, ventilation without fans is highly desirable. The concept has been and should continue to be used for modified environment animal housing facilities, provided feed costs are not significantly increased. Modified environment occurs when the internal building temperature fluctuates but stays within 5–8 C° above the outside temperature. This small temperature difference causes heavier cooler air to enter at the eaves or wall panels, and lighter warmer air to rise and exit through an open ridge. Modified environment is often used for beef, free-stall dairy, and dairy herd replacement animals, because the performance of these well-coated animals is not adversely affected by low or fluctuating temperatures (Fig. 16).

Increased energy cost has created a renewed interest in naturally ventilated swine-housing units in Canada. There are two basic styles of housing unit, one of which is shown in Fig. 17. For both the monoslope-style roof unit and the gable-style roof unit, the principle of operation is similar. As in modified environment buildings, each ceiling is sloped to match the roof. The buildings are well insulated, and air is let in low and let out high, using panels or dampers that are thermostatically or manually adjusted to control building temperature. These buildings do save ventilation energy and seem to work well with growing/finishing swine when management is above average. Although naturally ventilated barns are likely to increase in popularity, it is doubtful that this system will replace fan-ventilated buildings for farrowing and brooding. Winter exhaust fans, air-circulating systems, and heat-recovery systems may be required in buildings that are located in the colder agricultural regions of Canada.

Exhaust fans

Location. The position of exhaust fans that control air exchange or ventilation rate, as discussed earlier, is not as critical as often claimed. The exceptions are very long buildings; old two-story dairy barns with sufficient cracks or holes to act as air inlets; buildings that house more than one type/size of

Fig. 16 Open front, tilt panel, or other air inlet control for modified environment dairy/beef buildings eliminates fan and energy costs. The warm moisture-laden air rises out through a properly designed ridge opening.

Fig. 17 Thermostatic controls operate air intake panels (lower) and ridge opening (upper) to maintain winter temperature. The warmed air moves upward by thermosiphon action in this gable-style swine-feeder barn.

animal; or old "leaky" buildings to which a new tighter section has been added to extend one environmental area.

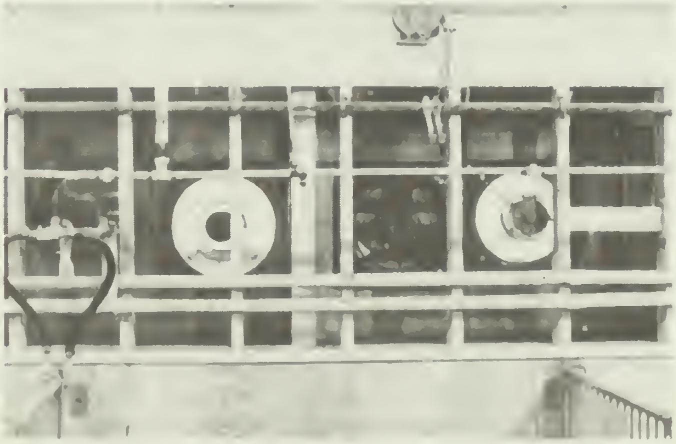
Basically, exhaust fans only create the incentive for fresh air to enter through any building opening, planned or otherwise; therefore, the inlet system, not the location of exhaust fans, determines the incoming fresh air distribution within the building space.

For buildings that are longer than 30 m, it is advisable to space the fans out in groups of two or three to minimize the concentration of stale used air in the room near the exhaust fans. This is of greatest concern with year-round ventilation in extremely hot weather. However, large fans can and should be paired with smaller fans to provide maximum rate flexibility at minimum installation cost and to permit the use of some higher capacity, more energy efficient fans; this assumes good inlet design and adjustment throughout the building to assure fresh air distribution.

If fans are installed in a group in a fan house (for safety and ease of maintenance), it is essential that the opening through the wall be large enough to minimize air friction losses where room air must accelerate through the opening (Fig. 18). Contrary to some thinking, a wall-mounted exhaust fan does not create a high air velocity in the building; it does so only on the downstream side or outside of the building.

In old two-story dairy barns where cracks around windows, doors, gutter ports, and over the plate are used for winter air inlets, the location of exhaust fans

Fig. 18 This wall opening is large enough to provide a free flow of air to the exhaust fans located in the fan house.



can be critical to optimize air distribution. Although these random air inlets are not adjustable, some sealing can be done or inlets added, if necessary, to permit the fan(s) to be located away from the milk house and not directed toward the farm residence.

Buildings housing more than one class or size of animal in the same environmental space present a unique problem, which should be resolved by environmental separation whenever possible. But many dairy farmers, for example, house some or all replacements at one end of the barn.

One reaction might be to put the winter (moisture control) ventilation fan over the younger animals, which are often on a manure pack. The argument is that heat from the mature cows will warm the calves. In fact, air from the cows is already at 75–80% relative humidity (RH) when drawn to the replacement section of the building. This section is inevitably several degrees cooler due to building "corner" heat losses and lower heat output from younger animals. The used, moisture-laden air, when cooled, can approach 100% RH, causing condensation on cold surfaces, and even fogging. This is not a good environment for younger animals, because used air will also contain airborne pathogens (bacteria and viruses) from the cows. Another reaction might be to locate supplemental heaters over the calves. This would involve warming all the winter ventilation air just before discharge, which is not an efficient use of either energy or money.

The best action to take is to locate the same exhaust fan near the center of concentration of the mature cows. Although the calf environment might become slightly cooler as a result of this action, it will be much healthier. Only a small amount of heat would need to be added in the calf area to warm incoming air, should the operator wish to have a warmer environment. Herd replacement calves need only a dry, draft-free environment, which is better provided in a separate room or even in calf hutches.

When a new tightly constructed addition is attached directly to an older "leaky" building, fan location problems can occur. The best solution, but not necessarily the cheapest one, is to tighten up the old building by insulating and sheathing, and then to put continuous air inlets throughout the total building space. If the addition is short, a workable solution is to locate at least one winter fan in the end of the new addition and let the cracks of the old building become the air inlet. An alternative is to provide air inlets, similar to cracks, in the new addition by using a porous ceiling. (Again, see Agric. Can. Publ. 1714, *Tie-stall dairy cattle housing,* for details of the porous ceiling concept.)

Installation.

Proper installation and adjustments, when necessary, of ventilation exhaust fans are often neglected. The building contractor provides the openings where fans are to be installed, the electrician provides the wiring, but neither one is concerned about responsibility for performance. Fans may be located in any wall of a barn or fan house, or over a fan-mounting plate, but care must be taken to insure that adequate free air can get to them.

A fan-mounting plate should be sealed and secured to the wall. If air leaks in around the fan, the effective ventilation rate is reduced because of short-circuiting. Leakage reduces system performance and efficiency, because energy will be ineffectively used. It also allows cold air to enter, which causes condensation and corrosion of the metal fan-mounting plate, a familiar sight in many barns.

Always check the location of the fan blade in the orifice plate. Some fan blades, particularly those on large-diameter belt-driven fans, are set back on the shaft to prevent damage during shipment. If the fan blade is not set out as illustrated in Fig. 19, fan output and efficiency could be reduced significantly. Many ventilation systems have failed to perform as designed because of this oversight.

Always have the fan wired in accordance with the local electrical code. Operating efficiency and motor life can be increased by using a conductor that is larger than the minimum size. When a conductor is overloaded, voltage at the motor is reduced. This, in turn, causes the motor to attempt to compensate by drawing more current, an action which causes the wire to become warm, and such heat represents wasted energy.

Operate fan motors on 240 V (volts) rather than on 120 V, whenever possible; this reduces the current (amperage) by 50% to deliver the same amount of power. Lower current means lower line losses and less voltage drop in the conductors. This voltage drop becomes increasingly critical as fans get farther away from the electrical service panel.

Fan hoods and louvres.

Most agricultural exhaust fans come with louvres or back-draft dampers attached (Fig. 19). Their purpose is to prevent entry of outside air through the fan when it is not operating. Such airflow prevention is critical for all fans except for those that operate continuously. If the exhaust fan system is properly designed, and the building fully stocked, the louvres can, and should, be removed (or not purchased) for the continuous-running fan(s)—provided that the fan(s) is properly hooded. Gravity louvres add to the working static pressure of the fan and reduce fan efficiency. They are also a high-maintenance item. Huffman and Pegg (1981) stated that shutters accounted for as much as 50% of the difference between measured flow rate and the manufacturer's suggested flow rate when two-speed 450-mm fans were operated on low speed. Their testing was done with new fans that had clean, free louvres (shutters). Testing by others, including Person (1977), indicates much higher flow rate reductions as the louvres become coated with dust and the hinges become sticky.

The lower flow rate, continuous-running fan is the most likely one to have significant accumulations on the louvres because it moves primarily humid, dust-laden air.

All exhaust fans should be properly hooded to provide protection from wind, which can increase the working static head pressure. The higher the static pressure, the harder the fans must work to remove air and the lower the output flow rate will be. Fig. 20

Fig. 19 When installing new fans or replacing motors check that the fan blade in the orifice is positioned correctly to insure optimum performance and energy efficiency.

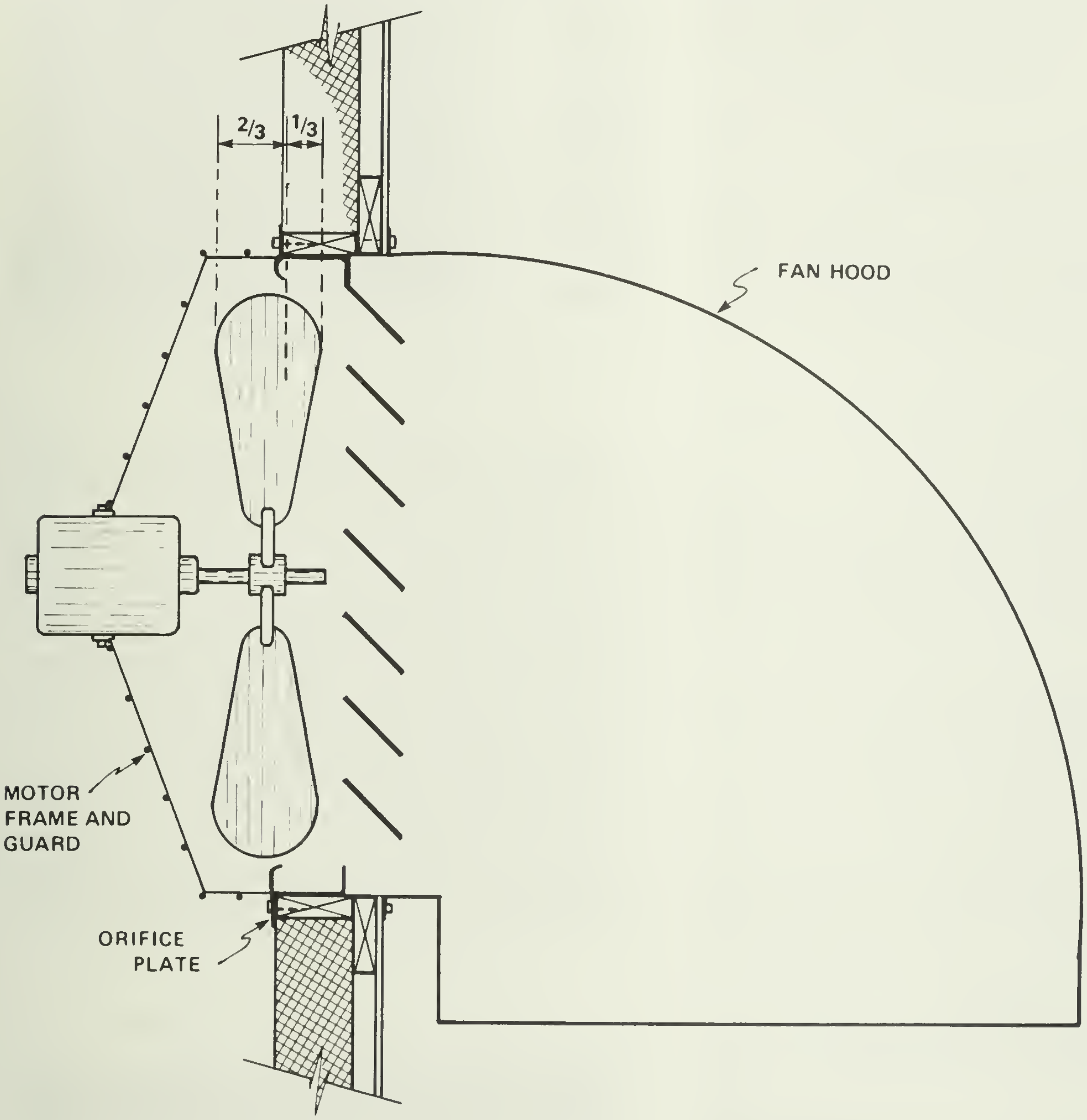
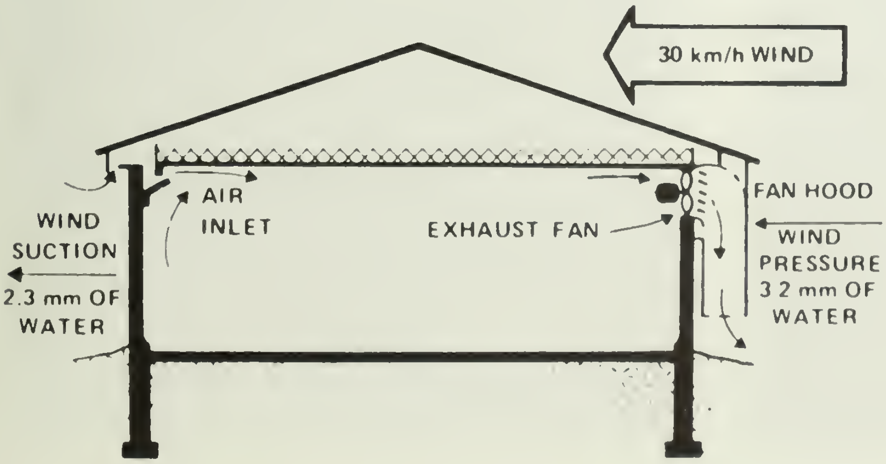


Fig. 20 Pressures caused by a 30-km/hour headwind on an exhaust fan.



shows the pressure effects of a 30-km/hour headwind blowing against the exhaust side of the building. If the fan blows straight into the wind without the protective hood shown, it has to put out 3.2 mm of water static pressure just to open the fan louvres. Yet another 2.3 mm of water suction has to be developed to draw air to the inlet slot through the leeward wall. Thus, total pressure at the fan (without fan hood) is as follows:

2.3 (leeward suction) + 1.3 (inlet slot) + 3.2 (headwind) = 6.8 mm of water (67 Pa).

This pressure 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/hour wind develops pressure four times as great as that developed by a 30 km/hour wind.

One erroneous alternative to installing hoods is to place exhaust fans in the leeward wall. Because wind can blow from any direction, the leeward wall today may be the windward wall tomorrow.

Part of the solution is to hood all air intakes and fan outlets so that air enters and leaves the building vertically (perpendicular to the wind flow). Fan hoods should be turned down a full 90 degrees, as illustrated in Fig. 20, and extended more than halfway down the wall. Wind effects can also be greatly reduced if the hood, which need only extend down 150 mm below the fan opening, is set out about 100 mm from the wall (see Figs. 19, 21). Both types of hood can also be used on through-the-wall air intakes. Another important item is to insure that all hoods have sufficient areas to prevent back-pressure, or pressure loss, when used on intakes. Fig. 22 shows a fan hood for three fans in a fan house. Although not all fan manufacturers supply hoods, these can be built by a local tinsmith or a building contractor, but your specifications must be clear.

Fig. 22 A well-designed multiple fan hood. Access to the fan house via the door makes fan maintenance easier.

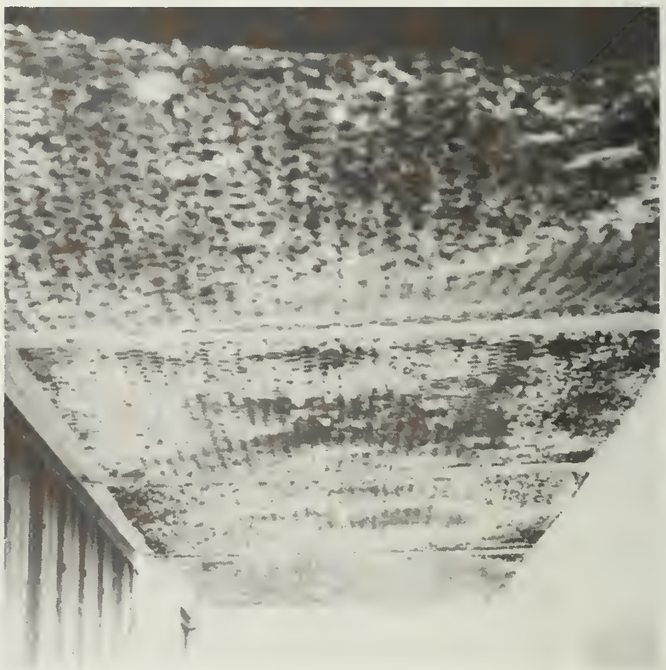
Fan maintenance.

Dirty, sticky, and broken fan louvres are the major maintenance items. Louvres are subject to continuous contact with humid, dust-laden air on one side and cold air on the other, and the result is condensation and caking. The louvres become heavy and the hinges become sticky. When unmaintained louvres are attached to small or slow-speed winter fans, they can greatly reduce output. They should be power-washed and/or wire-brushed regularly. Sticky hinges should also be freed.

Fig. 23 shows screens over the fan hood discharges. Although these screens are a good idea, they can become more of a detriment than an asset if they are not cleaned regularly.

Fig. 21 A well-designed exhaust fan or air intake hood, turned 90 degrees, and set out at least 100 mm from the vertical wall.

Fig. 23 Screening fan-hood discharges only increases system maintenance requirements.



Always keep fan motors and blades clean (Fig. 24). Dust on blades causes little reduction in air-moving capacity, but it can cause imbalance and vibration, and eventually result in fan failure. Dirty fan motors reduce efficiency by causing heat build-up, and because fan motors are totally enclosed they must be cooled by the ''air over'' principle. Dust also acts as insulation, which can promote overheating and lead to premature motor failure.

Check large-diameter belt-driven fans regularly for proper belt tension. A belt that is too loose decreases fan output and energy efficiency, and one that is too tight causes bearing overload, overheating, and motor failure.

Thermostatic controls

Why temperature controls in preference to humidity controls?

Exhaust fans and space-heating equipment are usually operated by thermostatic controls that respond only to temperature. These are thermostats for heating equipment and single- and multi-speed exhaust fans, and temperature controllers for variable-speed fans. They are wired to start fans or increase speed on temperature rise—above the set point. Conversely, most of the same thermostats can be wired to start heating equipment on temperature fall—below the set point. These controls are known as double-throw thermostats.

When operating below the ''heat deficit'' outside temperature, ventilation rate is determined by the required moisture removal rate (to limit maximum inside relative humidity). For this purpose a humidistat would seem to be a more desirable controller. However, commercial humidistats have not proven satisfactory in the long-term, because the moist-sensing elements collect dust and lose calibration quickly. The delicate and tedious cleaning routine required is not acceptable to livestock producers. Dust-laden humidistats often cause serious ventilation problems, and thermostats are usually still required to override the humidistats and prevent chilling. This adds to the expense of the control package.

When near-ideal ventilation rates are available (by having the correct exhaust fans in place), ventilation can be effectively controlled by thermostats, even in cold weather. However, such control is based on the assumption that the *correct* size of heating equipment is also in place.

Heat and moisture production from animals or birds are highly dependent on activity level as well as on other building/management factors. Traces from a hygrothermograph (a relative humidity and temperature recording instrument) located in a weaner cage room in January (Fig. 25), show the significant changes in relative humidity that can occur with time. When lights were turned on at feeding time (0700 hours), there were significant increases in activity and moisture production that show up on the graph as relative humidity. When lights were turned off at 1800 hours, the relative humidity decreased as the pigs retired for the night. The properly designed and

Fig. 24 Fan motors, blades, and louvres should be cleaned regularly to maintain system efficiency.

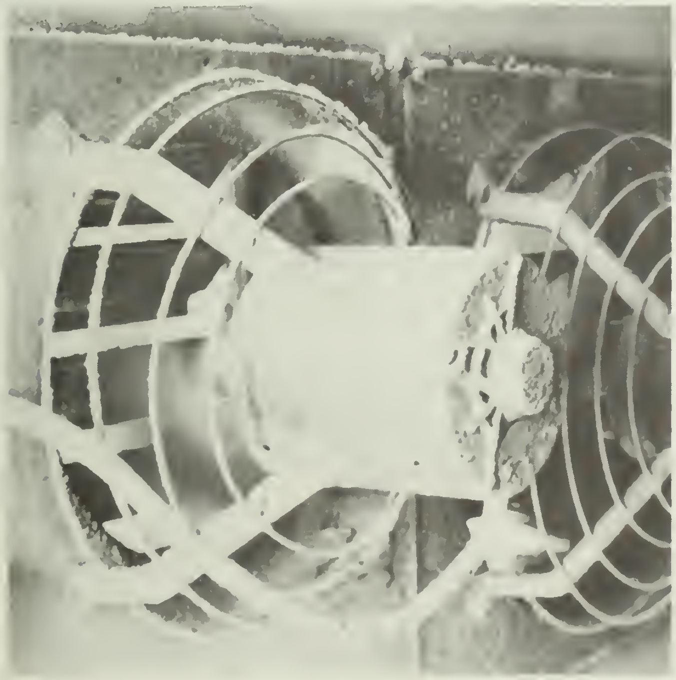
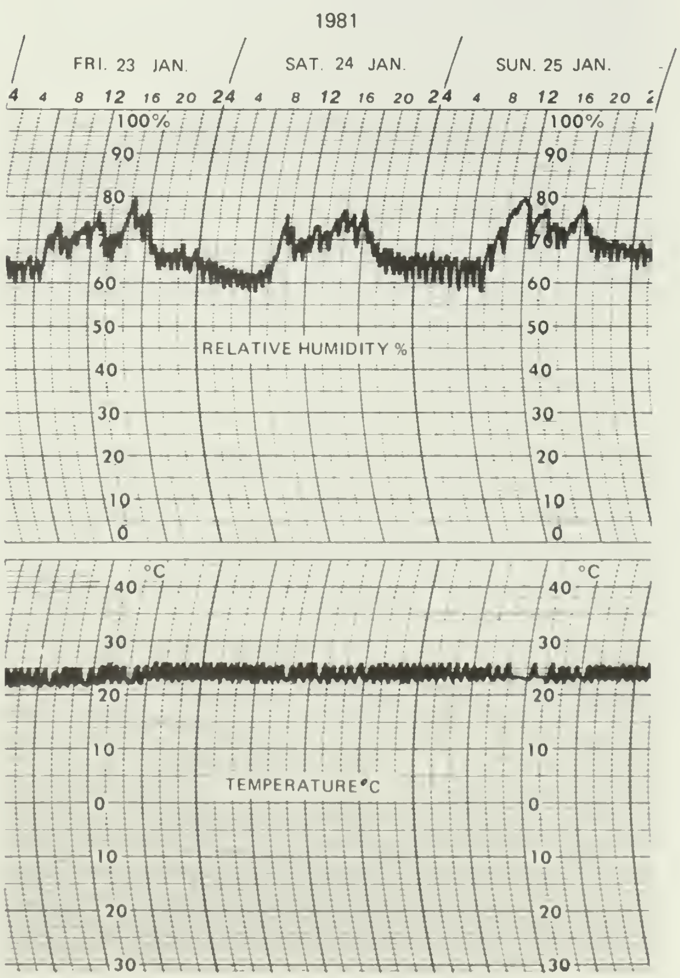


Fig. 25 A continuous recording of temperature and relative humidity in a weaner cage room where ventilation and heating are controlled by thermostats.



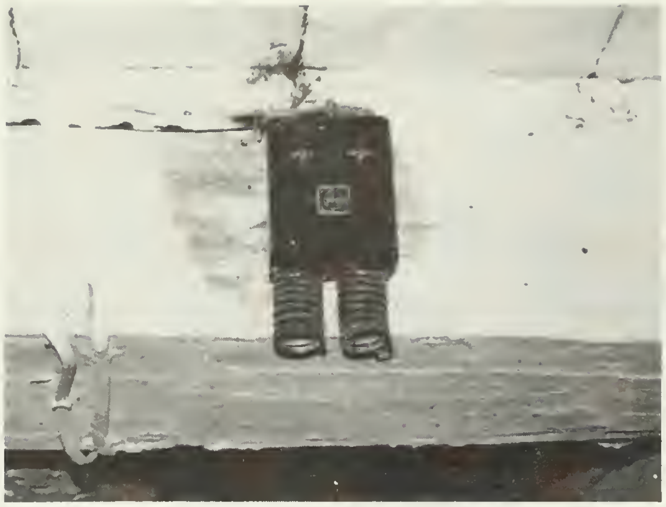


Fig. 26 Thermostatic control sensing elements should not be located outside the building airflow area.

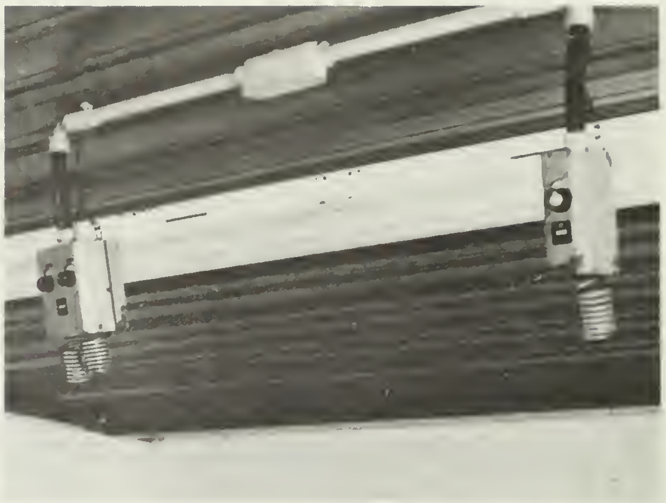


Fig. 27 These thermostatic controls are centrally located with flexible suspension to avoid mechanical damage.

operated thermostatically controlled ventilation system was able to keep the RH below the critical 80% level at all times. The temperature cycles in Fig. 25 resulted from an oversized heater.

During warm weather, ventilation rate is dictated by temperature; thus, the thermostatic control method is the better choice.

Thermostatic control location.

Many thermostatic controls, or sensing elements, are located on large pieces of plywood set perpendicular to the building airflow or up on a beam or on the ceiling, out of the way (Fig. 26). When shielded in this way, thermostatic controls cannot sense the average air temperature within the building space they are controlling. In the first two instances, they are in dead air pockets and are likely to cause overventilation, thus energy waste. In the third instance, they are likely to cause insufficient ventilation because of heat conduction from the colder ceiling or cooler air from the air inlet. All three locations result in less than desirable environments and often higher energy operating costs.

Thermostatic controls must be sensitive enough to detect a representative air temperature. This is best achieved by hanging the controls from the ceiling with flexible suspension and restraints (Fig. 27) to permit movement if they get bumped. Sensors should extend below the support (Fig. 28), if the support is located over a pen partition. If the thermostats are located on a plywood panel, it should be fixed in place parallel with the airflow (Fig. 29). The plywood panel should also be located over a partition, whenever possible, to prevent inadvertent contact by either the operator or the animals.

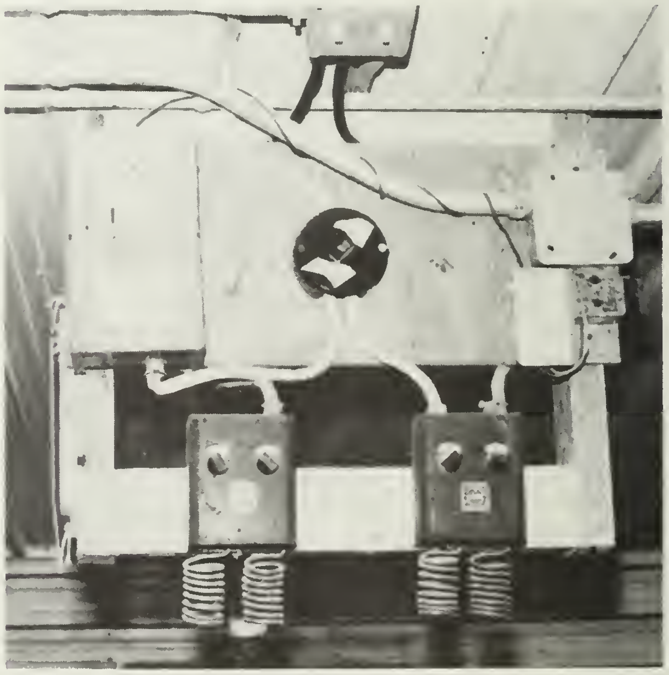
Thermostatic controllers should be located in well-mixed air about midway between inlet and exhaust, for them to sense average temperatures. The use of electric fan-forced heaters with integral thermostats can present problems. Heaters should be located near the air inlet in order to direct heat into the incoming cooler air. A remote-heater thermostat should be either located with the ventilation thermostats or interlocked by one of them.

Thermostatic control calibration.

Many controls, even new ones, are often out of calibration by 2°C, or more. This means that controls may start a fan or heater too soon or too late, according to the indicator setting. This conflict can be critical during cold weather when heating is required. For example, if an extra exhaust fan starts too soon, the heating equipment may be kept on by the extra cooling effect. This overlap of the two controls results in heat energy as well as fan energy being wasted.

A good-quality thermometer is a wise investment (Fig. 30). Ideally, the thermometer should be located with the thermostats (Fig. 29). This permits the operator to check actual air temperature when a fan or heater starts. If the thermostatic control is out of calibration, it can be adjusted and the discrepancy noted for future reference. The thermostatic control

Fig. 28 Control sensors can extend below the support if it is located over a pen partition.



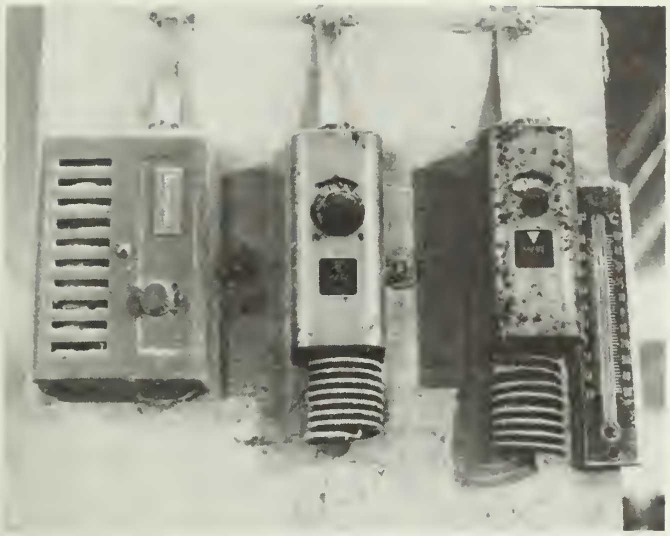


Fig. 29 Solid panels for protection of control sensors should be fixed in place parallel with the airflow.

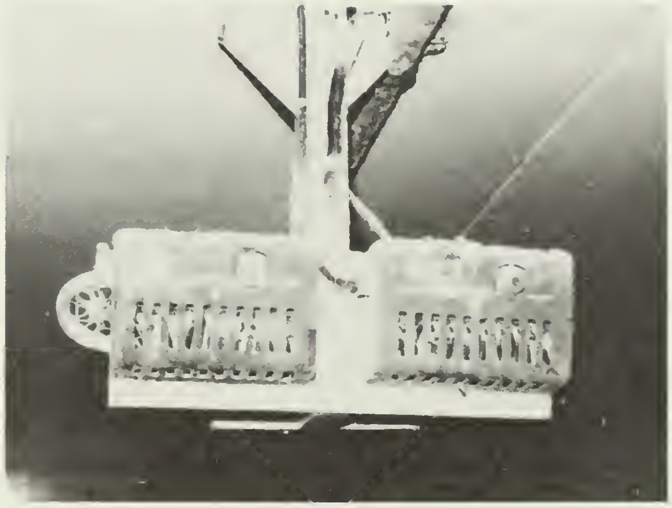


Fig. 31 The sensing elements of thermostatic controls need periodic cleaning with a cloth or air blast to maintain responsiveness.

Fig. 30 A good-quality thermometer for checking thermostatic control calibration is a wise investment.

Fig. 32 This commercial smoke generator provides an effective means of observing airflow patterns.

need not be replaced if its performance is repeatable. It will not likely cause further environmental or energy waste problems provided the control is kept clean and is properly located.

Thermostatic control maintenance. A thermostatic control will not perform effectively when dust accumulates on its sensing elements. The thermostats shown in Fig. 31 are in need of cleaning. The dust accumulation acts as insulation and delays the response of the control. This can have a more serious impact on both environment and energy waste than when the control is out of calibration. Cleaning can be done easily with a cloth or an air blast, as long as the controls are located where they should be—near operator eye level.

Environmental testing

A number of simple tests and some more complex ones can be applied to an environmentally controlled building to test ventilation effectiveness and energy efficiency.

Smoke testing. Before putting animals or poultry into a new facility, a smoke test can often reveal many potential problems. Chemical smoke in the air (Fig. 32), reveals airflow patterns, potential dead air spots, and draft problems. These problems can usually be corrected, often at minor expense, before they cause animals or birds to become distressed or sick. Sometimes, the solution is simply having the operator learn how to operate the air inlet system correctly to create the desired airflow patterns. Or it may be necessary to have the intakes changed to avoid restrictions, preferably before the building contractor is paid!

Another potential problem is the location of wiring, lights, or other objects that are too close to the air inlet. Fig. 33 shows pipes suspended from the ceiling to avoid conflict with the incoming air stream. Water pipes located on the ceiling in front of air inlets can bring a double penalty in cold weather: incoming air is deflected downward, causing drafts, and the cold air is likely to cause any water in the pipes to freeze.

Assistance with smoke testing can usually be obtained from ventilation equipment suppliers, provincial agricultural engineering extension specialists, utility personnel, or building contractors.

Maximum- minimum-indicating thermometers. No operator of controlled-environment facilities should be without a maximum- minimum-indicating thermometer (Fig. 34). These thermometers are relatively inexpensive, and indicate the maximum and minimum temperatures that have occurred within a controlled-environment room. Often this temperature cycle indicates a malfunction of heating equipment, a thermostatic control problem, or interrupted ventilation. Fig. 35 shows a trace from the hygrothermograph and illustrates what happens to temperature and relative humidity control when a dust-laden fan-forced heater is tripped out repeatedly by its high-limit thermostat. A maximum- minimum-indicating thermometer also indicates this kind of problem.

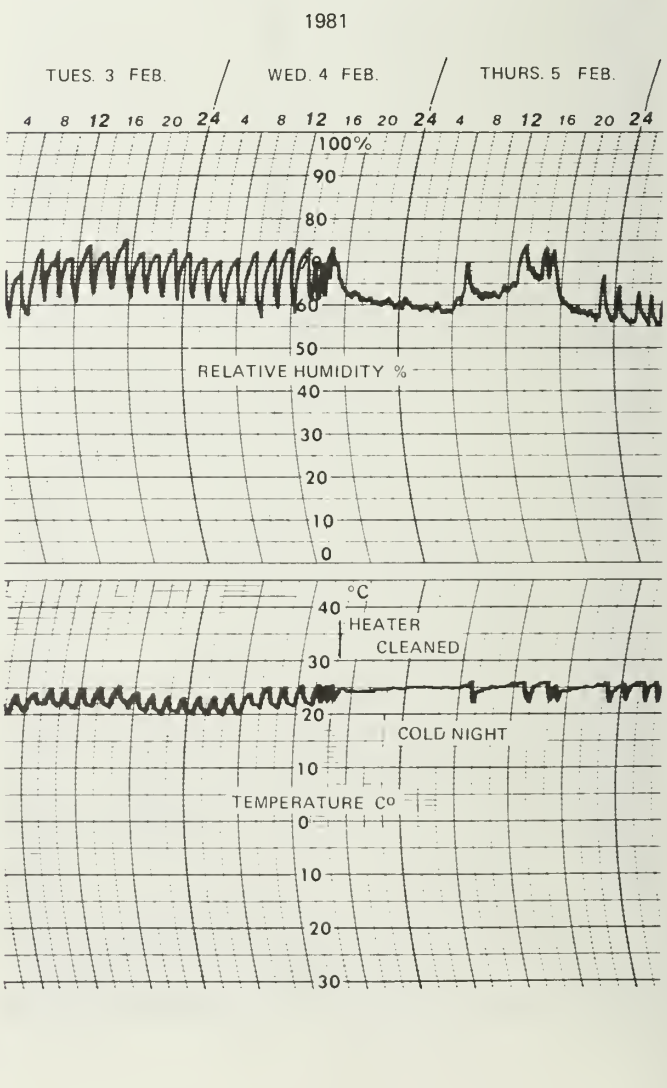
Maximum- minimum-indicating thermometers are available from ventilation-equipment dealers, feed company representatives, and so forth.

Air quality testing. When odor and gas problems persist, it is wise to seek professional help. Ammonia, hydrogen sulfide, carbon dioxide, and methane gas test kits are available, usually through provincial extension

Fig. 33 Hot-water heating pipes have been suspended from the ceiling to avoid disrupting the incoming air from the center air inlet.

Fig. 34 The maximum- minimum-indicating thermometer, *right,* indicates to the operator what has occurred in this controlled environment room.

Fig. 35 A trace from a hygrothermograph. Note the erratic relative humidity/temperature traces at left caused by a dirty cycling heater.



personnel and others experienced in troubleshooting problems of air quality. The results from these tests can often pinpoint an environmental control system problem, a unique management problem, i.e., feeding of uncommon feedstuffs, or a water-quality problem.

This type of testing has led to changes in the design of environmental control systems. For example, when liquid or semisolid manure is stored under animals or birds it is recommended that at least the continuous winter ventilation air be drawn down and out to expel undesirable gases from the sources as quickly as possible. An alternative is to dilute the gases by moving more air than usual. However, such an alternative wastes both heat and fan energy, and should not be used unless no other practical means is available.

Air velocity measurements. During cold weather, when the environmental space is at the minimum temperature, only very low air velocities are permissible at animal or bird level. Yet, as discussed earlier, high-velocity incoming air is essential to insure mixing. The slant-type manometer (Fig. 8) is a good indicator of air speed at slot-type inlets. Similarly, automatic air inlet controllers use the same pressure-difference measurement for activation.

However, drafts created by obstacles in the air stream can be effectively measured by velocity meters (velometers) or by observing the animals or birds. If, for example, small pigs pile up with heads facing inward they are too cold. Continually low temperature or drafts cause them to produce a thick, rough, unthrifty hair coat. A draft in small calf pens can often cause repeated respiratory problems.

Young animals or birds usually indicate that they are warm and comfortable by spreading themselves with heads turned away from a concentrated heat source such as a radiant heater. An observant manager does not need sophisticated air-velocity measuring equipment to spot winter drafts.

In summer, rapid air movement directly over larger animals or birds creates comfortable conditions and minimizes heat stress. Thus, being able to redirect incoming air down to the animals or birds is ideal for summer conditions. An air inlet system that incorporates some method of redirecting the fresh airflow directly onto the animals during very hot weather is highly desirable.

Sojak and Morris (1982) have developed a centerline, ceiling-mounted double-slot air inlet system that can manually or automatically redirect air downward. Fig. 36 shows the insulated center air intake plenum. Fig. 37 shows the adjustable flaps along either side of the center air inlet. With flaps up, as shown, the cooler air is directed along the ceiling; with flaps down, the very warm summer air is redirected down to the animals or birds, thus providing a breeze effect.

Many environmental control system operators try to create a breeze effect by increasing fan capacity and/or by opening building doors. Increasing fan capacity above a practical level wastes electrical energy

Fig. 36 Incoming air intake may take the form of an insulated attic plenum to deliver air to a center air inlet.

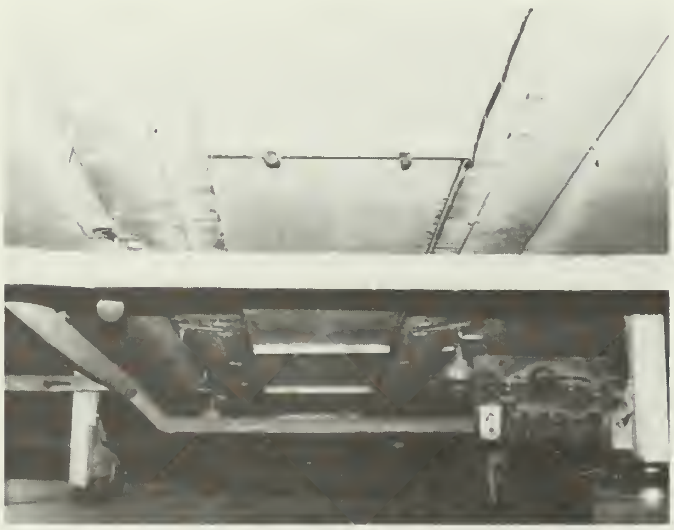


Fig. 37 The adjustable flaps on either side of this center air inlet can direct air along the smooth ceiling in winter and down onto the animals/birds in summer.

and often overloads the air intake system, making it necessary to open some doors.

If there are only a limited number of doors available, for example one at each end of a building, the complete ventilation system operates ineffectively. The animals or birds in front of the doors are very comfortable, but the others receive little or no fresh air because the air inlet system is not operating effectively. Air, like flowing water, takes the path of least resistance, i.e., from the open door directly to exhaust fan.

Maintain temperature for the animals or birds, not for the operator

Minimum winter building temperatures. Minimum winter building temperatures should be maintained for the comfort and productivity of the animals or birds, not for the operator, who spends only limited time in the building. When applicable, a lower building temperature saves supplemental heat and increases ventilation rate, thus providing cleaner, fresher air. This applies to many cattle housing units.

Radiant heaters. The use of radiant heaters is preferable to increasing the room temperature. When the operator provides radiant heaters, which supply spot heating, very young animals or birds can select their individual comfort level (Fig. 38). Radiant heaters also give the operator an opportunity to save energy during warm weather farrowing or brooding by using either a lower wattage heater, i.e., a 125-W heat lamp instead of a 250-W heat lamp, or a reduced control setting.

By using radiant heaters, preferably with the additional comfort of a nest box or semienclosed creep, the inside building temperature can be lower, thus reducing conducted heat loss through building walls and ceiling, because conducted heat is dependent on temperature difference.

In addition to the direct energy saving benefits of radiant heaters, keeping the farrowing room temperature lower improves comfort for the sows accustomed to a cooler area during gestation. Also, radiant heaters attract piglets away from the sow when she is not nursing; this helps to reduce crushing and death losses.

Fig. 38 Radiant heat provides comfortable conditions for young animals/birds in a cooler building, thus saving heat energy.

Supplemental air-heating equipment

Selection of system. Various types of equipment are suitable for heating air or space: the two most commonly used are fan-forced unit heaters, and black pipes, with or without fins, carrying hot water. Two requirements are essential:

1. The system must distribute heat uniformly, preferably along the inlet system. Air recirculation equipment is sometimes utilized to enhance distribution of heat, particularly in rooms ventilated at low rates.
2. The portion of the system exposed to the animal or bird environment must be easy to clean. A buildup of dust, skin flakes, and so forth, can become a fire hazard.

All conventional energy sources (natural gas, LPG, oil, and electricity) as well as renewable fuels such as straw, corn cobs, and wood can be used to produce hot water. The thermostat that controls the heating of the building usually also controls the water circulation pump, whereas a separate thermostat controls water temperature in the boiler. These systems, when properly designed, work well but are relatively expensive to install. There is also a risk of frost damage if the equipment is shut down in cold weather, e.g., between crops of broilers. If antifreeze solution or drainage is required, this adds to the management cost.

Direct-fired heating equipment operated by natural gas or LPG can also be used. However, this type of heating equipment adds moisture to the air and the minimum winter ventilation rate must be increased in order to remove it.

Air-heating furnaces can be used but have limitations in dusty environments because they recirculate air. Consequently, large filter areas must be installed and maintained at frequent intervals.

Another heat energy efficiency problem is that of floor heating systems—operated either by hot water or by electric resistance cable. Both types of heating are ideal for maintaining a warm floor in farrowing creeps, weaner pens, or milking parlor pits. Many attempts (usually limited to one winter) have been made to use these systems to heat space; however, the following problems arise: (*1*) The warmed floor area is usually small with respect to the building space and only sufficient heat is generated to warm the floor. (*2*) If the floor is hot enough to radiate significant heat, it may become too warm underfoot. (*3*) The higher concrete slab temperature pushes heat into the soil below, even with insulation under the floor. If the insulation under the floor is increased, the sleeping area may become undesirable for animals in very hot weather, and cause a reversal of housekeeping habits.

For animal areas use floor heating, if desired, only for floor warming. Warm-floor poultry brooding has been used successfully, primarily in the Maritime Provinces. For this application the warmed floor area required is extensive. Litter should not be used, as it would act as undesirable insulation. Insulation under the concrete floor is acceptable, because birds do not depend on heat conduction to the floor for summer relief, the way swine do.

Fan-forced electrical unit heaters* are being used extensively for space heating in many animal-housing areas, because of the relatively small size of

* Fan-forced electrical unit heaters must meet a "GX specification" before they can be used by livestock producers in certain provinces.

farrowing, weanling, and calf-housing rooms, which require varying amounts of supplemental heat. Fan-forced heaters (Fig 39) are usually suspended near building corners and set to direct warmed air either along the air inlet or into air recirculation equipment, if such equipment is being used.

Fan-forced unit heaters are relatively inexpensive to buy and install. Because they are portable they can be relocated as required, and are easy to clean with compressed air. As noted earlier, these heaters should be controlled by a remote thermostat (not the built-in type) for greater accuracy and energy efficiency.

Sizing the air-heating units. The philosophy that bigger is better should not be applied when selecting an air-heating unit. An oversized heating unit wastes heating energy. Winfield and Turnbull (1980) showed the undesirable environmental impact of using an oversized 4.8-kW fan-forced heater in a small calf-rearing facility. Fig. 40 shows the calf room temperature fluctuated 3–5 C° from the desired 10°C. These fluctuations occurred regularly as the oversized heater cycled on once every 40 minutes. When the heater was on, the relative humidity dropped, then increased again at least 10% during the off period. This frequent cycling provided a less-than-ideal environment for animals.

When a smaller 2.0-kW fan-forced heater was substituted, the room temperature was held almost constantly at 10°C (Fig. 41). Although the RH still fluctuated, it did not exceed the critical 80% level. The cycles were smaller and less frequent. In fact, the operator also felt the environment was improved.

The same effect of an oversized heater can be seen in Figs. 25 and 35. A heat exchanger had been installed in the weaner cage room, making the 5-kW fan-forced heater oversized. This caused the heater to cycle frequently and to give larger and more frequent temperature and RH fluctuations.

A common error, from an energy and cost viewpoint, is to increase the winter ventilation rate with oversized heating equipment in place. This dampens or reduces the temperature fluctuations by keeping the heater on almost continuously. The result is a lower RH and a much higher heating bill. Using the foregoing example, a 4.8-kW fan-forced heater operating constantly uses 4.8 kW × 24 hours/day, which equals 115 kWh/day; whereas a 2.0-kW fan-forced heater operating constantly uses 2.0 kW × 24 hours/day, which equals 48 kWh/day. The potential energy wastage, therefore, is 115–48 kWh, or 67 kWh/day for each heater installed. Thus, the wastage is more than the needed heat energy, 67 versus 48 kWh/day. The heating bill could be more than doubled with no benefit.

Fig. 39 A fan-forced unit heater suspended in front of the air inlet in a calf nursery.

Fig. 40 An air-heating unit that is larger than necessary causes frequent temperature and relative humidity cycles.

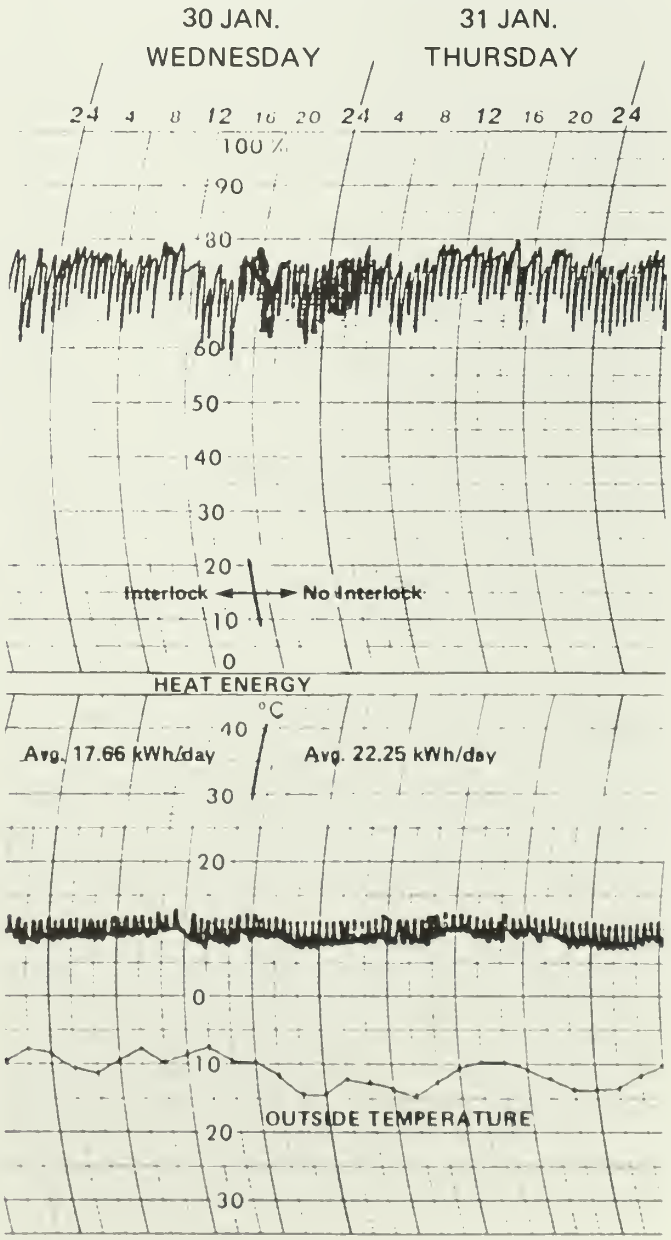
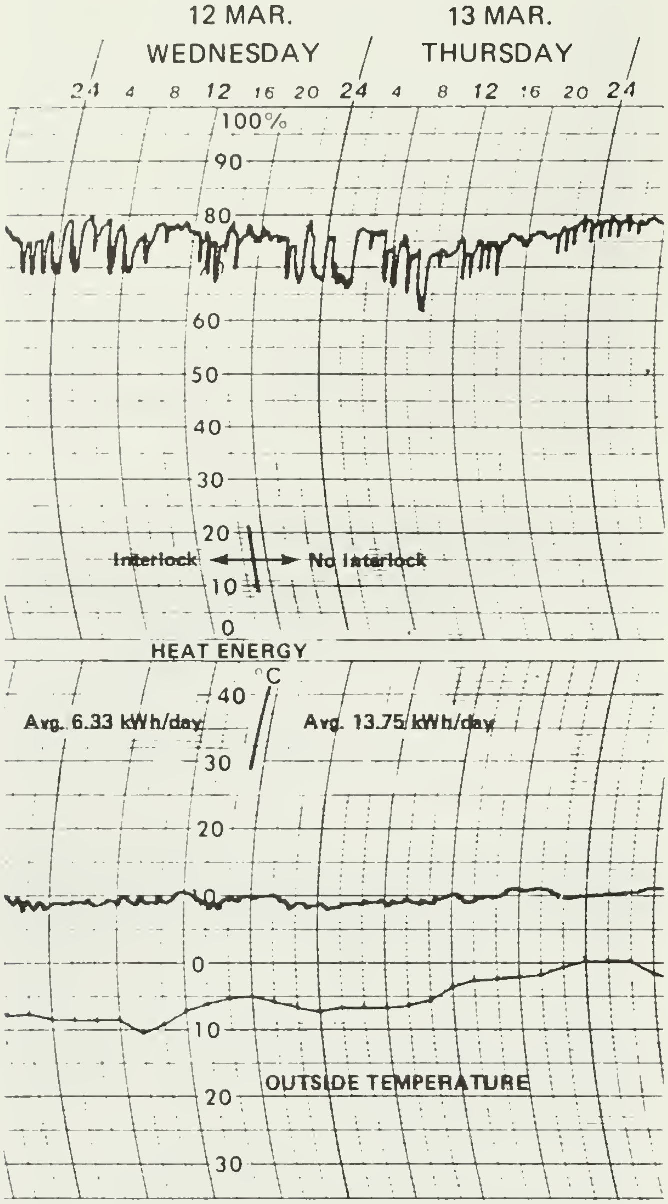


Fig. 41 A smaller heater can eliminate temperature cycles and save heat energy while maintaining the desired building temperature.



For many applications requiring supplemental heat with ventilation, both the heat energy usage and the dollar cost can easily be more than double that actually required, if the size of the heating equipment or the firing rate, is above the minimum needed. When sizing supplemental air-heating systems for controlled-environment buildings, it is worth remembering that animals usually produce a large portion of the necessary heat; therefore it is better to err on the small side. Although minimum winter room temperature might slip below the desired temperature on extremely cold days, environment quality will actually be improved on all other days, and both money and energy will be saved. (Poultry brooding is an exception.)

With potential heat energy savings of over 50% in many controlled-environment buildings, energy-type substitution—even to renewable energy sources—is not a valid starting point in reducing operating cost. Reducing the size or firing rate of the heating equipment is much more cost effective. A staged, or multistep, heating system would be an obvious choice for large poultry-brooding installations. A small portable backup heater could also be used for the extremely cold days in January or February.

Before reducing the size of the heating equipment it is essential to insure that the ventilation rates are adequate to maintain the humidity below the maximum level, which is around 80%, depending on the type of animals housed. Many references are available on this subject, including Agric. Can. Publ. 1451, *Confinement swine housing*; Agric. Can. Publ. 1714, *Tie-stall dairy cattle housing*; and Canadian Farm Building Code (1977).

Preventing overventilation while supplying heat. Overventilation (above moisture control rates) while supplying heat wastes energy and dollars. In many applications, overventilation can be prevented by properly calibrating thermostatic controllers for both the heating and ventilation equipment, and by stepping the controller settings of the heat-removal exhaust fans. This latter action insures that the high-capacity summer fan(s) cannot be started by supplemental heat.

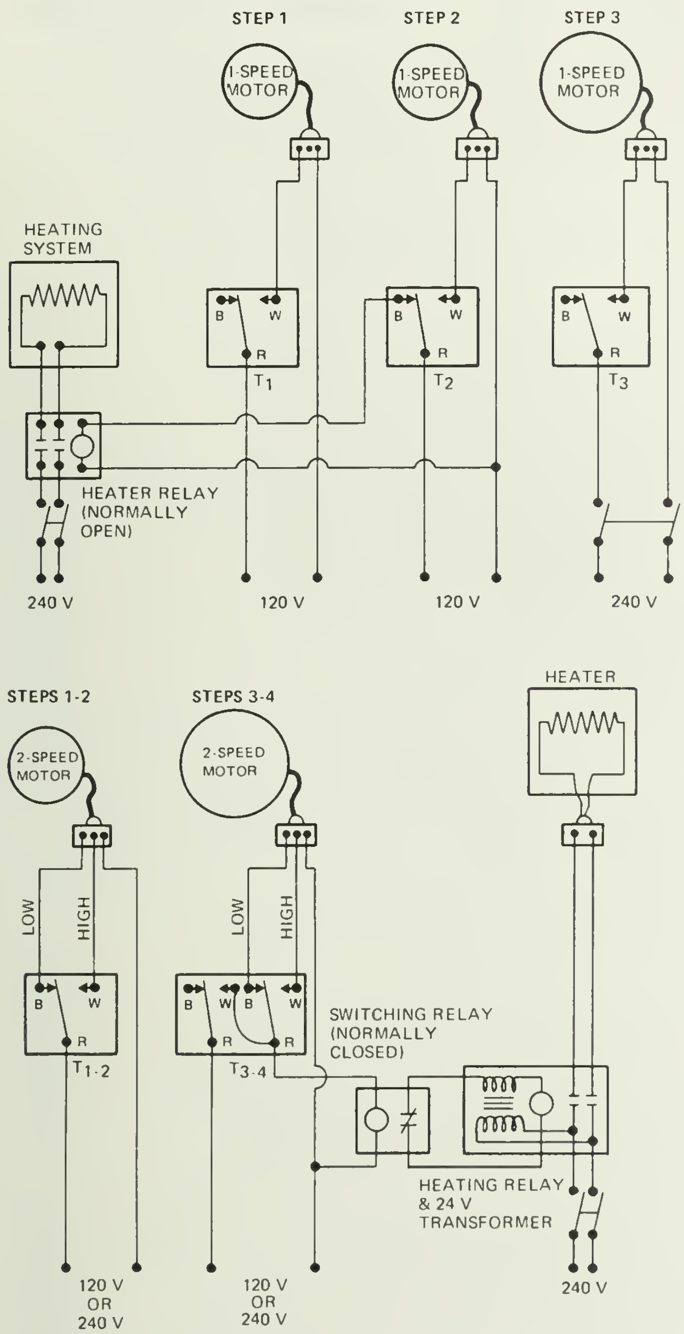
This technique should and usually does work reasonably well. By preventing overventilation when space-heating equipment is operating, heat energy is saved. The problem usually arises in the location and sensitivity of the 3–5 thermostatic controls, so that they all respond to the same average room temperature. If, for example, a large-capacity ventilation fan starts during a warm period, the building temperature may be drawn below the starting point of the heating system before the fan shuts off. This overlap occurs whenever there is a variation in sensitivity or response of individual controls.

To some extent, this overlap can be eliminated by stepping the thermostatic controls. This is done by setting moisture control ventilation controllers (controlling summer heat removal fans) at least 3°C above minimum winter building temperature to prevent simultaneous operation of heating and excess winter ventilation.

A more proven technique to prevent overventilation while heating in farrowing, weanling, and warm calf-housing facilities is to electrically interlock the heating/ventilation controllers. Two possible schematic wiring diagrams are shown in Fig. 42. Fig. 43 shows predicted performance and temperature-setting guidelines for a swine-finishing barn.

The practice of interlocking heating/ventilation controls saves energy. A field evaluation of a warm calf-rearing facility reported by Winfield and Turnbull (1980) showed average heat energy savings of 32% between 14 January and 30 March over that of a well-designed, calibrated, and managed conventional system. A competent electrical contractor can devise a system, such as the one shown in Fig. 28,

Fig. 42 Heating/ventilation controls can be electrically interlocked to prevent overventilation while heating.



that meets specific needs and approved electrical standards.

Again, remember that for the interlocking control system to be an effective energy-saving technique, the heating system, regardless of type, should not be oversized.

NOTE: In order for a two-speed motor to permit interlocking between low and high speed, it must contain an isolation switch. Check with your supplier or electrician to insure that the motor you wish to use has such a switch.

Heat only the necessary space. A sure method of reducing supplemental heat energy requirements is to maintain full-stocking density whenever possible. For example, as part of an experiment, Winfield (1981) reported on the supplemental air-heating energy consumed in a new, well-insulated, 20-crate building used for continuous farrowing. When partially stocked during the winter of 1978–1979 (because of sow herd buildup delays), the average energy consumption was 13.53 kWh/day (0.56 kW). When fully stocked during the winter of 1979–1980, the average energy consumption dropped to 2.155 kWh/day (0.09 kW), a reduction of 84%. The ventilation system had been designed, with some flexibility, for up to 20 sows and litters.

Poultry-brooding buildings are particularly vulnerable to low-stocking density. When the chicks or poults are small, the building temperatures must be high, and the conduction and air infiltration heat losses account for a high percentage of the energy use and resulting fuel bill. Although producers make a concerted effort to insulate or reinsulate buildings, weatherstrip doors, and caulk unnecessary openings, there is still a large amount of space to heat. Several other actions can be considered.

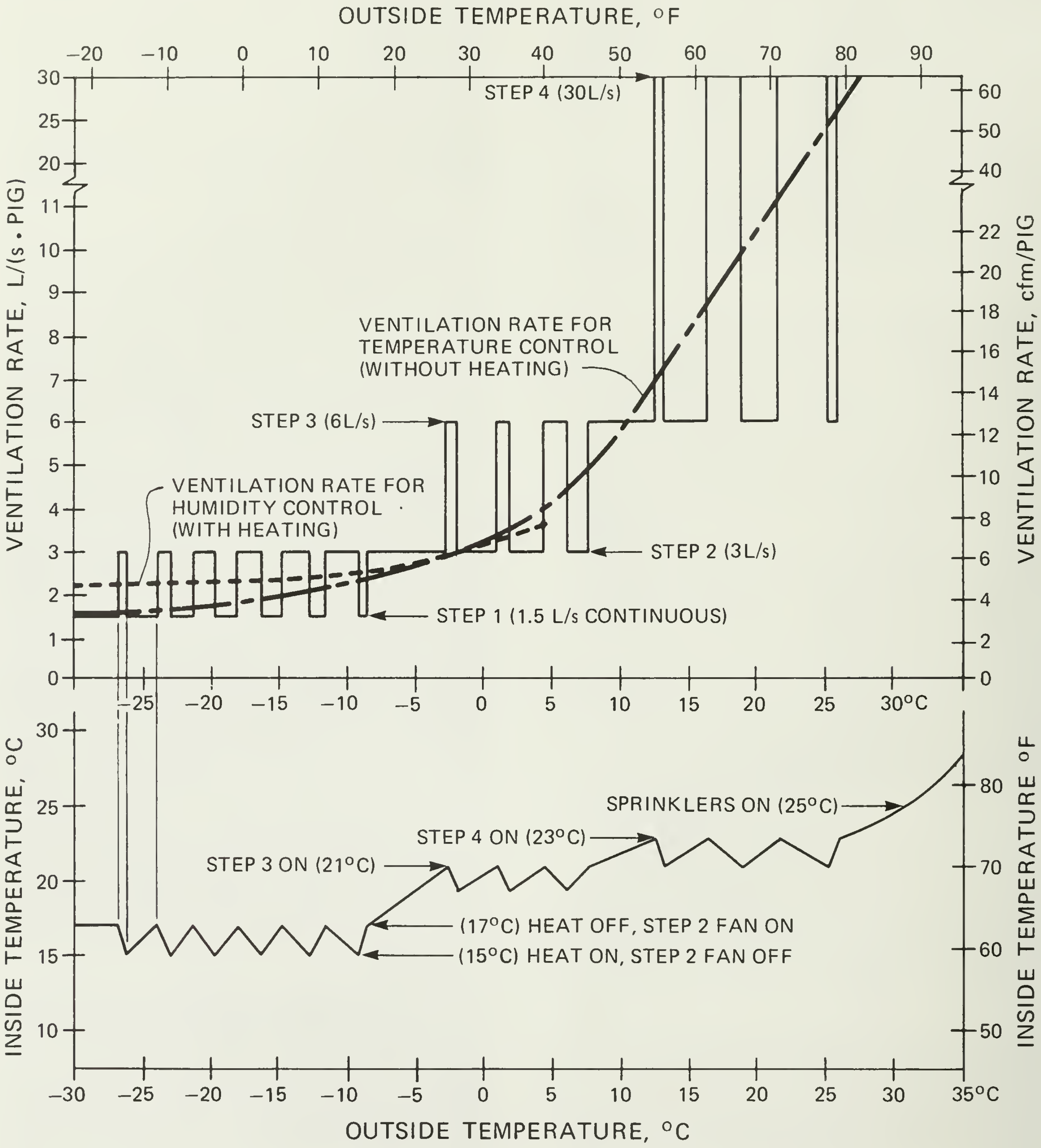
The heated building space can be reduced by the use of temporary dividers, usually polyethylene sheets. Some producers have effectively used one side (approximately one-third) of the building width during initial brooding. Others have used the double-brooding system, whereby the central half of the building is used initially. After approximately 2 weeks, when the building temperature is reduced and the chicks or poults start to produce more body heat and require additional ventilation, the temporary dividers are removed, thus expanding the building space. This technique is worthwhile, because it is estimated that 50% of brooding energy is used during the first 2 weeks.

Whenever possible, producers should consider using radiant heaters to maintain bird comfort while building air temperature is being reduce to minimize conducted heat losses. Reducing the number of operating brooders during warmer weather brooding can also reduce the excess heat that would be exhausted by ventilation.

Last, but not least, air exchange should be kept to a minimum. Moisture and gases produced by direct-fired brooders must be removed. However, large summer exhaust fans should be sealed off with insulated covers when not in use. With a 39 C° temperature difference between inside and outside air, unnecessary air exchange at the rate of 500 L/s represents 574 kWh/day, or LPG at the rate of 81 L/day.

Because of the very low exhaust ventilation rates that are required during early brooding, many producers are indicating an environmental and energy advantage by destratifying (mixing) the air within the brooding area. This is usually accomplished by suspended fans or other commercially available air-recirculating equipment.

Fig. 43 An example of staged ventilation with interlocked heating control for a swine growing-finishing barn requiring supplemental heat.



Summer comfort of animals or birds

Animals and birds suffer effects of heat stress when air temperatures rise above 29°C. The objectives are to relieve heat stress, improve gain rate, improve feed conversion, increase breeding efficiency, and minimize death losses.

Rapid air movement. Most animals and birds, like humans, gain relief from heat stress by having rapid air movement over the body. Summer ventilation rates are based on this criterion—rapid air movement. However, to move large quantities of air by fan to create the required cooling effect demands more electrical energy. One alternative is to open up the building if it has large doors, tilt panels, or curtain walls. Wind speeds of even 3-5 km/hour provide acceptable cooling. Although this method is effective, the inherent leakage in such buildings can present air infiltration problems in cold weather. (This is not a major problem for modified environment buildings housing beef and mature dairy animals.)

Most classes of poultry can be comfortable and productive with the normally recommended summer ventilation rates. Care must be taken to insure a good fresh air distribution, particularly for birds confined in cages. With floor systems, birds tend to migrate to fresh air spots—an indication to the operator that the inlets need to be adjusted for better air distribution and/or circulation within the building.

Swine, however, do not have the capability to sweat, thus evaporative cooling cannot occur naturally on the skin surface.

Cooling swine by spraying water. Research and field experience indicate that cooling swine by spraying water is effective. A coarse spray of water (Fig. 44) is provided intermittently over the slatted floor to attract and wet down the pigs. Spray from the nozzles shown in Fig. 45 is regulated by a cycling timer and thermostat. The thermostat energizes the timer when air temperature reaches the set point, e.g., 25°C (see Fig. 43). The cycling timer then provides a large droplet spray for short periods, about 2 minutes every half an hour (Sojak and Morris 1975). Total water consumption and hence pit fill are not likely to be increased significantly, because pigs drink less water when they are not suffering from heat stress.

Evaporative cooling of air. When warm dry air is passed through a water-saturated pad, it is cooled

Fig. 44 Pigs are attracted to the intermittent spray over the slatted pen area.

Fig. 45 The coarse spray from these nozzles is provided by a thermostatic and cycling timer that activates a solenoid valve.

by the evaporation of the water into the air. A simple example can be found in many residences. The air coming from a free standing humidifier will be cooler than entering room air. By picking up moisture, however, the absolute and relative humidity of the air is increased. This increase is the reason humidifiers are purchased for residential use during the winter.

The principle of evaporative cooling of air for animal and poultry buildings works extremely well in hot, dry climatic regions. However, most parts of Canada do not have these conditions. When air temperature is high, the relative humidity is usually high as well, which makes the principle less attractive. The comfort level is determined by the humidex reading, a calculation based on the combined temperature and humidity readings.

Evaporative cooling of animal and poultry building air is being used successfully in some locations for relief of heat stress.

Energy efficient motors

Manufacturers of electric motors are responding to energy costs by building more energy efficient motors. Energy efficient motors are worth considering when purchasing a new or replacement motor, especially if the motor is to be run for many hours or for nearly continuous operation. Buying a new energy efficient motor for an existing silo unloader, for example, is not likely to provide payback or significant energy savings, because the motor is operated for less than an hour each day, on most farms.

Energy efficiency should be considered when purchasing new ventilating fans. As discussed earlier, large-diameter, slow-speed fans usually produce more litres per second per watt than similar fans with a small diameter. They should be used for summer temperature control whenever practical. Small, direct-drive fans are also being sold on the basis of energy savings potential. This factor should not be overlooked when selecting the winter, continuous-operating fans. However, caution and good judgment must prevail. Some of the fan motors run slower than the standard 1725 rpm, thus their full-load amperage will be lower but so will the output (litres per second). A value judgment is necessary—based on price premium—until results of independent tests on agricultural fans in Canada become available.

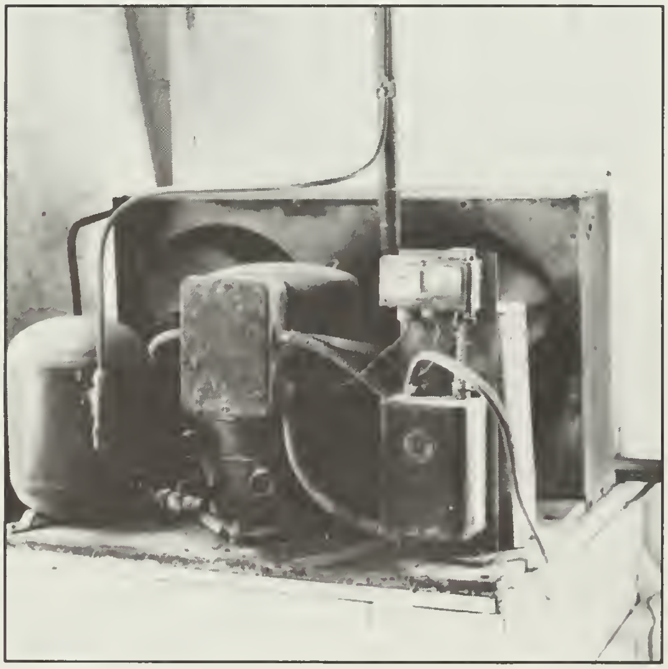
Reducing lighting energy

For many applications, particularly in poultry operations, lighting intensity and/or "on" time can be reduced to save energy and money. If 60-W bulbs are adequate, where 100-W bulbs have been used, a 40% reduction of electrical energy will occur for that application.

Dimmers, or rheostats, can also be used to reduce light intensity in many poultry or swine units. Operators can increase the intensity manually when they are doing specific tasks such as feeding, observing, or cleaning, and then reduce the intensity when they leave. The objective is to provide only sufficient light for the animals or birds to locate the feed and water. Light dimming not only saves energy but also greatly increases the life of incandescent light bulbs.

Although fluorescent lights are more energy efficient than incandescent lights, under ideal environmental conditions, they should be used with discretion in animal or poultry buildings. At temperatures below 13°C, they require special cold-start ballasts and do not maintain higher operating efficiencies.

Fig. 46 A conventional air-cooled condensing system for a bulk-milk cooler discharging heat into the milk room.



Dimming fluorescent lights is not practical. The alternative is to wire every second unit to one switch, a practice known as skip wiring, which will provide localized high intensity. Fluorescent lights can and should be used for task lighting in warm office and service areas. Other applications are lighting windowless swine-breeding areas and dairy barns housing show cattle. In these areas, good lighting is imperative and tubes should be regularly cleaned.

Timers to turn lights on and off to provide specific photoperiods or eating schedules, can also be effective energy saving devices. They can be used in buildings housing broilers, pullet replacements, and layers, as well as for numerous other applications.

Outside security lighting can be provided by high-efficiency lighting units, e.g., sodium or mercury vapor lights; however, they should be operated only when required, by light-sensitive controllers, to obtain maximum light with minimum energy.

CONVENTIONAL ENERGY CONSUMPTION CAN BE REDUCED—WITH NEW TECHNOLOGY

Using heat pumps and refrigeration units

Heat pumps and refrigeration units both have the capability to move heat (kilojoules of energy). Heat energy is picked up from a liquid or air by an evaporator unit when the refrigerant changes from a liquid to a gas. The gas is then compressed, usually by an electrical powered compressor, which makes it very hot. The compressed superheated refrigerant is then passed through a water or air-cooled condenser, where it gives up heat and reverts to a liquid. Heat from the condenser can either be "dumped" or used.

Heat pumps or refrigeration units, when properly designed for the application, can transfer more heat energy than the equivalent electrical energy they consume. With heat pumps specifically designed to provide heat, this ratio is known as the coefficient of performance (COP). The COP is often in the range of 2–4, depending on application and, more specifically, the availability of heat.

Recovering heat from milk. Refrigeration units on bulk milk tanks remove heat from the milk, and bring it down to the designed holding temperature of 3°C.

Each litre of milk releases about 136 kJ (0.0378 kWh) of heat energy. Thus, with a daily milk production of 1000 L, 136 000 kJ, (37.8 kWh) of heat energy is released (3600 kJ is equal to 1 kWh).

With a conventional air-cooled condenser (Fig. 46), heat is discharged from the milkroom most of the year in order to keep the milkroom cool. Some heat

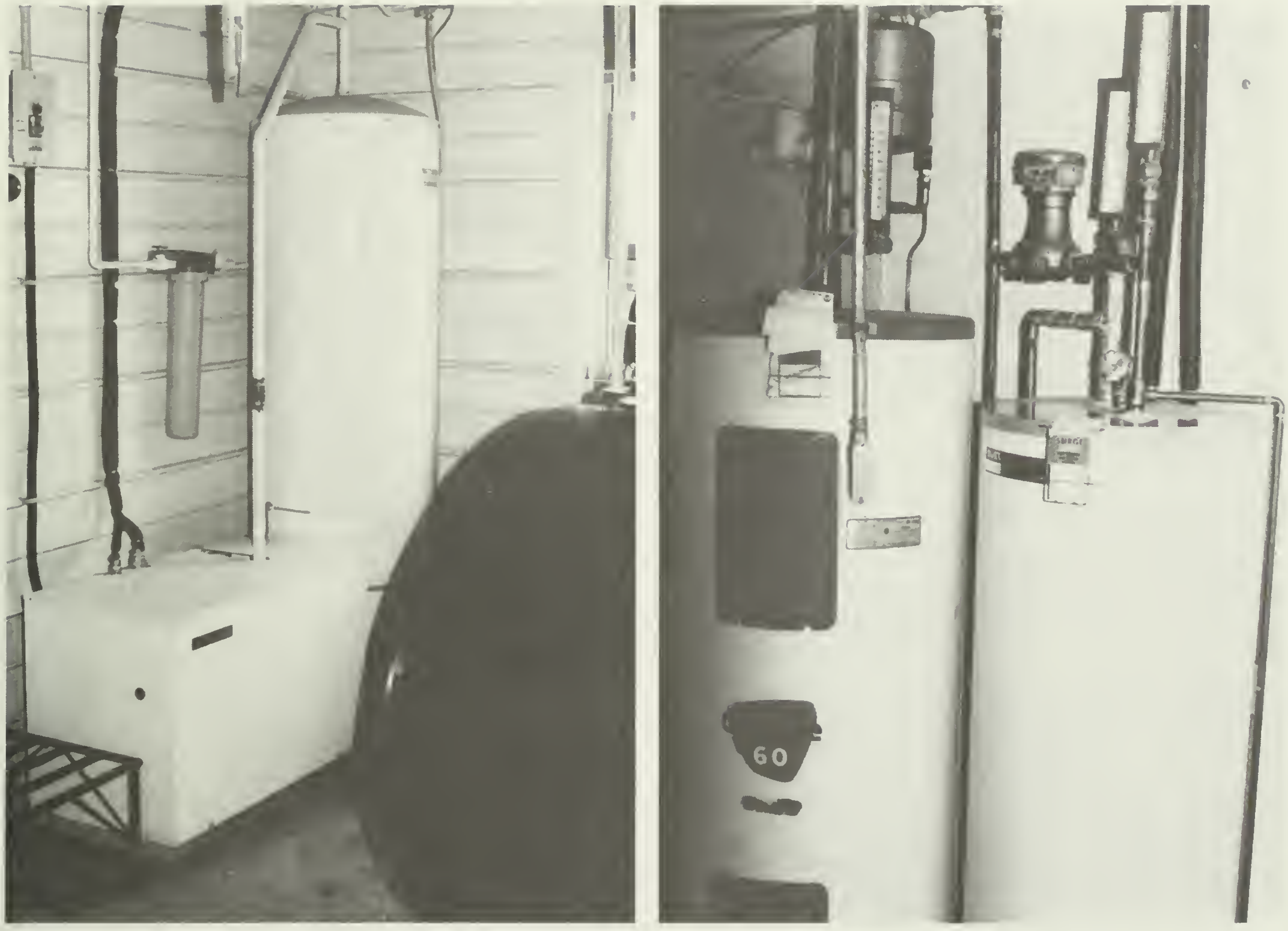


Fig. 47 Water-cooled condensing units and preheater units can transfer milk heat to water.

can be used effectively for milkroom heating during cold weather.

Either totally water-cooled condensing units or add-on desuperheater-type preheater units can be used to put all or part of the milk heat into water (Fig. 47). The temperature of the water provided by these units varies from 40 to 60°C, which means that the water is suitable for facilities and cow (udder) washing but not for equipment sanitizing. The effectiveness of this heat recovery system, therefore, is dependent on daily milk production, water requirements at 40–60°C, and the cost of conventional water heating energy.

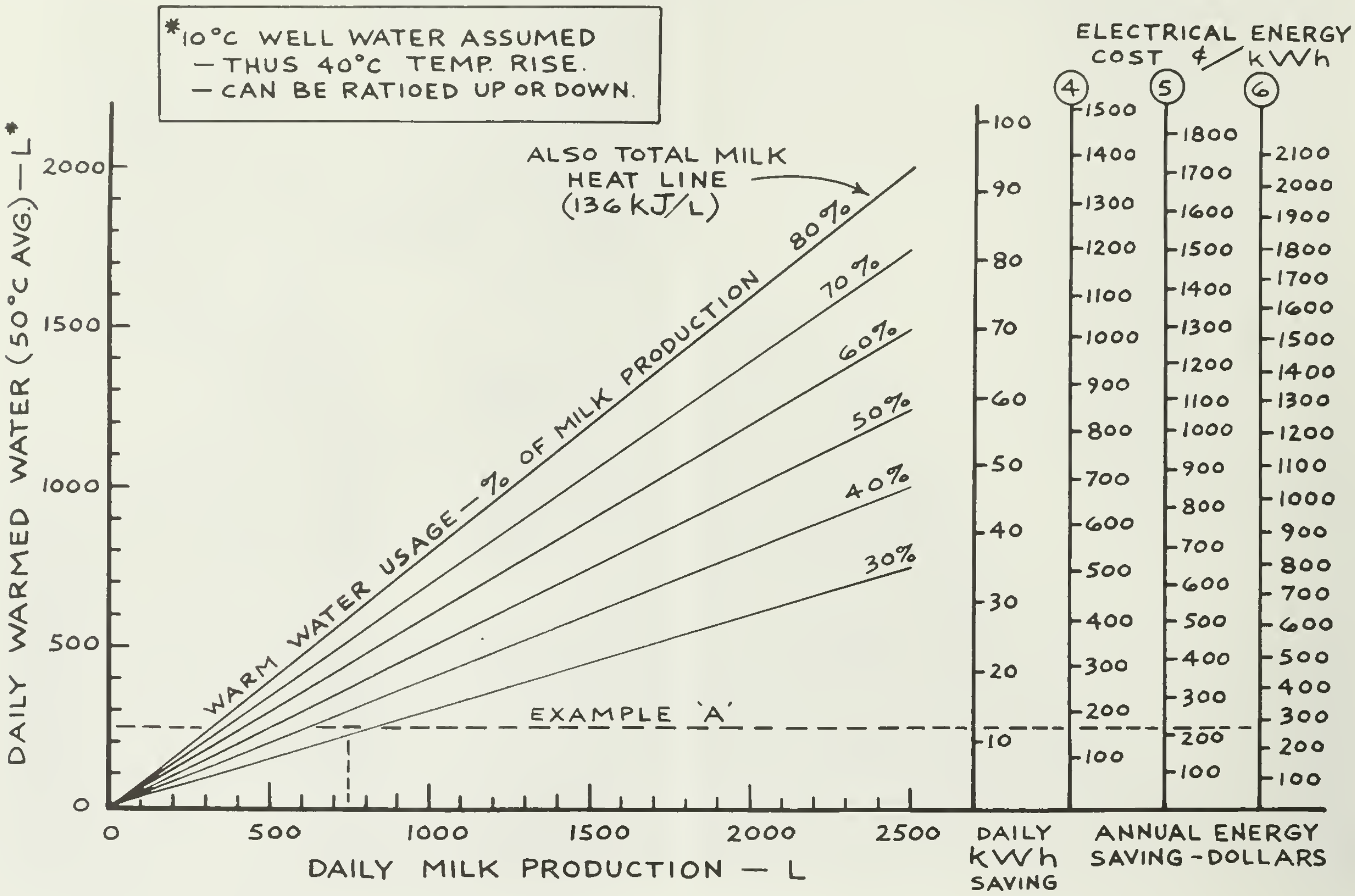
A field study by Winfield and Gee (1983) indicates that for small tie-stall herds producing milk at a rate of less than 1000 L/day and requiring only 200–300 L/day of 74–77°C water, primarily for sanitizing, it is not economically viable to use either one of these heat recovery units when electrical energy for water heating is less than $0.05/kWh. For a $1000 preheater investment, just over 40% of the milk heat was recoverable, representing only one-third of the water-heating energy. The balance of the water-heating energy was used to raise water temperature and make up standby heat losses. These are heat losses from high temperature water (74–77°C) to the cold air (5°C) in the milkroom. Milk producers would be well advised to minimize the quantity of *hot* water held, and to install "superinsulated" water heaters that have a fast recovery capability, for all the sanitizing needs.

Milk producers would also be well advised to check hot water consumption. A trip switch in a line or tank wash controller that has slipped can increase hot water consumption by 40% with no apparent benefit (Winfield and Gee 1983).

Large milk-producing units having a daily milk production of 1500–2000 L, or more, and requiring larger volumes of warm water at a temperature of 40–60°C for washing cows and facilities, can definitely benefit from heat recovery systems. Boris (1981) reported that water-heating energy at the rate of 37 kWh/day was saved with an 80-cow milking herd. Average milk production was 1655 L/day and hot water usage was 1099 L/day. The preheater provided water at 41°C, indicating even higher potential savings if the preheated (warm) water average was close to 50°C.

Winfield and Gee (1983) prepared a chart (Fig. 48) to permit estimates of energy and dollar savings by preheating water with milk heat. Example A shows how the chart works. The tie-stall herd referred to earlier produced milk at the rate of 750 L/day—enter

Fig. 48 Potential energy savings by transferring milk heat to water, based on warm water usage.



on horizontal axis. Warmed water (50°C) was delivered to the water heater at an average rate of 250 L/day—enter on the vertical axis. By moving horizontally from 250, the following information is provided: (*1*) warm water usage is 33% of milk production; (*2*) electrical water heating energy (approximately 12 kWh/day) is saved; and (*3*) annual dollar savings are approximately $170 at $0.04/kWh, $210 at $0.05/kWh, and $260 at $0.06/kWh. If, for example, warmed water is produced at an average of 40°C or 60°C, the ratio of the heat energy savings can be up or down, using the 50°C - 10°C = 40°C as the best temperature rise. Some heat may escape from warm water held in storage, particularly from uninsulated tanks. Although this heat loss may be desirable if all the warm water cannot be used effectively, it can be used to warm the milkroom in cold weather. In some instances, the warmed water can be circulated through unit heaters, but this leaves an oversupply of warmed water in summer.

For large milk-producing units, for example, with a daily milk production of 2000 L/day, one water-cooled unit and one air-cooled condenser unit can be used on a single-bulk tank, if all the potential warm water cannot be used effectively. Assuming that only 800 L of warmed water (50°C) can be used effectively, Fig. 48 shows the following: (*1*) warm water usage is 40% of milk production; (*2*) electrical water heating energy (approximately 37 kWh/day) is saved; and (*3*) annual dollar savings are approximately $690 at $0.05/kWh. The $690 would provide a simple payback on $2000 (the estimated incremental cost of installing one 2.2-kW water-cooled condensing unit), in less than 3 years—a good energy savings investment.

If two small water-cooled condensing units or one large unit had been installed, for the foregoing example, warm water would have been dumped to maintain cooling water temperature under 60°C. Water is also a valuable resource.

Reducing compressor running time by using water-cooled condensers or preheaters is not well documented. There is, however, no doubt that water-cooled condensers or preheaters are more energy efficient when the ambient air temperature approaches 30°C. This temperature can occur on hot summer days, or even on warm days when the room containing the condenser or preheater is closed and unventilated.

As the cost of water-heating energy increases, water-cooled condensers or preheaters become more viable, even for milk-producing units having a daily milk production of less than 1000 L. The equipment is available and works well, if properly selected for the application. Selection should be based on daily milk production to provide heat, effective use of 40–60°C water (part or all of which can be boosted for sanitation), and the cost of water-heating energy. In the short-term, it would be advisable for operators of small milk-producing units to minimize hot (74–77°C) water usage and volume held at that temperature. A newly purchased "superinsulated" water heater could provide payback in a much shorter time than any heat recovery equipment.

Taking heat from air, water, or soil. Heat pumps are capable of picking up heat and delivering it to a higher temperature use, and their COP (coefficient of performance) is high, provided sufficient quantities of heat are available. This provision can be a limiting factor in Canada's colder climatic conditions, when maximum heat is needed.

Air-source heat pumps do present problems when the outside air temperature is well below the freezing point. Moisture vapor in the cold air condenses and freezes on the evaporator, or heat pick-up coils, and it then becomes necessary to reverse the heat pump cycle to defrost the coils. Unlike a residential application, supplemental heating of controlled-environment animal or poultry buildings is only necessary in cold weather—below the heat deficit temperature—which may be below freezing for a well-insulated, fully stocked building.

Drawing heat in a significant quantity from soil, groundwater, or liquid-manure tanks presents similar problems. Before purchasing a heat pump for animal or bird space heating, which is a major investment, the availability of free heat should be investigated. In addition, many environments cause corrosion and dust fouling of the condenser unit or of the evaporator coils if they are placed in a liquid-manure tank. The liquid-manure tank is also likely to freeze if heat is removed at a high rate.

Using heat exchangers

A radiator on a truck or tractor is a heat exchanger. It has a hot fluid on the inside of the radiator core. Dry (sensible) heat is conducted through the core and given up to a cooler fluid (air) on the outside. In this example, the heat is being dumped, but in many farm buildings opportunities exist to recover and reuse heat. Such opportunities, however, occasionally present problems but they are sometimes surmountable.

Liquid-to-liquid exchanger applications. Inline heat exchangers are available to precool milk before entering the bulk tank. Heat can be transferred or exchanged to cold well water during the milking process. In order for the application to be effective, constant water flow is essential. The water will only be raised to about 18°C, offering limited direct uses. Animal drinking water could be tempered, but the advantage of this is minimal, not constant, and undesirable in hot weather, when the water is needed most.

One real advantage is a reduced milk blend temperature, which can enhance milk quality. Another advantage is reduced cooling compressor running time. Water-cooled condenser-type milk coolers, although more expensive initially, do offer the most advantages while producing warm water at usable temperatures, if required.

Air-to-air heat exchangers. Ventilation heat losses from animal or poultry buildings greatly exceed conduction heat losses. By recapturing only a portion of the heat from exhaust air in cold weather, many continuously ventilated housing facilities could maintain a heat balance, thus requiring no supplemental heat.

Some home-built (Fig. 49) and commercially built (Fig. 50) heat exchangers have been field tested, with varying degrees of success. Saskatchewan Agriculture has published an excellent booklet titled *Livestock ventilation heat recovery systems*, which describes basic design principles, systems available, operational problems, and techniques for projecting capital cost recovery.

Although the concept of air-to-air heat exchangers is sound, animal or poultry buildings present the following unique application and operational problems:

1. In cold weather the exhaust air is always moist and can be almost saturated (80% RH). Cooling will condense and freeze this moisture vapor, restricting exhaust airflow in the heat exchanger, specially if the unit has a high effectiveness in recovering heat.

Units of lower effectiveness can reduce condensate freezing. Defrosting the condensation water on the exhaust side of the heat exchanger is usually done by stopping or slowing the rate of cold air supply as freezing occurs. An acceptable method to

Fig. 49 Heat exchangers that are used to recover heat from exhaust air can be built on-site.

Fig. 50 Inside and outside view of one commercial, wall-mounted, heat exchanger that is used to recover heat from ventilation exhaust air.

initiate the defrosting of condensation water is by sensing the exhaust air temperature at the outlet of the heat exchanger with a thermostat.

2. The dust in exhaust air can collect separately and in the condensed water, causing plugging and corrosion of metal exchanger components. Plastic cores or plates can be used to eliminate corrosion, but scheduled cleaning to clear exchanger exhaust channels is still required.

3. Some exchanger systems require significant additional fan energy in the form of electricity, to overcome air friction losses within the exchanger. This energy must be deducted from the heat energy savings when calculating cost effectiveness or payback.

4. The tempered incoming air is often delivered at one location from the heat exchangers, which is unacceptable for most applications. The incoming air must be distributed by forced jetting or by an air-recirculation system, which might otherwise be unnecessary. Its capital and operating cost then must be added to the heat exchanger system.

Currently available heat exchanger systems in many animal or poultry applications require regular maintenance in order to operate effectively on a constant basis, and this maintenance time must be planned for in the work schedule.

The development of better heat exchangers for animal and poultry environments is continuing through research and innovation. The heat exchanger concept is a good one and the increasing energy costs will stimulate production of even better designs.

One innovative idea is to take larger volumes of exhaust air from environments with excess heat, such as that for swine-finishing or dairy cow units, and use it to heat smaller volumes of air delivered to adjacent heat-deficient units, such as farrowing/weanling cow/calf units. Because the warm airflow rate is much higher than the cold airflow rate, the freezing problem is greatly reduced. For this type of application the total supplemental heat requirements can be provided, and possibly a higher ventilation rate maintained, giving a healthier environment for the young animals.

Using solar energy

Solar energy is free, but collecting and storing it is not. The capital investment must be repaid with interest in an acceptable period of time (less than 5 years is generally acceptable to most farm operators).

During the winter, clear sunny weather usually accompanies very cold outside air temperatures. Thus, applications that can use any solar heat available, not necessarily at a specific temperature, have promise for Canadian agriculture. Two such field proven applications are as follows:

Preheating ventilation air.

During cold weather any temperature increase to incoming ventilation air is beneficial, even 2 or 3 C°. The added heat will assist in maintaining moisture control ventilation rates with less supplemental heat. Some increase in ventilation rate is also desirable to provide an excess of fresh air to dry the building and remove gases, dust, and bacteria.

Field-scale test installations of a vertical solar collector with heat storage in walls facing nearly south, have performed well, are cost effective for many Canadian locations, and require very little maintenance (Winfield 1981). For latitudes above 40°, and this includes all of Canada, a vertical solar collector is ideal for winter heating. Such a collector will collect more solar energy when the ground is snow covered than a collector tilted to latitude plus 15 to 20°. This makes the vertical collector an ideal choice for preheating ventilation air. Fig. 51 shows an installation in a small farrowing unit.

The addition of a properly sized heat storage is essential. With the vertical wall, a properly sized heat storage is accomplished easily with 240 mm, 75% solid concrete blocks (see Fig. 52 for details of construction). Fig. 53 shows the wall performance on a sunny winter day. By comparing the peak temperatures of "air in collector" with "air from wall to barn" (30°C versus 20°C), the need for heat storage is evident.

Without the concrete block walls, 30°C air would have been delivered, causing full summer ventilation rate in February, with no benefit at night when heat

Fig. 51 A vertical solar collector with heat storage was built into this farrowing unit to preheat the winter ventilation air.

is needed most. By adding the concrete block wall to provide thermal inertia or time lag, maximum air temperature delivered was an acceptable 20°C and a significant amount of solar heat was carried over for night use. This is shown as "concrete inner column (storage)" temperature in Fig. 53.

The solar collector/storage wall must obviously be bypassed on warm spring days and during the summer. By using the hallway or retrofit configuration, the bypass can be accomplished easily by opening one or more doors, leaving the screened door in place (Fig. 54).

Complete details on preheating ventilation air and a Canada Plan Service (CPS) Plan M-9732, *Solar ventilation wall with heat storage,* are available from provincial agricultural engineers or extension advisers.

For many Canadian locations the average amount of heat the solar collector/storage wall collects is 2 kWh/m^2 per day during the 180-day heating season. This heat energy can be used effectively in heat-deficient animal housing units, such as farrowing, weanling, and veal-calf units, or even swine-finishing units in colder regions. A 1-m length of wall 2.44 m high provides an annual energy savings of $2.44 \times 2 \times 180$, which equals 878 kWh, or $43.92, with electrical energy at $0.05/kWh. That amount should pay for the building of a solar wall into a new building in much less than 5 years, which is an attractive investment. Adding a solar wall to an existing building with additional new footings and foundation wall, however, is not such an attractive investment.

When preheating ventilation air to continuously ventilated, heat-deficient animal/poultry buildings, do not cut costs by omitting a heat storage system. Conversely, do not use an oversized heat storage system, because this will probably cost more. Energy might be required to charge and discharge the oversized heat storage system and it is not likely to perform any better or be as cost effective as the system previously described.

Some clean air applications, such as the one described in the following section, permit recycling of air through a solar collector. Do not recycle dirty dust-laden air from animal or poultry buildings. The dust will quickly coat the black collector, turning it white, and will act as undesirable insulation.

Warming the farm shop.

Another practical use of solar energy on the farmstead, where a specific temperature is not required, is to warm the farm shop. Many Canadian farm operators desire a warm workplace where they can repair machinery and equipment or store tractors and pick-up trucks, for easier winter starting.

A simple covered-plate collector on the building's south wall, without heat storage of fan air circulation, is effective. An Ontario Ministry of Agriculture and Food Factsheet (Spieser 1981) describes the wall system tested in southwestern Ontario. Construction details are also available through provincial agricultural engineers or extension advisers (CPS Plan Q-9731). Fig. 55 shows a solar wall cross section; Fig. 56 shows the complete installation of one in an actual farm shop.

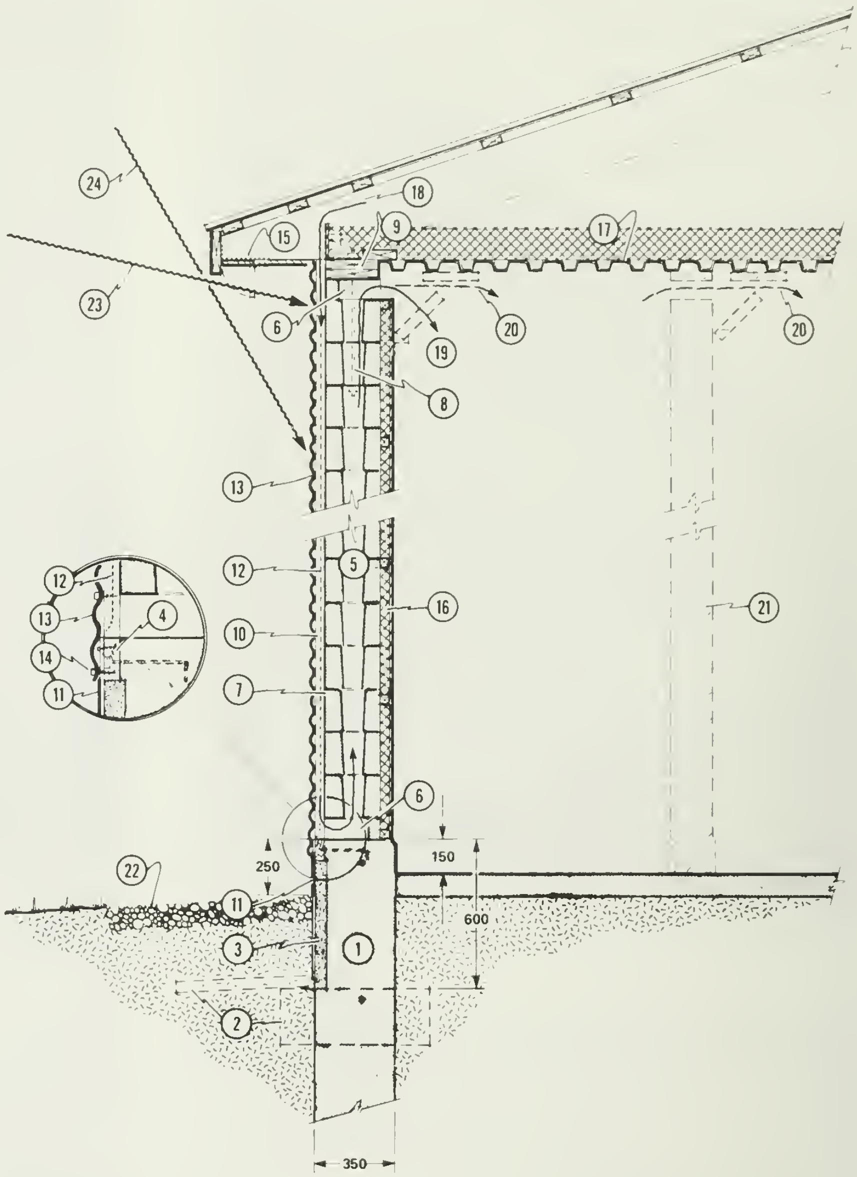
The lighter warmed air in the solar collector rises and is replaced by heavier cool air at the bottom. In most applications, air circulation within the farm shop is adequate. However, a destratification fan(s) can be suspended from the ceiling, if desired, to push the warmer air down to the work level. A polyethylene anti-backdraft valve is highly desirable to stop heat losses caused by airflow reversal at night.

With this system, a planned heat storage is not worth the additional cost, because the concrete floor, the building components, and all the equipment or machinery in the shop will act as heat storage.

Although the temperature in the farm shop will vary, it can provide "coverall" working comfort on sunny winter days. Here again, corrugated glazing is essential to absorb thermal expansion.

Unless they are used regularly during the winter, most farm shops have low capital investment and potential energy savings. Again, if the shop is already insulated, payback should be less than 5 years.

Fig. 52 Details of construction for a vertical solar collector with heat storage to preheat winter ventilation air.



1. shallow or deep concrete foundation
2. optional shallow footing, 400 x 200 mm, with 50 x 600 mm horizontal perimeter insulation, (Dow Styrofoam SM, or equal)
3. 50 x 550 mm vertical perimeter insulation, (Dow Styrofoam SM, or equal); tack to formwork with finishing nails before placing concrete, or glue if (1) is concrete block
4. 38 x 89 mm wood sill, CCA pressure-treated, anchor to (1) with M10 x 150 mm bolts cast into concrete @ 1200 mm oc or less
5. 240 mm concrete block (size code 25), 3-core, 75% solid, laid in running bond pattern (not stack bond)
6. concrete bricks on edge, 6 bricks per block
7. collector surface, blocks and wood strapping (10) painted flat black
8. M12 x 600 mm threaded rod anchor bolt @ 1200 mm oc, 100 mm square washers and nuts top and bottom, set in mortar
9. 2-38 mm plates continuous, joints staggered @ 2400 mm oc, caulk airtight to bricks, blocking and ceiling
10. 38 x 38 mm cedar strapping @ 600 mm oc
11. 5 x 600 mm high-density recompressed cement-asbestos board, predrill and screw top edge to (4)
12. optional black aluminum fly screen absorber, bend to midway between blocks (5) and cover (13)
13. glass-fiber-reinforced clear corrugated plastic (Filon, Excelite or equal, by Graham Products Ltd.), coat with UV-screen lacquer, caulk and lap all edge joints airtight
14. 3 x 25 mm (#8 x 1 in. (2.5 cm)) hex-head roofing screws with neoprene washers, drill and drive in valleys @ 600 mm horizontal and 200 mm vertical spacings
15. soffit vent slot with bird screen; 19 x 140 mm continuous flap door closed in winter, open in summer
16. 38 mm strapping @ 600 mm oc, glass fiber insulation, vapor barrier and plywood paneling; if air (20) enters directly into animal rooms, increase to 89 mm strapping and insulation
17. steel or plywood ceiling diaphragm (see M-9371, M-9373, or M-9374)
18. winter air enters collector from ventilated attic
19. solar-heated air enters preheating hallway or (20)
20. air enters animal room through adjustable slot inlet
21. optional insulated wall divides preheat hallway from animal room
22. coarse gravel or crushed stone, stops mud from splashing on wall
23. solar angle on 21 December, Winnipeg (50° N)
24. solar angle on 21 June, Winnipeg (50° N)

Fig. 53 Recorded temperatures versus time of day for one vertical solar collector wall with heat storage.

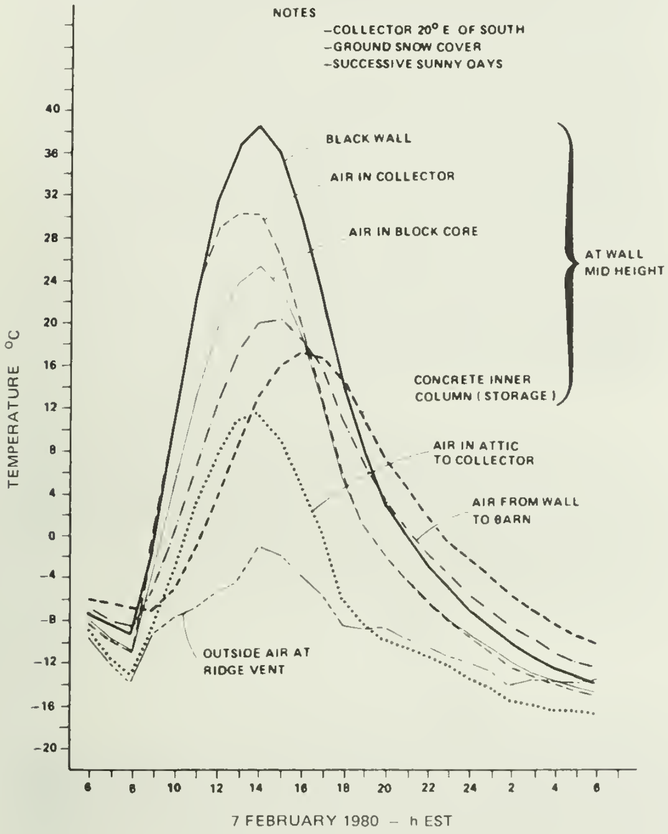


Fig. 54 This vertical solar air preheating wall is easily bypassed during the summer by opening (removing) the solid door, allowing intake air to flow directly to the plenum or south hallway.

Fig. 55 Cross section of vertical, passive solar wall for farm shop heating.

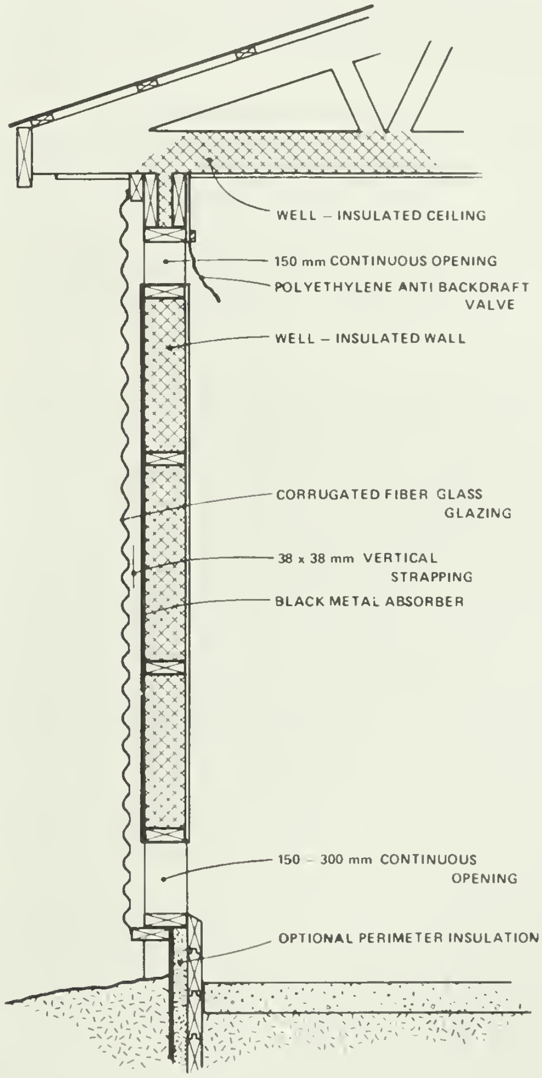


Fig. 56 A south-facing passive solar wall on a farm shop.

Using biomass energy

Many field-crop and forest residues can be used directly or indirectly for low-grade heating fuel. The major factor influencing decisions to use biomass energy is one of economics. Will the total system provide an acceptable return on investment? If a farm owner has already justified the purchase of large package haymaking equipment, then the cost of adapting that equipment and using it to collect excess straw or other crop residue for burning will be much lower. Similarly, being close to an assured supply of sawdust or wood chips can affect the economic viability of a proposed scheme.

Combustion for heating.

For animal or poultry housing operations that require large quantities of supplemental heat, direct combustion of biomass materials to produce hot water may be viable. This system is more likely to be viable for large commercial operations, justifying a central heating plant with attendant, to provide heat for several buildings or for a combination of uses, such as building heating and crop drying.

Commercial equipment that permits automatic feeding and temperature control is available. Applications must be assessed individually to establish feasibility and cost effectiveness.

Conversion for fuel.

Biomass can be converted by many processes to provide energy in more convenient forms. However, few family farm operations maintaining livestock or poultry have an excess of managerial and operating personnel. Distillation, fermentation, gasification, and so forth, require specialized equipment and operator skills. To date, few *farm-scale* systems are operating successfully, and it is unlikely they will be used extensively in the near future.

Biogas, or manure gas as it is often called, is being produced on North American farms. In many instances, it is not being produced to provide heat energy but to reduce odor created by large animal concentrations near urban centers, or to recover single-cell protein for refeeding.

Although biogas, primarily methane, can be produced, storage is a problem because unlike LPG (propane) it cannot be compressed to a liquid. Storage in the gaseous form requires a large gastight, variable volume container. Because of the large volume required, portable use in tractors, combines, and so forth, is not practical.

Continuous research in this area might result in fuels derived from biomass being practical, safe, and cost effective for animal or poultry producers in the future.

Using wind energy

Wind energy is significant in quantity but unreliable in intensity, and few regions in Canada have sufficient wind energy to warrant its use.

Fig. 57 Naturally ventilated livestock buildings make effective use of wind energy in warm weather.

Using windpower to replace significant amounts of energy in and around farm buildings is not likely to be a major economic factor. It has been and will continue to be used for purposes such as the following:

For ventilation.

Ventilation of some animal or poultry confinement buildings has been done either partly or completely by wind energy and this trend should be continued. All naturally ventilated buildings for beef, dairy, sheep, turkey, and even swine in some climatic conditions, are dependent on wind. In winter, natural ventilation is often hard to control unless large doors (panels) can be sealed to prevent overventilation. In summer, however, large side panels, doors, or curtains can be opened so that even a light breeze becomes an asset (Fig. 57).

For pumping water.

Windmills were once a familiar sight across Canada. They were used to pump water and, although most of them have now been replaced by inexpensive electrical energy, some windmills are still being used in remote locations. A large water storage was the key to success. On a windy day sufficient water could be pumped to meet the animals' needs for several days.

For most large livestock or poultry operations the use of wind to pump water is no longer viable, because the demand for and assurance of water supply is too critical; electrical energy is being used to pump and pressurize water very efficiently.

For generating electricity. A lot has been said, written, and observed in recent years about using wind energy to generate electricity. Again, the problem is not one of production but of storage. Alternating current energy, as produced, must either be used immediately or be converted to direct current for storage in batteries. For most farm purposes, for example conventional electric motors, it must be converted back to alternating current.

Most farms, and particularly dairy farms, do not have a constant electrical demand, thus a large portion of the electrical energy generated would have to be stored for the two high-demand periods—morning and evening chore times.

An alternative is to sell excess electrical energy to the utilities. The utilities would want to buy the energy at generation cost, which is well below distributed cost of about $0.05/kWh. Electrical utilities in Canada, as well as some in the United States, are setting up "wind farms" to supplement their own generating capacity, and this action is both prudent and more practical than individual farm generation.

Using geothermal energy

In some areas of the world, including isolated locations in Canada, hot water is available at or near the earth's surface. For most locations, soil or groundwater temperature is constant but at relatively low temperatures (3-15°C). Extracting significant quantities of heat from soil or water at these temperatures is still relatively expensive. Three techniques are being utilized to take advantage of this heat:

To reduce low ambient air exposure. Residences have been built into south-sloping banks to reduce exposure to prevailing winds and cold outside temperatures. Although the technique is effective, the view and siting are limited. Farm buildings with ideal drainage conditions can be set partially underground, or earth can be banked up the walls. However, this would require farm buildings to be completely redesigned to accept soil pressure and to prevent wood rot and so forth, and this would result in increased building costs. A well-insulated building is a cheaper alternative, because building heat loss is minimal compared to ventilation heat loss.

As a heat source for heat pumps. Heat pumps upgrade heat by moving it from a lower to a higher temperature efficiently. With soil or groundwater temperature at 3-15°C, the size of the heat collection system in the earth or the pumping rate from a well would have to be sufficient to permit extraction of large quantities of heat without causing freezing.

For example, if water is cooled 5 C° it requires a flow rate of 3448 L/hour to provide the heat equivalent of a 20-kW (72 000 kJ/hour) heating unit. That flow rate is the total output from a very good farm well. In order to conserve water, a second well, preferably one with a large diameter, is required to return the water to the groundwater source. The capital cost for wells and heat pumps is high compared to alternatives such as a solar wall or a heat exchanger.

To condition incoming ventilation air. Earth-tube heat exchangers have been field tested at various locations in the United States. Some test installations have been made in Canada, but there are no reported results available. The principle is to bury a number of corrugated plastic drain tubes (without perforations) in either a radial or a parallel pattern with header. The exposed end of each lateral is turned up out of the ground to act as an air intake. The buried end of each lateral is placed to converge to an insulated, vertical collection duct near the building.

To get sufficient heat transfer surface, the laterals must be long (38-76 m), and of sufficient size (150-300 mm) to reduce air friction losses. This permits a low-head fan to be used to draw air through the rough corrugated plastic tubing. The tubing must be located deep enough, at least 3 m in most locations, to minimize surface temperature fluctuations. Ideally, the tubing should be put into groundwater but because it has to be buried so deeply special precautions must be taken to avoid trench slides. Tubing connections must be watertight, and the tubing must slope uniformly to permit drainage or pumping of condensate and leaked groundwater.

Air passing through the tubes can be cooled in summer and warmed in winter, benefits which are highly desirable. The problem, however, is the capital cost of large-diameter tubing and deep trenching. Estimates by Goetsch and Muehling (1981) put the near-optimum (least cost) system costs for a 1000-L/s system between $4000-$5000. A 1000-L/s system could provide total winter ventilation rate for a large building but only "snout cooling" for sows in hot weather. Winter air heating only, with an earth-tube system, is likely to provide an unacceptably long payback period. If the benefits derived from summer cooling, for example reduction in sow heat stress, are given equal economic value, then the system could be considered a viable new-technology alternative, with a simple payback of 2 to 3 years.

SUMMARY

This publication is an attempt to put energy management in farm buildings housing livestock and poultry into perspective. It is believed that, with few exceptions, minor changes can be implemented at minimal cost to reduce conventional energy use by 10, 30, or even 50% in some farm building operations.

The troubleshooting charts are a good place to start an energy audit of production facilities.

Attention to details, such as preventing over-ventilation when supplemental heat is on; correctly calibrating thermostatic controls; using the proper air intake design and air inlet adjustment; and carefully sizing heating units, can save energy and money directly. At the same time, a better environment means healthier, more productive animals or birds, which, in turn, means reduced feed energy, veterinary expenses, and operating costs.

Some new technology should be adopted now. Heat recovery from milk to preheat dairy washwater is a sound investment for many of the larger dairy operations, if the recovery system is carefully selected. It does not make sense to dump hot water; "super-insulated," high recovery rate water heaters are a better investment for many small-volume producers.

If well-insulated but heat-deficient, continuously ventilated animal buildings are being constructed, the incorporation of a vertical south-facing solar collector/storage wall should be considered for many Canadian locations. A solar wall for farm workshops should also be considered.

Field-proven developments by researchers and innovators will continue to be made and refined. These developments must be evaluated for individual housing systems and management requirements. Good management, an understanding of objectives, and attention to details are likely to provide the greatest economic benefits; good enery management in farm buildings cannot be purchased or acquired from any one supplier.

TABLE 1 Troubleshooting environmental control/energy use in winter

Problem	Possible cause(s)	Remedies
A. Undesirable air throughout building	1. Lack of continuous (exhaust) ventilation or too low a flow rate	1.(a) Check fan louvres for free movements that permit fan(s) to exhaust rated flow. (b) Install one or more exhaust fans with lower or correct capacity. (c) Reduce building air temperature, if practical, to increase ventilation rate. (d) Provide some air inlet in an airtight building.
	2. Thermostatic control(s) of continuous fans not located, set, or wired properly	2.(a) Check control location for drafts or dead air pocket. (b) Check calibration (setting), using a thermometer. (c) Check that two-speed fans are switching to low speed (not high) when temperature falls.
	3. Insufficient heat to force continuous ventilation while maintaining building temperature	3. Add supplemental heat to maintain temperature in critical areas, i.e., farrowing units.
	4. Exhaust fans not protected from outside wind pressure	4. Install proper fan hoods, thus permitting fans to exhaust.
	5. Significant amount of exhaust air recycling to air intake	5. Divert exhaust air from intake outside of building.
B. Undesirable air in localized areas within building	1. Inlet air not well distributed within building space	1.(a) Adjust or add air inlet in building. This might take the form of recirculation equipment. (b) Seal some excess cracks or holes where air is good, in older buildings.
	2. Air intake on outside of building not protected from wind effect	2. Modify air intake system as described in text.
C. Condensation on walls or ceiling of building	1. Lack of insulation	1.(a) Add or replace insulation. (b) Lower building temperature by increasing exhaust rate, if practical.
	2. Insufficient heat to provide moisture control at desired building temperature	2. Add supplemental heat, particularly for young animals and birds.

TABLE 1 Troubleshooting environmental control/energy use in winter (continued)

Problem	Possible cause(s)	Remedies
	3. Building air temperature too high for available heat and insulation level	3. Lower winter exhaust fan thermostatic control setting(s).
	4. Nearly saturated air being drawn to cooler building area	4.(a) Move winter fan to area for mature animals and birds.
		(b) Redistribute animals. Move some mature animals to cooler area.
	5. Leaking waterers	5. Repair waterers.
	6. Distressed animals or birds	6.(a) Obtain veterinary assistance.
		(b) Test water and/or feed for high salt content.
D. Large building temperature cycles, e.g., 5 C° every 40 minutes	1. Excess ventilation: (a) exhaust fan capacity steps too large	1.(a) Install lower-capacity fan(s).
	(b) more than one fan per thermostatic control	(b) Install additional thermostatic control or switch off one fan during very cold weather.
	(c) faulty (insensitive) thermostatic control	(c) Clean or replace thermostatic control.
	(d) thermostatic control not located to sense average ambient conditions	(d) Move thermostatic control or correct draft or heat source affecting sensor.
	2. Oversized heating unit: supplementary heater larger than required	2. Reduce firing rate or replace with smaller heating unit.
E. Building too cold, air quality good	1. Excess ventilation: (a) thermostatic control set too low	1.(a) Readjust, clean, or replace thermostatic control(s).
	(b) exhaust rates too high	(b) Install one, or more, lower-capacity exhaust fans.
		(b) Switch off one of two or three fans connected to one thermostatic control.
		(b) Calibrate thermostatic control with an accurate thermometer.
		(b) Stage thermostat settings to prevent overventilation in cold weather by the higher-capacity fans.
	(c) lack of rate control by wind ventilation	(c) Close gutter cleaner ports when not in use.
		(c) Close doors to feed room containing silo chute(s).
		(c) Seal excess cracks or holes around windows and doors.
		(c) Close down air inlet.
		(c) Cover large (summer) exhaust fans.
		(c) Check air intake system for proper wind protection (see text).
	2. Lack of insulation or heat: (a) overventilation is used to control condensation	2.(a) Insulate building to permit higher relative humidity without condensation.
	(b) insufficient heat	(b) Increase animal/bird stocking density.

TABLE 1 Troubleshooting environmental control/energy use in winter (continued)

Problem	Possible cause(s)	Remedies
		(b) Consider porous ceiling in dairy barn, solar preheat wall in new construction, heat exchangers, or conventional supplemental heating.
F. Drafts	1. Air inlet opening too wide, causing cold air to fall	1. Reduce inlet opening to create air jetting and mixing above animals/birds.
	2. Obstruction on ceiling, causing cold air to fall (greatest effect in low airflow applications, e.g., farrowing and calf units)	2.(a) Remove obstruction or reduce effect, thus smoothing airflow path. (b) Suspend conduit from ceiling. (c) Install corrugated metal ceiling in direction of airflow during construction. (d) Preheat incoming air in hallway, if possible.
	3. Air intake (outside of building) not hooded or protected from wind	3.(a) Move intake away from vertical wall (to fascia board) with overplate intakes. (b) Install updraft deflector on outside of wall for through-wall intakes. (c) Restrict (close down) external air intake for winter period, using a hinged door or sliding panel. (d) Draw attic air during winter, if continuous ventilation is certain.
	4. Leaky older building, poor fitting doors and windows	4. Seal excess cracks and holes. Cover summer exhaust fans.
	5. Mechanical air recirculation (distribution) systems that are oversized, misplaced, or misdirected	5. Consult the manufacturer's literature or representative for assistance.
G. High heating (energy) bills	1. Overventilation: (a) continuous/moisture control fan(s) with too high capacity	1.(a) Install lower-capacity exhaust fan(s) for cold weather ventilation.
	(b) heating thermostat set too high	(b) Reduce heating thermostat setting. (b) Increase ventilation thermostat setting.
	(c) heating/ventilation thermostats inaccurate or not sensing same temperature	(c) Check calibration of thermostatic control with thermometer. (c) Bring thermostatic controls to same location. (c) Electrically interlock heating/ventilation controls.
	(d) lack of exhaust fan thermostatic control setting differences	(d) Insure fall/spring ventilation thermostatic controls are staged above winter minimum setting.
	2. Supplementary heater that is larger than required, forcing overventilation to dampen temperature cycles	2. Reduce firing rate, replace with a smaller or two-stage heating unit, or install more than one smaller unit to permit staging.

TABLE 1 Troubleshooting environmental control/energy use in winter (concluded)

Problem	Possible cause(s)	Remedies
	3. Overheating in low airflow rate buildings to improve temperature at animal/bird level, e.g., poultry brooding and swine farrowing facilities	3.(a) Add insulation and weatherstripping. (b) Lower ceiling, if cathedral-type. (c) Install a recirculation system to minimize temperature stratification and maximize pickup.
	4. Heating air with limited (small) warmed floor area	4. Install air heating equipment.
	5. High building air temperatures increase building shell heat losses	5.(a) Add insulation and weatherstripping. (b) Use radiant spot heating for small animals/birds to reduce building air temperature. (c) Reduce building temperature to the optimum for animal/bird productivity.
	6. Energy-inefficient ventilation fans	6. When buying new or replacement fans compare the litres per second per watt ratings.
	7. Heat-deficient buildings requiring heat for adequate moisture control ventilation at higher temperatures, e.g., swine farrowing/weanling and veal calf housing units	7.(a) Add insulation and weatherstripping. (b) If new facilities are being built, consider including a solar ventilation wall with heat storage (see CPS Plan M-9732). (c) Consider purchasing a heat recovery unit to reclaim heat from exhaust air. (d) Consider biomass heating for some applications. Individual assessment is essential.

NOTE: Heat recovery units (heat exchangers) to recover heat from exhaust air may be considered in lieu of supplementary heat for some heat-deficient applications.

TABLE 2 Troubleshooting environmental control/energy use in summer

Problem	Possible cause(s)	Remedies
A. Building air too hot throughout building, compared to outside temperature	1. Insufficient air movement:	
	(a) fan(s) not operating	1.(a) Replace defective controls or change fan location.
	(b) fan blades not set properly in orifice	(b) Adjust fan on shaft for one-third protrusion.
	(c) insufficient fan capacity	(c) Add high-capacity fans or open building completely by opening doors and windows.
	(d) fan hoods too small or obstructed	(d) Increase fan hood size to at least fan area.
	(e) opening to fan bank too small	(e) Increase wall opening or move fan(s) from bank to other wall location.
	2. Lack of desirable intake air (from outside to inlet):	
	(a) air intake not large enough	2.(a) Increase air intake area on outside of building.
	(b) warmed attic air drawn in because of insufficient air intake area	(b) Increase air intake area on outside of building and insure vertical blocking is placed between trusses.
	3. Excess attic heat load to building:	
	(a) insufficient attic insulation and/or ventilation	3.(a) Reinsulate attic and insure adequate eave inlet and ridge or gable outlet area.
	(b) dark (nonreflective) roof surface	(b) Consider either painting the existing roof white, gray, or silver to reflect the sunlight or installing a new roof that has a solar-reflective surface.
	4. Excess animal density	4. Reduce animal/bird density during summer (if practical).
B. Building air too hot (in specific areas)	1. Air inlets open too far, causing short circuiting to exhaust fan(s) (or concentrated air inlet)	1. Reduce air inlet opening to cause jetting in all areas (close doors).
	2. Lack of fresh air	2. Add continuous air inlet or air circulation system.
	3. Excessively hot air in front of banked (grouped) fans	3. Move one or more fans to another location to reduce concentration of stale, hot room air.
C. Building too dry, (problem with broilers on litter)	1. Lack of water intake by birds	1.(a) Wet down litter with hose.
		(b) Adjust feed ration.
D. Building air hotter than desirable for mature swine (pigs showing signs of heat stress)	1. Swine showing signs of heat stress	1.(a) Install intermittent spray-cooling system rather than increase fan capacity above normal rates, thus permitting evaporative cooling from body surfaces.
		(b) Use evaporative air-cooling systems if the outside air relative humidities are low when temperatures are high.
		(c) Remove any insulation under concrete floors where mature animals are being housed.

TABLE 2 Troubleshooting environmental control/energy use in summer (concluded)

Problem	Possible cause(s)	Remedies
E. Excessive daily building temperature changes and/or draft problems	1. Thermostatic control settings too low	1. Increase temperature control fan(s) thermostatic control settings to reflect a higher acceptable room temperature during warm weather.
	2. Lack of air control	2. Adjust air inlets, as necessary, to maintain jetting action.
F. High energy bill	1. Operation of several ventilation fans	1. Consider natural ventilation by windows, doors, wall curtains, and open ridges when conditions permit.
	2. Too many fans	2. Use larger diameter, slower-speed fans. They are more energy efficient for the higher summer rates and provide more litres per second per watt.
	3. Energy-inefficient fans	3. Use energy-efficient motors for new and replacement installations.

GLOSSARY

air inlet The planned slots, ports, or holes through which air, at a controlled velocity, is introduced into the area of the building where the animals or birds are located.

air intake The opening through which outside air enters the building and flows to the air inlet.

coefficient of performance (COP) The amount of heat energy moved by a heat pump relative to the amount of energy consumed.

effectiveness ratio A measure of performance of a heat recovery (exchanger) system. The relative amount of heat recovered is compared to the amount available for recovery and is usually expressed as a decimal or a percentage, e.g., 0.6 or 60%.

fascia The vertically positioned structural component at the edge of a roof; usually a 150-mm piece of lumber attached to the rafter ends and covered with aluminum or steel.

heat recovery The process of removing heat (that would otherwise be wasted) from exhaust air or milk for reuse in preheating incoming air or heating water. Heat exchangers or refrigeration units are common recovery mechanisms. Recovered heat can be used to displace purchased or supplemental heat.

humidistat An electrical control or switching device that regulates the relative humidity (RH) of air.

hygrothermograph A device that senses and records air temperature and relative humidity (RH) simultaneously.

leakage Air entering a building through other than a planned air inlet system, usually through cracks or holes.

power efficiency A rating of exhaust fan air moving capacity in comparison to power use and usually expressed as litres per second per watt.

relative humidity (RH) The relative amount, usually expressed as a percentage, of moisture vapor in the air compared to the maximum possible density of moisture vapor in the air at a given temperature.

soffit The horizontal or sloped sheathing between the fascia and the vertical outside wall of the building.

superinsulated (water heater) A term used to describe the new generation of electric water heaters that have a beige-colored outer casing. These heater units have about 50% more thermal insulation around the tank than the white units.

supplemental heat The additional heat required in a ventilated animal or poultry building to maintain a desired minimum building air temperature. It supplements the heat provided by the animals or birds, and can be provided in many ways, including recovered heat from ventilation exhaust air.

thermostatic control An electrical control or switching device that is actuated by the surrounding air temperature. Variable output controls adjust fan speed or heater output infinitely over their capacity range. Switching controls turn fans and heaters on or off in a stepped sequence. Exhaust fan controls must be wired to increase speed or to close when the temperature rises. Heater controls must be wired to increase heater output or to close when the temperature falls. (Many farm-type thermostats can be used for fans or heaters, if wired correctly.)

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