New Systems of Ventilation and Environmental Control in Dairy Barns

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Introduction

Dairy barn ventilation is more evolutionary than revolutionary. Changes in the management of the ventilation system have been as significant as the changes in hardware. The changes discussed are based on our experience with warm tie stall dairy barns of both new and old two story construction which are the predominant dairy housing used in Ontario.

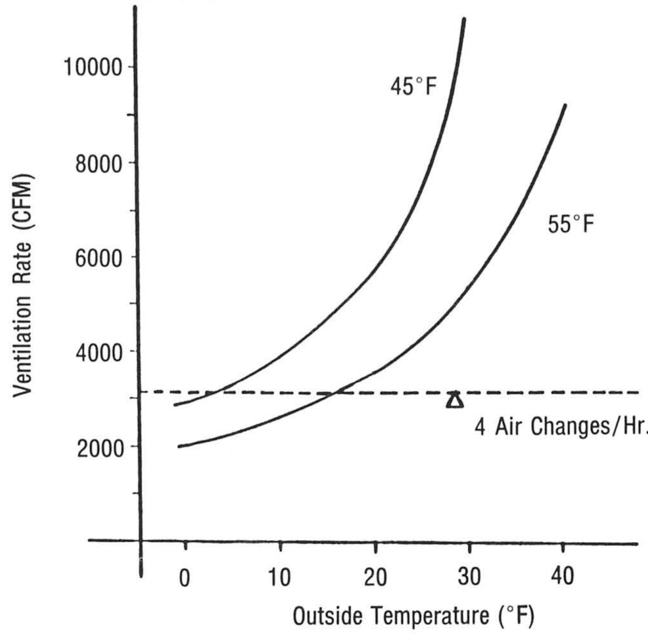
Barn Temperature Reduction

The most profound change in tie stall dairy barn ventilation in the last fifteen years is the general reduction in barn temperature. Without any more changes than a simple turn of the thermostat dial, farmers have significantly reduced barn moisture, gas, and pathogen loads. Barns in the past were kept at 55° F, a temperature at which a farmer could comfortably chore in his shirt sleeves.

With a recent interest and emphasis on barn environment, many farmers are willing to reduce barn temperature to 45° F and wearing a jacket at milking time as a concession to improve air quality.

Figure 1 illustrates this change very well. A typical insulated tie stall dairy barn, 120′ x 40′, housing 50-1400# dairy cows was put through our Ontario Ministry of Agriculture and Food ventilation program.[1] The graph shows the ventilation rates for a range of outside winter temperatures typical for southwestern Ontario for two barn temperatures—55° F and 45° F (both at 75% R.H.).

FIGURE 1. Ventilation Rate for a 50 Cow Dairy Barn Held at 55°F and 45°F.



Some authorities suggest a minimum of 4 air changes per hour[2]. Note that the cooler barn (45° F) is still providing this exchange rate at 5° F. The warmer barn (55° F) has slipped below this level at 17° F outside temperature.

The average January temperature for Waterloo is 19° F. At this outside temperature, the lower barn temperature represents a 60% increase in ventilation rate.

At all winter temperatures, the ventilation rate is significantly higher with the cooler inside temperature leading to a comparable reduction in gas and pathogen loads. As well, more moisture will be expelled from the barn but since the air is cooler and can not hold as much moisture, *relative* humidity is not likely reduced.

Fans

The main changes in fans has been the recent popularity of European made fans. These fans have cast aluminum motor housings and orifices, plastic blades and energy efficient motors. Prices for this new wave of fans has been about 50% higher than conventional domestic steel fans with pressed aluminum blades.

Much of this enthusiasm has been based on the preception that these fans are considerably more energy efficient, that is they deliver more CFM with less energy for a comparable size of domestic fan. Early indications from the Prairie Agricultural Machinery Institute (PAMI), an independent fan test facility, suggest that this may not be the case. In their tests,[3,4] European fans had only a modest improvement in energy efficiency. It would take 7 to 8 years to pay for the difference in initial cost if the fan operated at high speed continuously. This based on Ontario electrical cost of $0.05 CDN/KwH.

Another selling point of some fans is their use of non-corroding elements—fibreglass, cast aluminum, stainless steel bolts etc. Dairy barns are not as tough an environment as other livestock barns and standard type fans usually last fairly well. If these expensive fans are used at all, it is the winter fans that would benefit the most. They operate continuously and so use more energy. They are also subject to the worst air since air exhaust in the winter will be highest in ammonia and moisture.

One trick that is often used in old 2 story barns is to locate the exhaust fans in the second story with a duct down to the livestock room. This is often for ease of installation where the farmer does not want to knock a new hole through the old wall nor use a window and lose the natural light. The interesting benefit, is that the fan located upstairs is much quieter making a more pleasant working environment. Duct size should be at least two times as large in cross sectional area as the area of the fan.

Air Inlets

Air inlets in cross ventilation systems are important in determining air patterns in a barn, far more important than fan location. Inlets should be as nearly continuous as possible to achieve good distribution.

As well as location, the ideal inlet will vary the opening depending on the number of fans operating. Why should this be done? Figure 2A illustrates an inlet open too far allowing cold incoming air to drop down lazily onto the livestock as a cold draft. Properly adjusted, Figure 2B, the cold air clings to the ceiling (the Coanda effect) and gets well mixed with room air before dropping. To achieve good mixing, air inlet velocity should be 1000 ft/min. which is achieved with a static pressure in the barn of 0.08″ of water.

Fixed or manually adjusted inlets are seldom at the correct opening to achieve these results. The self-adjusting inlet, Figure 3, automatically changes the opening to maintain an even static. An inexpensive static pressure gauge (example Dwyer Air Filter Gauge) is installed in the room and used to adjust the counter balance weights initially. After that the system is self regulating. This design should be an improvement over other self adjusting inlets on the market which have not directed the air to the ceiling.

Recirculation

Under most circumstances, cross ventilation is the preferred system for inletting and distributing air into a barn. It is simple, inexpensive and if properly done, gives an adequate distribution of fresh air without creating drafts.

However, there are circumstances where good distribution of air is hard to achieve. Old two storey barns with low ceilings and one or more walls with no inlets (at least along the barn bank wall) can have dead, stale areas with little air exchange. A single story addition is likely to be of much tighter construction than the old 2 story barn to which it is attached. Fans operating in the new wing draw their air not from the inlets but from the old barn. The old barn is cold and fresh while the new addition (the farmers pride and joy) is too hot and stuffy. Finally, calf rooms with their low winter ventilation rates where supplemental heat is added often have problems with drafts from the inlets, poor distribution of heat and high floor to ceiling and end to end temperature differentials.

Under these circumstances, a recirculating system can help to mix and distribute the air within the room. Floor to ceiling and end to end temperature differentials can be reduced. Warm air at the ceiling brought down to the floor reduces the humidity at animal level.

Two systems are common on Ontario dairy farms. The

FIGURE 2. Control of Cross Ventilation Inlet.

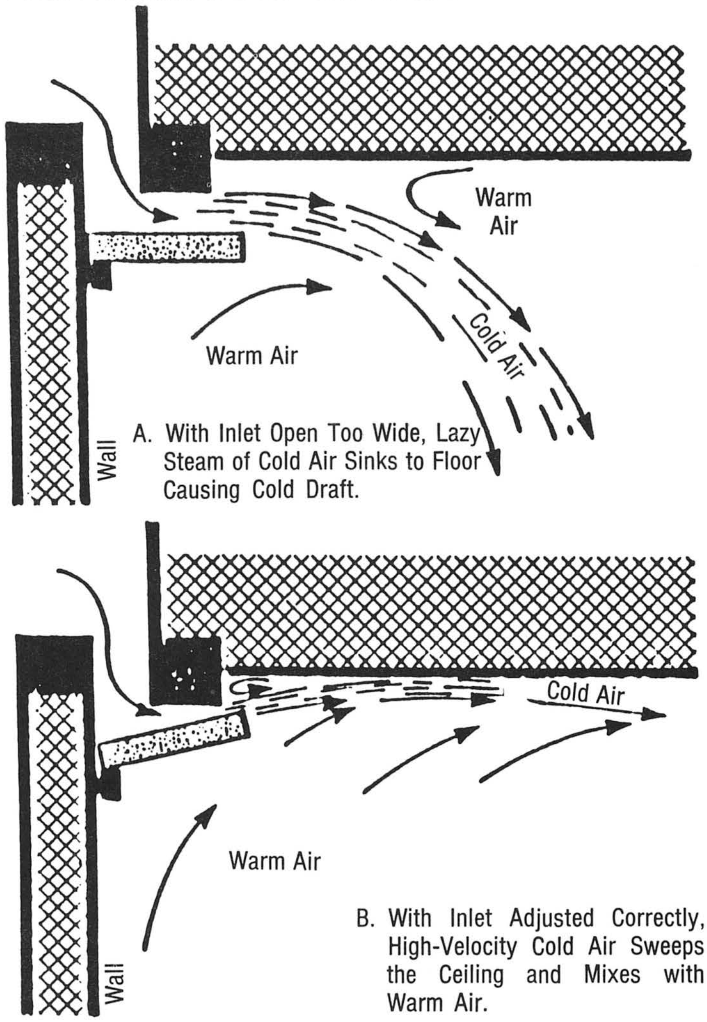
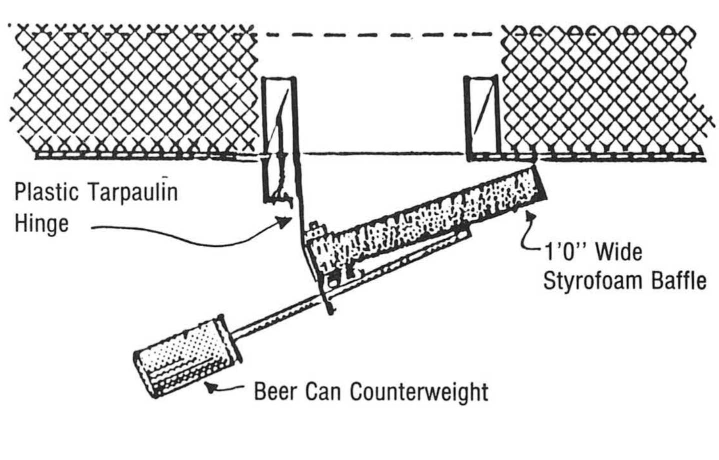


FIGURE 3. Self Adjusting Air Inlet (CPS Plan No. M9715).



first is the commercially available polyethylene tube running the length of the barn with a fan at the end. Holes on either side of tube distribute air. The second, a variation of the first, is a plywood duct with either round holes or rectangular slots. The plywood ducts cost more but are more attractive than the plastic tubes and can be built wide and shallow so that headroom is not sacrificed. (Figure 4).

Recirculating systems have had a bad reputation in the past, often deservedly so. The major complaint is that recirculating systems, for a variety of reasons, cause too high an air speed at livestock level. Often there was too much air recirculated, up to 50% of the summer ventilation rate. In other cases, air coming from the holes in the tube would hit a beam or collide with the air stream from a neighbouring tube and fall to the floor as a draft. By restricting the recirculation to 1-1½ CFM/sq. ft., and avoiding conflicts with neighbouring air streams, beams or other obstructions, drafts can be avoided.

A second problem has been the sophisticated motorized shutters freezing and failing. The shutters are supposed to open when specified exhaust fans come on. Certainly, such sophistication in a dairy barn seems unnecessary when all we really want to do is stir up air a bit to make it more homogeneous.

A more fundamental criticism of recirculation is that we are distributing and recycling pathogens from sick animals throughout the barn space more than with cross ventilation.

If this in fact is the case, then pathogen concentration should be reduced in the area of the shedding animal and at a low concentration in the rest of the room. If contraction of disease is dose related, then any increased risk to health by creating a low dose throughout the room should be offset by the reduced risk in the area of the sick animal.

A final point which is often misunderstood: recirculation and the ventilation rate are independent items. The need for exhaust of air is not reduced by the use of recirculation. Increasing this exhaust rate by lowering the barn temperature is still the major tool to reducing pathogen and gas loads and generally improving air quality. Figure 5 summarizes recommendations for recirculation design.

FIGURE 4. Rigid Ducts, F. A. Kains, O.M.A.F., Waterloo, Chapter 3.9. Agdex 717/320, September 83.

Air circulating ventilation systems often use plastic tubes to distribute air throughout the barn. Farmers may wish to use the air tube principle but for reasons of lack of headroom, appearance, or longevity want a more permanent plywoood duct.

The rigid duct shown is relatively simple to make of ½ inch plywood or chipboard. The bottom and one side swing away to provide access for cleaning. Painting the interior will make cleaning easier and more thorough. Wide ducts may require 1" X 2" straps nailed across the underside of the duct for extra stiffness to prevent sagging.

The design principles are the same for a rigid duct as for plastic tubes, and are outlined below:

DUCT SIZE—Ducts are sized for an air speed of 1500 feet/min. (eg. a 12" X 12" duct will handle 1500 cubic feet/min.)

Determine the amount of air to be circulated and choose the appropriate fan (CFM to be rated @ ⅛" static pressure). A simplified formula for duct size is as follows:

Duct size in sq. inches = 0.1(CFM of fan @ ⅛ S.P.)

TYPICAL DUCTS

Fan Capacity (CFM)	Area Required (Sq. In.)	Duct Size Combinations (H" X W")
1200	120	6" X 24", 8" X 16", 10" X 12"
2500	250	6" X 42", 8" X 32", 10" X 28"
3500	350	6" X 60", 8" X 48", 10" X 36"

HOLE SIZE—Air speed exiting from the holes is calculated at 1000 ft./min. Selection of hole size is somewhat arbitrary. Larger holes will obviously be spaced farther apart to achieve the same air speed. Longer holes will throw air farther than smaller ones, and thus hole size may be selected on the width of coverage you wish to achieve. Common hole sizes are 2", 2½" and 3" diameter.

HOLE SPACING—Having selected a fan capacity and a hole diameter, the hole spacing to achieve a 1000 feet/min., exit velocity can be calculated from the following:

$$\text{Hole spacing (inches)} = \frac{65\ R\ L\ D^2}{CFM}$$

Where R = number of rows of holes 1 or 2 for holes on one side or both sides of duct)
L = Length of duct (ft.)
D = Hole Diameter (in.)
CFM = Fan capacity in CFM at ⅛" static pressure.

A simplified approximation for ducts with a row of holes along with sides as in the diagram is as follows:

$$\text{Spacing (in inches) for 2" Holes} = \frac{500\ (L)}{CFM}$$

$$2\tfrac{1}{2}\text{" holes} = \frac{800\ (L)}{CFM}$$

$$3\text{" holes} = \frac{1200\ (L)}{CFM}$$

For ducts with holes on only one side (where the duct may run along a wall) the spacing would be one half of that calculated above.

EXAMPLE—Design a duct for a dairy barn 84' long using an 18", 3500 CFM fan. It should leave maximum headroom and have a wide distribution of air.

SOLUTION—

Duct size = 0.1 X CFM of fan.
= 0.1 X 3500.
= 350 sq. inches

From the table choose a 6" X 60" duct to give maximum headroom.

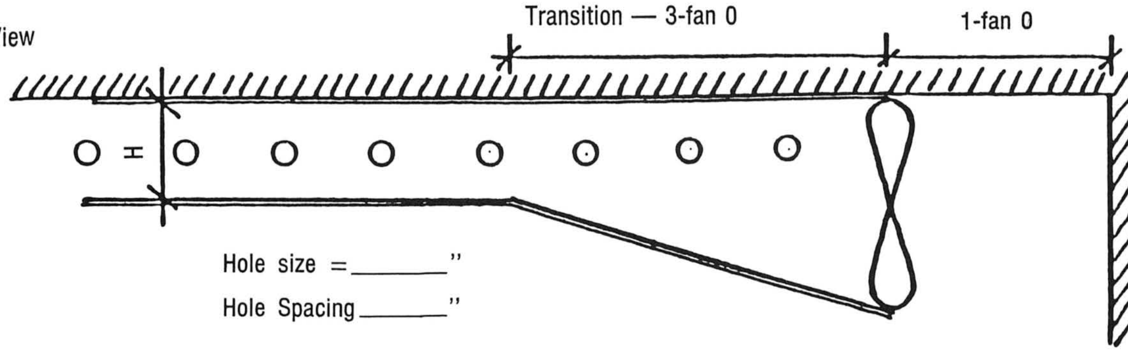
Hole size:
Choose a 3" diameter to get a wider coverage than the smaller holes will provide.

$$\text{Hole spacing} = \frac{(1200)\ (L)}{CFM} = \frac{(1200)\ (84)}{3500} = 28.8\text{"}$$

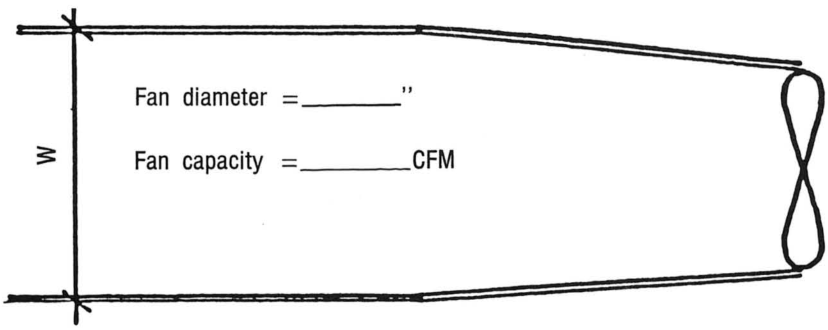
Use a 30" spacing.

Rigid Duct Plan

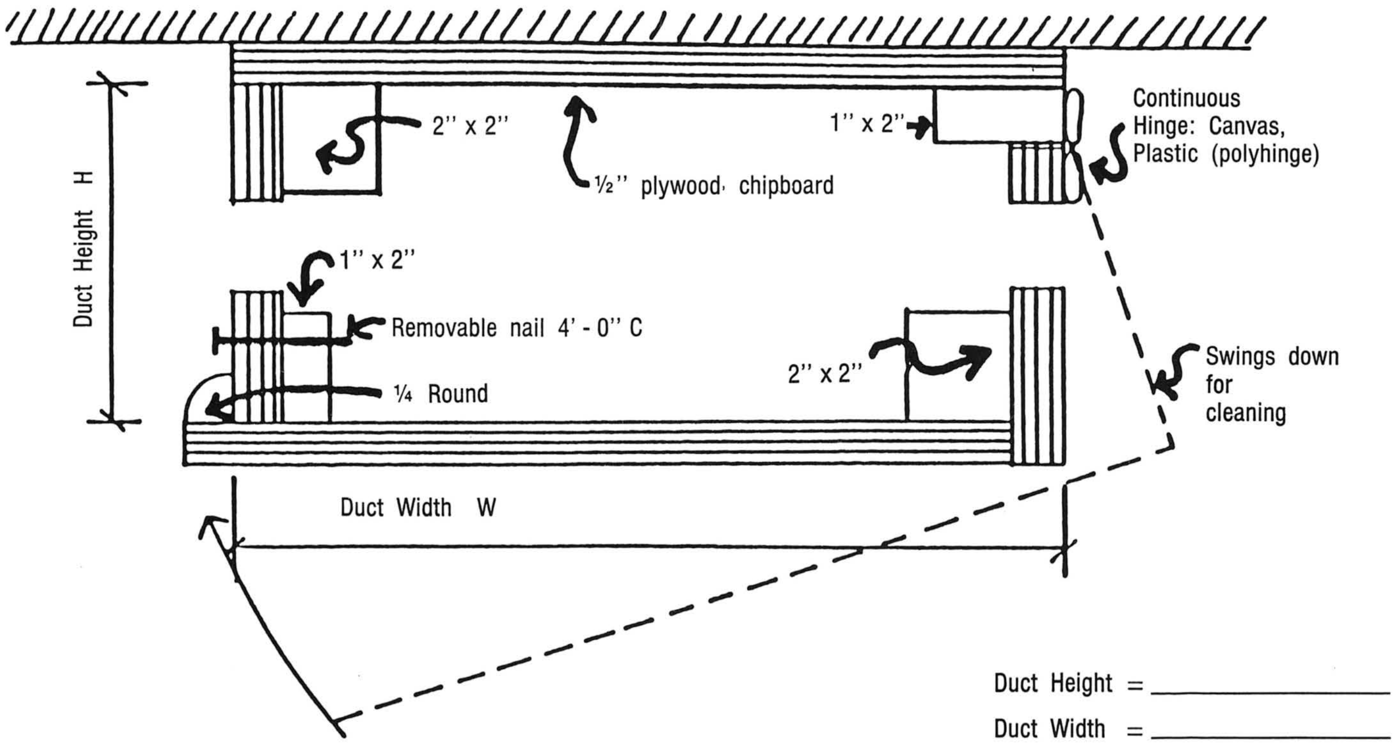
Side View



Top View



End View



Duct Height = ________________

Duct Width = ________________

From "Ventilation Manuel", Ontario Ministry of Agriculture & Food,
Guelph Agric. Centre, Guelph, Ontario.

FIGURE 5. Guidelines For Recirculating.

Amount To Recirculate:	1 — 1½ CFM/Sq. Ft. of Barn	
Air Speed Thru Duct:	1500 Ft./Minute	
Air Speed Thru Holes:	1000 Ft./Minute	
Size of Holes:	Hole Diameter	Distance Thrown
	1"	6'
	2"	12'
	3"	18'

Other: Obstructions To Air Flow (eg. Beams, Air Stream From Neighboring Tube or Duct) Can lead to drafts at animal level.

Heat Exchangers

Heat exchangers have become a popular energy saving device for livestock buildings especially in the cold areas of the western provinces and states.

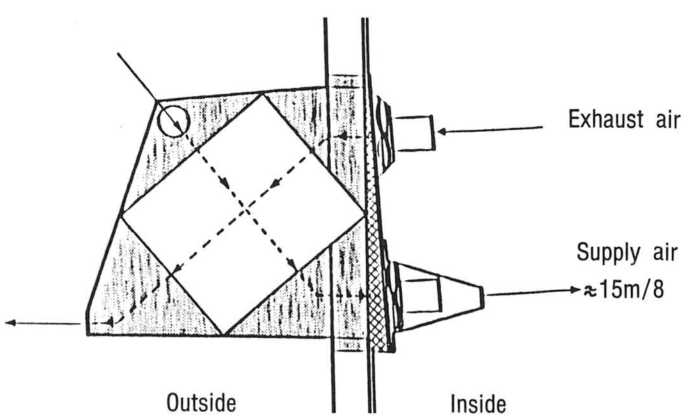
Supplemental heat is seldom added to dairy barns but is often added to warm calf nurseries. Several tests of heat exchangers have been conducted by the Energy Branch of the Ontario Ministry of Agriculture and Food for several species and classes of livestock. Included in these tests were four in dairy calf barns for both replacement and veal calves. The following are some selected results from those tests. (Fig. 6 shows the heat exchanger used in these tests.)

TABLE 1. Heat Exchanges Tests In Calf Barns.

	Calf Type	Outside Design Temp. (°F)	Air Exchange Rate/Hr.	Barn Temp (°F)	Payback* (Yrs.)
Test 1[5]	Veal	—7	4.0	61	2.2
Test 2[6]	Replacement	—2	4.0	55	4.5
Test 3[7]	Replacement	—12	3.0	50	4.8
Test 4[8]	Replacement	—12	1.5	50	10

NOTES: 1. Payback is based on simple straight line payback of initial cost with electricity valued at $0.05/KwH (Prevailing Ontario average cost)
2. Initial cost of Heat Exchanges adjusted to November/85 retail price.
3. Outside Design Temperature is the value below which statistically the temperature does not fall for more than 2½% of the time during January.

FIGURE 6. Cross Section of "Del-Air" Heat Exhanger.



The best payback is 2.2 years and the worst about 10 years. The table shows that a high desired room temperature, high air exchange rate and/or low outside temperature reduce the payback period. A low room temperature, low air exchange rate and/or a more moderate winter increase the payback period.

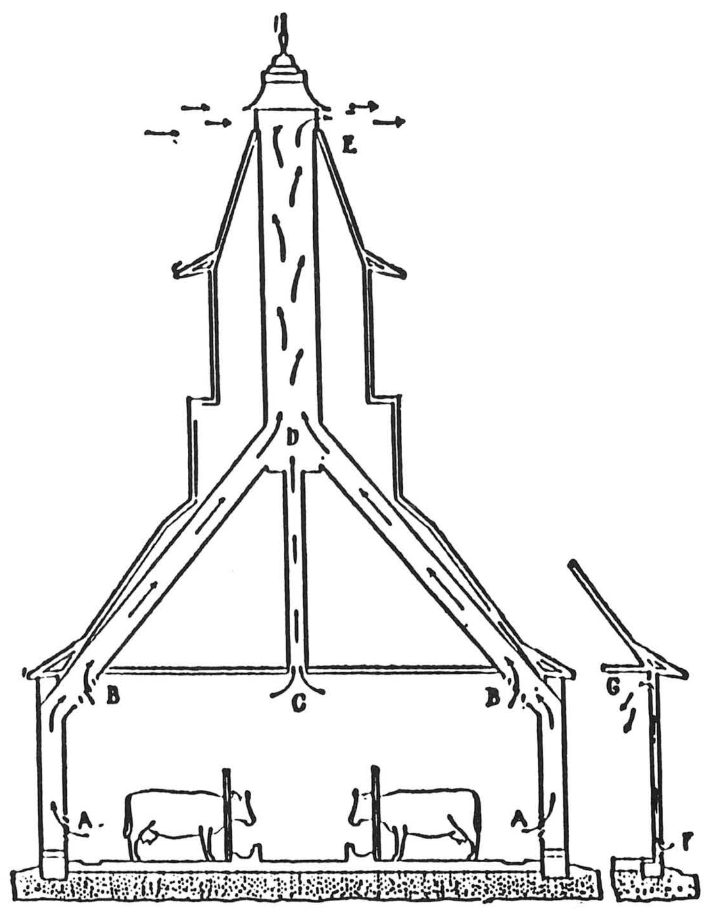
Industry (other than farming) would consider a 2 year payback for such equipment to be attractive but a 4 year payback to be only interesting. Couple with this, periodic cleaning and maintenance of a heat exchanger, the decision to install one in a calf barn must be done with care. An analysis of local winter weather data, as well as decisions on room temperature and desired minimum ventilation rates, are needed to determine their feasibility.

Natural Ventilation

A more recent development in the ventilation of tie stall dairy barns has been the adaption of natural ventilation. This has been a spin-off of its widespread use in swine housing in Ontario since 1979. Fig. 7 illustrates that natural ventilation is an old idea recycled.

There are several features about natural ventilation that dairy farmers have found attractive.[9] When you enter a naturally ventilated barn, the lack of fan noise is the most

FIGURE 7. King Ventilation System from "Physics of Agriculture," 1907.



obvious advantage. With an increasing awareness on the part of farmers of their working conditions, this advantage is taking on greater significance.

A second advantage is enhanced summer ventilation. Seldom are our dairy barns equipped with enough fan capacity to ventilate them if the cows are kept in for more than just milking. Naturally ventilated barns usually have an excess of sidewall opening giving high summer ventilation rates.

A third advantage is reduced maintenance. This is not as great an issue in dairy barns as it is in swine barns where fans and controls fail regularly.

A fourth advantage is reduced operating costs—again not a substantial saving in Ontario where electricity is presently \$0.05/KwH CDN but may be if electricity is expensive or fans operate for an extended period of time (such as in warner climates or where cows are kept in for the summer).

Through experience, we have developed several simple guidelines which have worked well in design of such barns.

TABLE 2. Natural Ventilation Design Thumbrules.

Area of Inlet Opening:	Minimum	— 4% of Floor Area
	Desirable	— 8%+ of Floor Area
Area of Outlet Opening:	Minimum	— 1% of Floor Area
	Desirable	— 2%+ of Floor Area

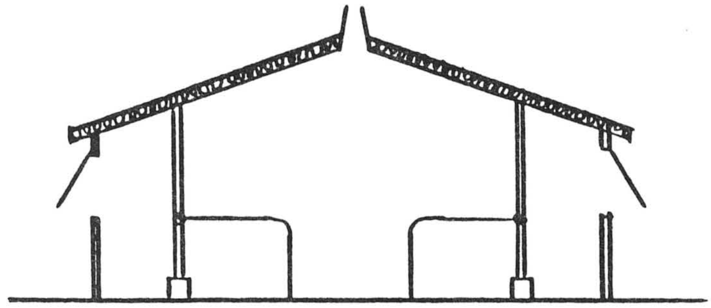
For new construction, the desirable figures are easily achieved. However, in retrofitting old barns, installing air inlets and exhausts can be difficult and expensive. Thus, it should be recognized that the desirable figures above are only important when maximum ventilation is necessary ie. the heat of the summer with cows in the barn. If the farmer is not concerned about maximum ventilation (eg. cows are only in during milking, etc.), the minimum figures should be quite acceptable.

Continuity of inlet is far more important than continuity of exhaust. We have found that chimneys have worked as well as continuous ridge outlets common in swine barns. Chimneys are particularly useful in retrofits since they are cheaper and easier to install. They should be insulated to an R10 and extend above the peak of the barn for good draw. Generally, a 4′x4′ chimney will service 1500 sq. ft. of barn area.

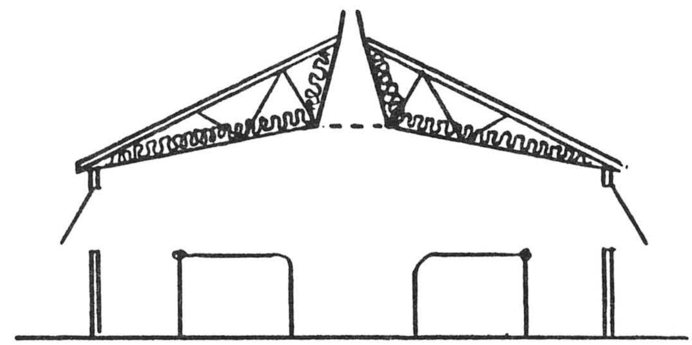
One of the main reasons for the success of naturally ventilated buildings is their high ceilings. Either a 10 foot flat ceiling, sloped cathedral ceiling or even a mini cathedral ceiling created in the web members of the truss, provide a larger volume/animal than most standard construction. (Figure 8) In old barns with low ceilings, the ventilation is not likely to be as good. However, this will be true if the barn were to be fan ventilated.

Farmers either chose to control the exhaust and intake openings manually or automatically. Those who chose manual like the simplicity, reduced maintenance, safety and lower cost. They are likely to be in the barn a lot to make the

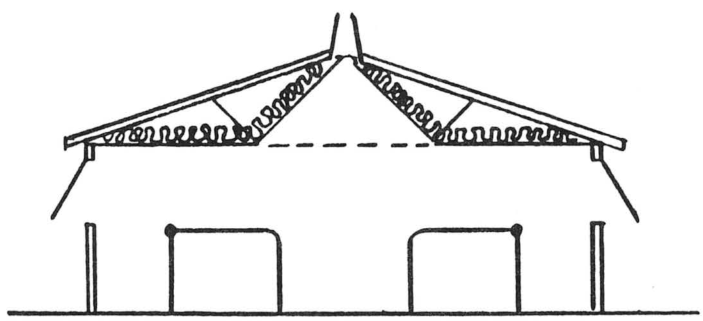
FIGURE 8. Roof Structures For Naturally Ventilated Barns.



Post and Beam



Scissor Truss



Standard Truss — Mini Cathedral

necessary changes. Automation in the form of electrically or pneumatically controlled doors and peak closures reduces the adjustments the operator must make. However, it adds to the cost, complexity and maintenance.

In general, the inlet openings should be operated (manually or automatically) such that the inlet panels on the leeward side open before those on the windward side.

Conclusion

In summary, the major change in tie stall dairy barn ventilation has been the lowering of the barn temperature. With the increased ventilation rate, pathogen and gas levels are significantly lowered.

In some situations, recirculation can improve distribution of air within the barn if a cross ventilation system is inadequate.

Heat exchangers are a good source of supplemental heat but must be evaluated against other sources of heat on a cost recovery basis to justify them.

Finally, the enthusiasm the swine farmers have had for natural ventilation has spilled over to tie stall dairy barns. Several new and retrofitted old barns have gone this route recently and it seems to be a continuing trend.

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Colleagues from France

Left to right — Prof. Dr. and Mrs. Espinasse; Dr. Espinasse is the president of World Association for Buiatrics, Dr. and Mrs. H. Navatet; Dr. Navatet is responsible for the calf disease and programs, French Buiatrics Society.

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