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Potential Energy Savings of Natural Versus Mechanical Ventilation for Livestock Housing in Ontario

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ABSTRACT

A model based on ventilation rates was prepared to evaluate the energy requirements for mechanical ventilation for dairy, swine and poultry operations. These types of production were selected since they are readily adaptable to natural ventilation, which has negligible energy cost. The model was tested using long term on-farm measurements of energy consumption in two hog finishing barns and indicated good agreement. The predicted biggest user of energy for mechanical ventilation was the dairy industry, followed by operations for growing-finishing hogs and gestating sows, then turkeys and broiler chickens. For Ontario, there is a potential energy savings of 194 million kWh per year if natural ventilation were used instead of fan ventilation. This would represent a cost reduction of $9.2 million for Ontario farmers.

RESUME

Un modèle pour prédire les taux de ventilation en fonction des températures extérieures fût préparé. Les consommations d'énergie enregistrées par l'utilisation d'un système de ventilation mécanique furent évaluées. Ce modèle s'applique pour les productions laitières, porcine et de volailles de chair. Ces types de production furent sélectionnés car il fût démontré que la ventilation naturelle peux y être utilisée avec succès.

Une étude à long-terme, de la consommation d'électicité par le système de ventilation mécanique sur une ferme porcine a démontré l'exactitude du modèle à prédire les quantités d'énergie consommées. Voici l'ordre des consommateurs d'électricité selon les prédictions du modèle. La production laitière est la première consommatrice suivi des porcheries d'engraissement, les étables pour truies gestantes, la production de dinde, et finallement la production de poulet de chair.

Pour l'Ontario seulement, il y a un potentiel pour réduire la consommation d'électicité de 194 millions de kWh par année si la ventilation naturelle remplaçait complètement la ventilation mécanique. Ceci représenterais une réduction des dépenses énergitiques pour les producteurs Ontariens de l'ordre de $9.2 millions.

INTRODUCTION

Mechanical ventilation has long been the most popular means of ventilating warm animal barns. For many types of animal production, a viable, safe and more economical alternative to mechanical ventilation is natural ventilation. Economical, in terms of the cost of electricity to the farmer, and ultimately, in terms of energy consumption to Ontario Hydro.

The issue at hand is to assess the energy consumption of mechanical ventilation systems and their related costs, with respect to different types of animal production. Any model developed to predict energy requirements for mechanical ventilation in an animal or poultry production unit must be tested and found reliable using actual case histories.

LITERATURE REVIEW

Types of Production

Natural ventilation has been previously recommended as a viable alternative for the ventilation of warm barns for certain types of animal production, such as dairy cattle, growing/finishing hogs and gestating sows (Munroe and Choinière, 1986). Simmons and Lott (1989) and Trivers and van Dieren (1986) demonstrated the possibility of utilizing natural ventilation for broiler chickens, as did Timmons (1989) for turkey production. In contrast, beef cattle, sheep and goats are normally housed in cold, naturally ventilated buildings. However, natural ventilation should not be used for all types of production. It has been reported that rabbits, laying hens and other animals requiring light level control should not use natural ventilation since the required large ventilation openings are difficult to make light proof (Munroe and Choinière, 1986). If used, such light proofing mechanisms are costly, difficult to install, and often restrict airflow.

Calculation of Ventilation Rates

House and Huffman (1987) described a computer program that calculates the required ventilation rates relative to external temperature. Calculated rates are based on control of inside temperature and humidity in cool weather, and minimal interior temperature rise in hot weather.

Daily Simulation of Meteorological Data

Trivers and van Dieren (1986) used monthly averaged temperatures and the ventilation computer program of House and Huffman (1987) to estimate the required ventilation rates in South Western Ontario. Based on these ventilation rates they then calculated the associated electricity costs. However, there is a certain amount of error associated in a monthly averaging of external temperatures. A more precise method to estimate ventilation rates would be to consider a smaller time unit, such as daily temperature data.

Based on studies by Monteith (1973), Campbell (1977) and Baumgartner et al., (1982), we can assume a sinusoidal curve for generating the hourly temperatures between given minimum and maximum daily temperatures, as well as assume that the minimum temperature occurs at 03:00 h and the maximum temperature occurs at 15:00 h regularly.

Cost of Electricity in Ventilation

White and Parker (1981) reported on two studies on finishing hogs which concluded that electricity costs were between $0.44 and $0.66 per hog. This included running the ventilation system, feeding equipment and lighting in the barn.

MacDonald et al. (1985) reported a cost of $0.44 per hog (at $0.045/kWh) for mechanical ventilation and $0.04 per hog when utilizing natural ventilation. However, the producer was using an earlier type of natural ventilation system actuated by compressed air. This type of system uses more energy than more recently developed modulated systems using electric motor driven actuators. The duration of the test was only for 252 days (July 18, 1984 to March 25, 1985). The calculated energy used over the time period was 9.8 kWh per pig and the turnover of hogs was 2.03 cycles per year. The peak energy consumption period was during the summer, while the lowest consumption was during the winter.

OBJECTIVES

The following objectives were pursued in this project:

1. Generate equations to predict ventilation rates for the following different animal production types: broiler chickens, dairy cattle, gestating sows, growing-finishing hogs, and turkeys.

2. Predict the total cumulative ventilation volume required on an annual basis.

3. Assess the cost of electricity for such mechanical ventilation on both a per animal basis and a total industry basis.

4. Compare the predicted versus the measured energy consumption for a long term test in a finishing hog building.

DEVELOPMENT OF THE PREDICTION MODEL

Meteorological Data

Seventeen weather gathering stations (Table 1) were chosen in the five Ontario Regions to compare the monthly averaged daily minimum, maximum and mean temperatures. Environment Canada (1982) published such data averaged over 30 years (1951-1980). Temperatures were averaged within a Region and these Regional average values were then compared with each other.

For the Ottawa Valley area, Chaput (1989) supplied the necessary meteorological data containing the minimum and maximum temperatures for each day of the year. These values were obtained from data collected at the Agriculture Canada Experimental Farm in Ottawa and averaged over 30 years (1951 to 1980).

Types of Animals

Five animal types were considered: broiler chickens, dairy cattle, growing-finishing hogs (over 20 kg), gestating sows, and turkeys.

As well, two scenarios were considered for dairy: cattle that were housed year-round, and cattle that were outside May 15 to September 15, except during the daily milking periods (06:00 h to 10:00 h and 16:00 h to 19:00 h). Growing-finishing hogs, gestating sows, broiler chickens and turkeys were treated as housed year-round.

Calculation of the Required Ventilation Rates

Fig. 1 shows graphically , the typical ventilation requirements for a livestock room, in this case for growing-finishing hogs. As the exterior temperature approaches the maximum desired inside temperature (thermostat setting), it takes an enormous amount of air exchange to control the inside temperature. To be practical, the inside temperature is then allowed to rise. Starting at an outside temperature approximately 2°C below the maximum desired room temperature, the ventilation rate shown is that required to limit the room temperature to be no more than approximately 2°C above the outside temperature. In many cases even this ventilation rate will lead to excessive air velocities in the room and as a result an arbitrary maximum ventilation rate, often 1 room air change per minute, is superimposed on the recommended ventilation rate curve; in Fig. 1 this maximum rate is equivalent to approximately 30 L/s/hog.

The ventilation rates versus external temperature were determined using the Ventilation Program described by House and Huffman (1987). The external temperature range considered was from -30 to 35°C.

Tables 3 and 4 summarize the sources and information required for the input data in the Ventilation Program for the various types of animals studied. Recommendations on animal densities and average weights were taken from "La ferme canadienne: Manuel de constuction" (1988). The desired interior temperatures were obtained from the Alberta Ventilation Handbook (Harms and Borg, 1985). Finally, typical barn layouts were selected from the Canadian Plan Service series for each production type (CPS, 1985a; CPS, 1985b; CPS, 1987). All production animals were considered to be housed year-round, with the exception as already noted of dairy cattle.

Fig. 3 depicts the required ventilation rates determined via the Ventilation Program for the specific animal production types. The data shows that for dairy and growing-finishing hogs, a maximum ventilation rate plateau is reached. However, for the turkeys, broiler chickens and gestating sows, the recommended maximum ventilation rates were not reached. This reflects differences in animal densities in the room as well as animal sensitivity to air velocity. Instead of a level cut off at the maximum desired interior temperature, the data showed a linear increase in ventilation rate with exterior temperature. Under these conditions the room temperature shouldn't exceed the exterior temperature by more than about 2° C.

The ventilation rates predicted for temperatures below the maximum desired interior temperature were fitted with a polynomial regression using a commercial software program, (Stat Pak, NWA, 1984). Linear regression was used to predict the rates for temperatures above the maximum desired interior temperature for the turkeys, broiler chickens and gestating sows.

Fan Capacity

Fans with louvers (shutters) are the most popular in Ontario. Based on PAMI (Prairie Agricultural Machinery Institute, 1986), the average performance of fans with louvers was calculated to be 4.06 L/sW (Std. ± 0.57), or 14,616,000 L/kWh. Martin and Crisp (1984) and Person et al., (1977) discussed the potential reduction in fan efficiency due to dust accumulation on shutters and blades. For this particular study, no efficiency factor (or losses) were considered.

Computer Programs for Data Processing and Energy Consumption

Hourly Temperature Simulation

A program was written to predict for each day of the year the hourly temperature based on the daily minimum and maximum temperatures. It was assumed that the minimum temperature occurs at 03:00 h and the maximum temperature at 15:00 h regularly and that the temperature varies in a sinusoidal fashion.

$$T = [(T_{max} - T_{min})/2] \times \sin[15°(h-9) \times PI/180] + [(T_{min} + T_{max})/2] \quad (1)$$

where, T = hourly temperature (°C)
T_{min} = minimum temperature for the day (°C)
T_{max} = maximum temperature for the day (°C)
h = hour of the day, 0 to 23
PI = 3.141593

Equation Selection and Ventilation Rate Calculation

The program then checked the generated hourly exterior temperature with the prediction equation of the ventilation rates. For exterior temperatures below the maximum desired interior temperature, a polynomial equation was used to calculate the required ventilation rates, but for temperatures above the maximum desired interior temperature, the maximum ventilation rate or the linear regression equation was used as appropriate (Fig. 3). The equations and temperature ranges are listed in Appendix 1.

Volume, Energy and Cost Calculations

Daily ventilation rates were converted to volumes of air moved through the barns per day per animal unit. This was then multiplied by the number of animal units on farms on any day (from Table 5, row 1), thus giving the total volume of air moved per day. The daily energy requirement (kWh) to ventilate was equal to the daily volume of air moved (L) divided by 14,616,000. The daily energy requirements were summed to calculate the total energy requirement for the year.

The cost of electricity per animal unit per annum, was the product of the cost per unit of energy ($0.0473/kWh) (Ontario Hydro, 1989) and the total yearly energy requirement per animal unit, divided by the number of production cycles per year. Production cycles can be calculated from the data shown in Table 5.

The cost of electricity per production type per annum, was a product of the electricity cost per animal unit per annum, multiplied by the total number of animal units over the year (Table 5, row 2).

Extraction of Peaks

Table 6 shows the seasonal daily average energy demands for all six scenarios. The peak value was established by a visual check of energy use during the heaviest demand period in the summer. For broiler chickens, dairy cattle kept inside and growing-finishing hogs, it was July 18, but for gestating sows and turkeys, it was July 14. For dairy cattle kept outside in the summer months, the peak day was September 23.

ON-FARM MEASUREMENT OF ENERGY CONSUMPTION FOR MECHANICAL VERSUS NATURAL VENTILATION FOR A FINISHING HOG OPERATION

Location

The research site was a farrow-to-finish swine operation owned by Albert de Wit, R.R. 4, Spencerville, Ontario. On this site, there was a mechanically ventilated finishing hog barn with a housing capacity of 380 hogs adjoining a naturally ventilated building for 300 hogs. These buildings usually had 80% occupancy.

The mechanically ventilated barn was oriented in a north-south direction. Table 9 shows the fans installed in this barn. The summer maximum ventilation rate was about one air change per minute, following OMAF recommendations (OMAF, 1983).

The naturally ventilated barn was an in-line extension of the mechanically ventilated barn with matching roof and wall planes. A continuous ridge outlet was manually adjustable. The barn was equipped with an automatic modulated control ventilation system consisting of two thermostats, time delays and gear motor driven actuators that opened or closed rotating ventilation doors in the sidewalls (Choinière et al., 1987).

The adjustable timer activated the control system periodically (for example, every three minutes). A gear motor then opened or closed the ventilation doors. An adjustable time delay controlled the length of time that the gear motor was energized after being activated (for example, three seconds). This allowed the doors to move in increments of about 20-30 mm, thus modulating the operation of the system. The thermostats had a dead band of about 2°C. This modulated system was distributed by Faromor Inc., Waterloo, Ontario.

Measurement of Energy Consumption

Two kilowatthour meters were installed to measure the amount of energy used. One meter measured the power used in the mechanically ventilated barn to run fans from January 1, 1985 to August 2, 1988. The other meter measured the power used in the naturally ventilated barn to operate the electrical system that moved the sidewall panels.

RESULTS AND DISCUSSION

Meteorological Data

The seventeen weather gathering stations located thoughout the province of Ontario are listed in Table 1. Upon comparing Regional average values (Fig. 2 and Table 2), it appeared that only at temperatures below freezing was there much variation between Regions. The standard deviations for temperatures below freezing are greater than 1.5°C, while for temperatures above freezing are less than 1.5°C. Consequently, for the purpose of this study, temperatures across Ontario were considered to be very similar. For the purpose of ventilating barns, there was little difference anticipated in ventilation rates below -5°C since ventilation rates at this time are low. As a result, the utilization of Agricultural Canada's Experimental Farm's averaged thirty-year data of minimum and maximum daily temperatures could be considered representative of the whole province.

Results of the Ventilation Program

Fig. 3 shows the best-fit curves generated for the ventilation output from the Ventilation Program. These curves were basically a polynomial best-fit for the temperatures below the maximum desired interior temperature and a linear fit or maximum value for temperatures above. Appendix 1 lists the equations used for this study.

Daily Simulation

Fig. 4 shows a typical simulation of the sinusoidal variation of hourly temperatures occurring between the daily minimum and maximum temperatures. This particular date was selected because of its wide range between the two extreme temperatures.

Fig. 5 depicts the hourly ventilation rates required for the different production types on May 24, based on exterior temperatures shown in Fig. 3. The ventilation rate is at a minimum during the night, and a maximum during the day. The peaks for different animal types are reached at different hours because the desired interior temperatures are not the same for each. Nearly all the animal production types required maximum ventilation rates on that day. The peak ventilation rate was obtained first with dairy followed by the growing-finishing hogs, gestating sows and then turkeys. The broiler chickens did not require their maximum ventilation rate since an exterior temperature of 25°C was never attained on that date. The slight dip at the peak of the turkey curve is due to the switching of equations of best-fit from the polynomial to linear and back, in a short period of time.

There is a considerable change in ventilation rate during the day. For example, the nightly ventilation rate for the gestating sows is 10 L/s but climbs to 90 L/s during the day.

Yearly Energy Consumption

Fig. 6 shows the amount of energy, in kWh, needed daily to ventilate an animal building. Some specific examples are given in Appendix 2. The maximum energy demand is during the summer months (July and August), while the least demand is in the winter months.

Table 6 shows that the average daily energy demand for the dairy industry goes from 85,348 kWh in the winter to 677,551 kWh in the summer, an eight-fold increase. From Fig. 6 it is clear that cattle housed year-round need more energy for ventilation. But in the future, farmers will be following this practice since it allows an increased efficiency in feeding, milking and management and as a result an increase in production. Cattle that are outside during the summertime have a reduced energy requirement, but they are still the second highest consumer.

Total numbers of animals, of course, has an effect on the total provincial cost per industry. For instance, growing-finishing hogs require $0.70 per head per year in electricity costs, but because such a large number is produced, they are the next highest provincial consumers in energy. In contrast, gestating sows require $2.78 per head, but are fewer in number. With poultry, the total annual cost reflects the cost per bird and the total number of birds produced per year; the latter reflects the number of production cycles per year.

Consequently, in terms of energy, the dairy industry is the largest consumer, followed by growing-finishing hogs, gestating sows, turkeys and broiler chickens. On this basis, it would seem reasonable to place the emphasis for research and promotion of natural ventilation on the two highest consumers, the dairy and hog industries. The total potential energy savings for Ontario Hydro, if natural ventilation completely replaced mechanical ventilation, would be 2.45×10^8 kWh per year (assuming dairy cattle are housed year-round). If it is assumed that dairy farmers keep their cattle outside for the summer period, this figure is decreased to 1.94×10^8 kWh per year.

Effect of Production Cycles

As shown in Table 8, the more efficient farmers who have a higher turnover of animals inside their barn see their electricity costs per animal reduced. For example, a hog farmer who has an average of two growing/finishing cycles per year would have a cost of

15.9 kWh x \$0.0473/kWh = \$0.75 per hog (2)

whereas, a more efficient producer with 3 rotations per year would have a cost of

10.6 kWh x \$0.0473/kWh = \$0.50 per hog. (3)

Results of the On-Farm Energy Consumption Tests

The comparison of actual on-farm energy consumptions for the mechanical or natural ventilation systems is shown in Table 10. The total number of hogs that were finished during the experiment, assuming 2.15 cycles/a as an Ontario average, was

$$\frac{310 \text{ hogs} \times 2.15 \text{ cycle/a} \times 43 \text{ months}}{12 \text{ months/a}} = 2388 \quad (4)$$

the cost of energy per hog was,

33641 kWh / 2388 hogs x \$0.0473 = \$0.67 (5)

Fig. 7 shows the cumulative energy consumption for this hog operation. Field data were compared with the predicted values from the ventilation rate model. After 43 months, the model seems to over-predict by 1600 kWh (approx. 4.5%).

It should be noted that during the second summer of the test, the motor of the 750 mm fan was not operating because of mechanical problems. Also, the hog population was below 300 during a 2 month period. Both these factors would reduce the actual energy used compared to predicted.

The model designed to predict daily ventilation rates and associated costs appears to work well in simulating reality. In the case of growing-finishing hogs, the electical cost for ventilation was \$0.67 per hog based on an average of 2.15 cycles per annum.

SUMMARY AND CONCLUSION

A prediction model for ventilation rates was prepared in order to evaluate the energy requirements for mechanical ventilation for dairy, swine and poultry productions. These animal types are suitable for natural ventilation. The predictions for finishing hogs by the model was compared with a long term on-farm measurement of energy consumption.

The following conclusions could be drawn from this study:

- The on-farm measurements showed a negligible consumption of electrical energy by natural ventilation.
- For a finishing hog barn monitored for 43 months, the measured energy consumption was 33,641 kWh versus a predicted value of

35,251 kWh - a 4.5% overprediction.

- The measured cost per hog per year was $0.67 versus a predicted value of $0.70.

With respect to ventilation energy demand by different production types, the biggest user was the dairy industry (8.7×10^7 kWh), followed by growing-finishing hogs (6.2×10^7 kWh), gestating sows (2.2×10^7 kWh), turkeys (1.4×10^7 kWh), and broiler chickens (9.1×10^6 kWh). For Ontario, there is a maximum potential energy savings of 194 million kWh per year. This represents a cost reduction of $9.2 million for Ontario farmers.

SOMMAIRE ET CONCLUSIONS

Un modèle pour prédire les taux de ventilation en fonctiondes températures extérieures fût préparé. Les consommations d'énergie enregistrées par l'utilisation d'un système de ventilation mécanique furent évaluées. Ce modèle s'applique pour les productions laitières, porcines et de volailles de chair. Ces types de productions furent sélectionés car il fût démontré que la ventilation naturelle peut y être utilisée avec succès. Les prédictions du modèle furent comparées avec des mesures de consommation d'électricité dans une porcherie d'engraissement échelonnées sur 3.5 ans.

De cette étude furent tirés les conclusions suivantes:

- La consommation d'électricité du système de ventilation naturelle est prciquement nulle.
- Selon les mesures de consommation d'électricité effectuées dans une porcherie d'engraissement échelonnées sur une période de 43 mois, le modèle a prédit un consommation de 35,251 kWh versus une mesure de 33,641 kWh. Ceci représente une sur-prédiction de 4.5% seulement.
- Pour l'étude à long-terme effectuée dans une porcherie d'engraissement, les mesures indiquent un coût moyen de $0.67 par porc versus $0.70 pour le modèle de prédiction.

Voici l'ordre des consommateurs d'électricité selon les prédictions du modèle. La production laitière est la première consommatrice avec 8.7×10^7 kWh, les porcheries d'engraissement sont deuxième avec 6.2×10^7 kWh, les étables pour truies gestantes sont troisième consommant 2.2×10^7 kWh suivi de la production de dinde avec 1.4×10^7 kWh. Finallement la production de poulet de chair requiert 9.1×10^6 kWh.

Pour l'Ontario seulement, il y a un potentiel pour réduire la consommation d'électicité de 194 millions de kWh par année si la ventilation naturelle remplaçait complètement la ventilation mécanique. Ceci représenterais une réduction des dépenses énergitiques pour les producteurs Ontariens de l'ordre de $9.2 millions.

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TABLE 1 : Locations used in the comparison of regional temperatures across Ontario.

Region	Location
Central	Huntsville MOE Peterborough Airport
Eastern	Cornwall Ontario Hydro Kingston Ontario Hydro Ottawa International Airport
Northern	New Liskeard North Bay Sudbury
Southern	Chatham Waterworks Hamilton London Airport Niagara Falls Ontario Hydro Woodstock
Western	Kitchener Orangeville MOE Stratford MOE Walkerton

TABLE 2 : Comparison of Regional average temperatures over the five regions of Ontario; Regional averages were based on values from each of the locations within a Region (Table 1).

Month	Mean temp., °C	StD	Minimum temp., °C	StD	Maximum temp., °C	StD
January	-8.7	2.8	-13.1	3.5	-4.3	2.1
February	-7.7	2.4	-12.5	3.2	-3.0	1.7
March	-2.3	1.9	-6.9	2.5	2.4	1.3
April	5.6	1.3	0.3	1.5	10.8	1.2
May	12.2	0.9	6.1	1.2	18.1	0.6
June	17.5	0.9	11.6	1.2	23.4	0.7
July	20.0	0.9	14.1	1.3	25.9	0.8
August	19.0	1.1	13.3	1.4	24.7	1.0
September	14.8	1.3	9.4	1.5	20.2	1.3
October	8.8	1.1	4.0	1.3	13.6	1.2
November	2.3	1.5	-1.3	1.5	5.8	1.5
December	-5.4	2.5	-9.2	3.0	-1.5	2.0

TABLE 3 : Description of input data for the "Ventilation Program", broiler chickens and dairy cattle.

	Broiler Chickens	Dairy Cattle Housed year-round	Dairy Cattle Outside May 15 to Sept 15
Typical plan CPS No.	5101	2106 2220	2106 2220
Desired Interior Temperature, (°C)	26	10	10
Average Weight, (kg)	1.1	550	550

TABLE 4 : Description of input data for the "Ventilation Program", swine and turkeys.

	Swine Gestating	Swine Growing-Finishing	Turkeys
Typical plan CPS No.	3236	3433	5101
Desired Interior Temperature, (°C)	20	18	18
Average Weight, (kg)	150	60	7.1

TABLE 5 : Numbers of animals assumed.

	Dairy	Broilers	Gestating Sows	Finishing Hogs	Turkeys
1	611,000[a]	18,904,799[b]	378,000[d]	1,951,000[e]	3,108,852[g]
2	611,000[a]	115,317,658[c]	378,000[d]	4,187,900[f]	6,200,000

1 Number of animals on farms in Ontario on any day.
2 Number of animals on farms in Ontario over the total year.
Cycles/year equals Row 2 divided by Row 1.

[a]Cows + bulls + ½(heifers and calves). McGee, 1987. p. 81.
[b]McGee, 1987. p. 83.
[c]E. Lashley. Ontario Chicken Producers Marketing Board. personal communication, 1988 figure.
[d]McGee, 1987. pg. 82.
[e]hogs over 20 kg. McGee, 1987. p. 82.
[f]A. King. Ontario Pork Producers Marketing Board. personnal communication, 1987 figure.
[g]McGee, 1987. p. 83.

TABLE 6 : Seasonal variation of average daily energy demands (kWh) for the different production types, and peak daily demand.

Production	Winter 21/12 -19/3	Spring 20/3 -20/6	Summer 21/6 -22/9	Autumn 23/9 -20/12	Peak daily demand
Broiler chickens	9,384	19,924	58,030	11,705	85,814
Dairy cattle[a]	85,348	456,646	677,551	285,923	686,250
Dairy cattle[b]	85,348	298,999	275,870	285,923	615,690
Finishing hogs	40,639	191,624	331,738	110,871	351,640
Gestating sows	8,169	63,416	143,676	26,377	172,010
Turkeys	5,018	40,946	86,274	18,300	98,641

[a]Dairy cattle that are housed year-round.
[b]Dairy cattle that remain outside during the summer period (May 15 to September 15) except for milking.

TABLE 7 : Energy demands and cost estimates for the different production groups as related to each animal and the total number of animals produced per annum.

Production	Total energy per animal produced (kWh)	Total energy per group per annum (kWh x 10^6)	Total cost per animal produced ($)	Total cost per group per annum ($ x 1000)
Broiler chickens	78.8[a]	9.09	3.73[a]	429.7
Dairy cattle[b]	226.3	138.3	10.70	6,540.7
Dairy cattle[c]	142.1	86.82	6.72	4,106.7
Finishing hogs	14.8	61.99	0.70	2,932.2
Gestating sows	58.8	22.21	2.78	1,050.4
Turkeys	2.2	13.84	0.11	654.7

[a]Per 1000 birds.
[b]Dairy cattle that are housed year-round.
[c]Dairy cattle that remain outside during the summer period (May 15 to September 15) except for milking.

TABLE 8 : The energy per animal required to ventilate chicken, turkey and growing-finishing hog facilities with varying cycles per annum.

Production	Energy per animal per annum (kWh)	Multiple cycles per annum (c/a) Energy per animal (kWh)	(kWh)	(kWh)
Broiler chickens	480.6[a]	5.0 c/a 96.1[a]	6.0 c/a 80.1[a]	7.0 c/a 68.7[a]
Finishing hogs	31.8	2.0 c/a 15.9	3.0 c/a 10.6	4.0 c/a 7.9
Turkeys	4.4	1.5 c/a 3.0	2.0 c/a 2.2	2.5 c/a 1.8

[a]Per 1000 birds.

TABLE 9 : List of fans used by Albert de Wit, R.R.4, Spencerville, in the mechanically ventilated finishing barn.

Fan diameter (mm)	Motor kW (hp)	Capacity[a] (L/s)
300	.18 (1/4)	600
450	.25 (1/3)	1,500
600	.75 (1)	3,300
750	.75 (1)	4,500
900	.75 (1)	5,700
	Total	15,600[b]

[a]OMAF Ventilation Manual (1983).
[b]About 1 air change per minute, OMAF recommendations.

TABLE 10 : Comparative data for mechanical and natural ventilation, on an actual farm (A. de Wit).

Ventilation type	Barn capacity-hogs	Energy consumption (kWh)	Cost per head ($)	Total number of hogs finished
Mechanical	310	33,641[a]	0.67	2,388
Natural	270	1	---	2,080

[a]Energy consumption based on model prediction = 35,251 kWh.

APPENDIX

Equations for the Calculation of the Required Ventilation Rates

The following equations were the equations of best-fit of the output data from the Ventilation Program of House and Huffman (1987).

Broiler Chickens

For exterior temperatures of $-30°C \leq T \leq 25°C$

$$Q = e^{(b_nT^n + \ldots + b_1T + b_0)} \qquad \text{(per 1000 birds)}$$

Q = ventilation rate (L/s)

where, $b_0 = 4.52$, $b_1 = 1.11 \times 10^{-2}$, $b_2 = -7.46 \times 10^{-5}$, $b_3 = 2.65 \times 10^{-5}$, $b_4 = 5.28 \times 10^{-6}$, $b_5 = 1.45 \times 10^{-7}$, $b_6 = -2.94 \times 10^{-9}$, $b_7 = -1.07 \times 10^{-10}$

For exterior temperatures of $25°C < T \leq 35°C$

$$Q = 1.31 \times 10^{-2}\,T + 1.12 \qquad \text{(per bird)}$$

Dairy Cattle (per cow basis)

For exterior temperatures of $-30°C \leq T \leq 12°C$

$$Q = b_nT^n + \ldots + b_1T + b_0$$

where, $b_0 = 40.83$, $b_1 = 2.85$, $b_2 = 1.94 \times 10^{-1}$, $b_3 = 2.20 \times 10^{-2}$, $b_4 = 1.60 \times 10^{-3}$, $b_5 = 5.14 \times 10^{-5}$, $b_6 = 5.94 \times 10^{-7}$

For exterior temperatures of $T > 12°C$

$$Q_{max} = 190 \text{ L/s}$$

Growing-Finishing Hogs (per hog basis)

For exterior temperatures of $-30°C \leq T \leq 15°C$

$$Q = b_nT^n + \ldots + b_1T + b_0$$

where, $b_0 = 5.65$, $b_1 = 2.80 \times 10^{-1}$, $b_2 = 4.90 \times 10^{-3}$, $b_3 = 1.19 \times 10^{-3}$, $b_4 = 1.70 \times 10^{-4}$, $b_5 = 7.51 \times 10^{-6}$, $b_6 = 1.07 \times 10^{-7}$

For exterior temperatures of $T > 15°C$

$Q_{max} = 30$ L/s

Gestating Sows (per sow basis)

For exterior temperatures of $-30°C \leq T \leq 20°C$

$$Q = e^{(b_nT^n + \ldots + b_1T + b_0)}$$

where, $b_0 = 1.77$, $b_1 = 6.46 \times 10^{-2}$, $b_2 = 2.03 \times 10^{-4}$,
$b_3 = 8.70 \times 10^{-5}$, $b_4 = 1.81 \times 10^{-5}$, $b_5 = 1.76 \times 10^{-7}$,
$b_6 = -3.10 \times 10^{-8}$, $b_7 = -7.12 \times 10^{-10}$

For exterior temperatures of $20°C < T \leq 35°C$

$$Q = 6.78 \times 10^{-1}\ T + 6.84$$

Turkeys (per turkey basis)

For exterior temperatures of $-30°C \leq T \leq 20°C$

$$Q = b_nT^n + \ldots + b_1T + b_0$$

where, $b_0 = 4.62 \times 10^{-1}$, $b_1 = 2.39 \times 10^{-4}$, $b_2 = -1.42 \times 10^{-3}$,
$b_3 = 5.74 \times 10^{-4}$, $b_4 = 5.62 \times 10^{-5}$, $b_5 = 1.55 \times 10^{-7}$,
$b_6 = -9.34 \times 10^{-8}$, $b_7 = -1.96 \times 10^{-9}$

For exterior temperatures of $20°C < T \leq 35°C$

$$Q = 4.63 \times 10^{-2}\ T + 4.54$$

Practical Examples

Example 1:

A typical broiler chicken producer, 20,000 broilers grown per cycle and 6.1 cycles per annum:

Energy

20,000 birds/cycle x 78.787 kWh/1,000 birds = 1,576 kWh/cycle

1,576 kWh/cycle x 6.1 cycle/a = 9,614 kWh/a

Cost

20,000 birds/cycle x $3.73/1,000 birds = $74.60/cycle

$74.60 x 6.1 cycle/a = $455.06 per annum

Validation

9,614 kWh/a x $0.0473/kWh = $454.74 per annum

Example 2:
A typical dairy producer with 50 milking cows, 30 heifers and 30 calves, no cycles involved, all animals are totally confined:

Animals

50 cows + (30 heifers + 30 calves)/2 = 80 animals

Energy

80 animals x 226.319 kWh/animal = 18,105 kWh/a

Cost

80 animals x $10.70/animal = $856.00 per annum

Validation

18,105 kWh/a x $0.0473/kWh = $856.37 per annum

The discrepancy in the cost per annum comes from rounding off the cost per animal to $10.70.

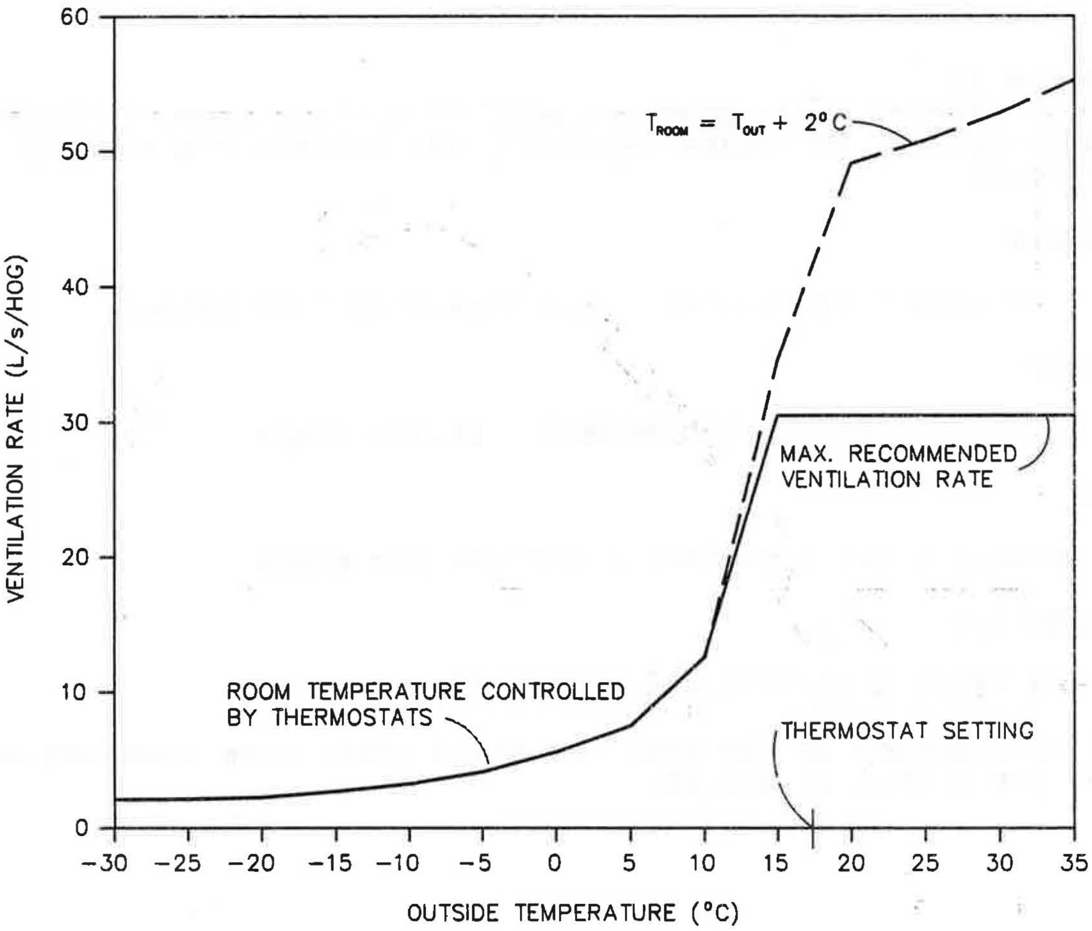

Fig. 1 Ventilation rates to control temperature for growing/finishing hogs (over 20 kg.) in a well insulated barn with partially slotted floors.

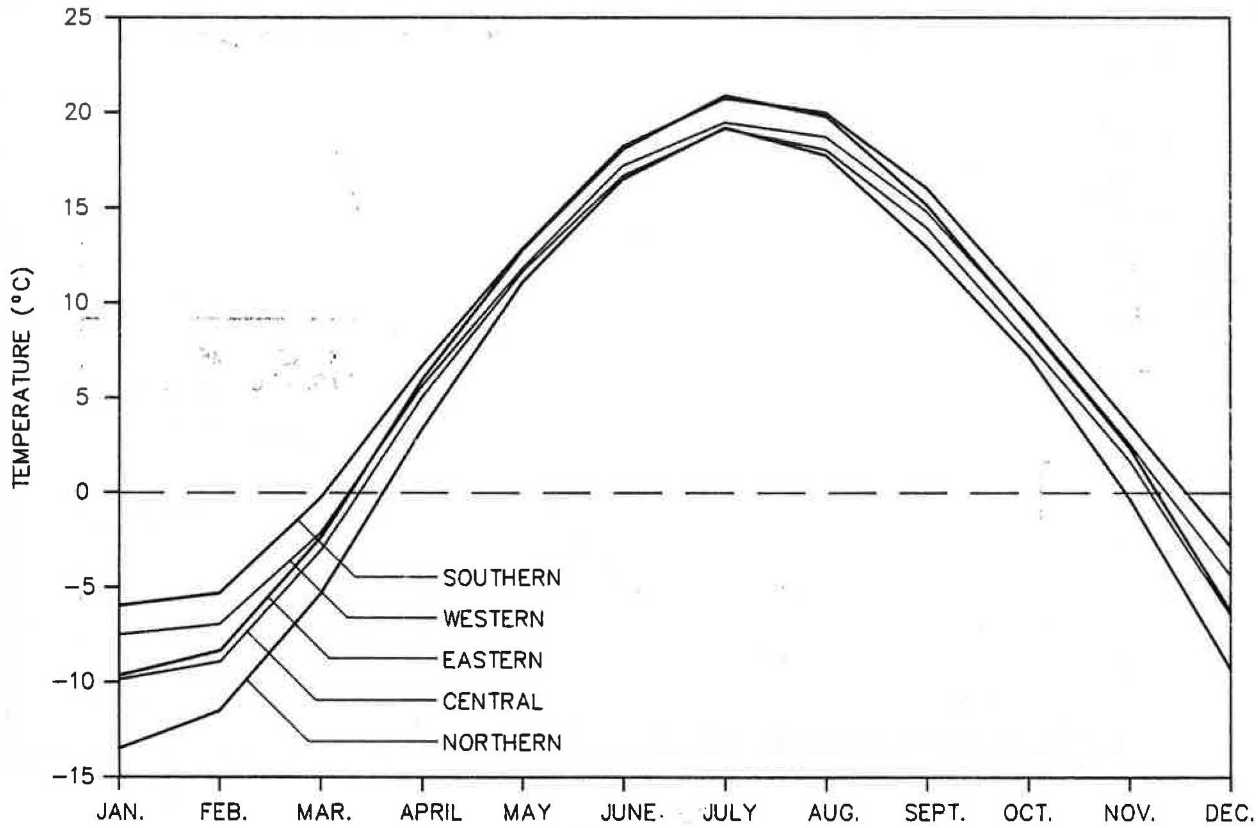

Fig. 2 Monthly Regional average daily mean temperatures for the five Ontario Regions.

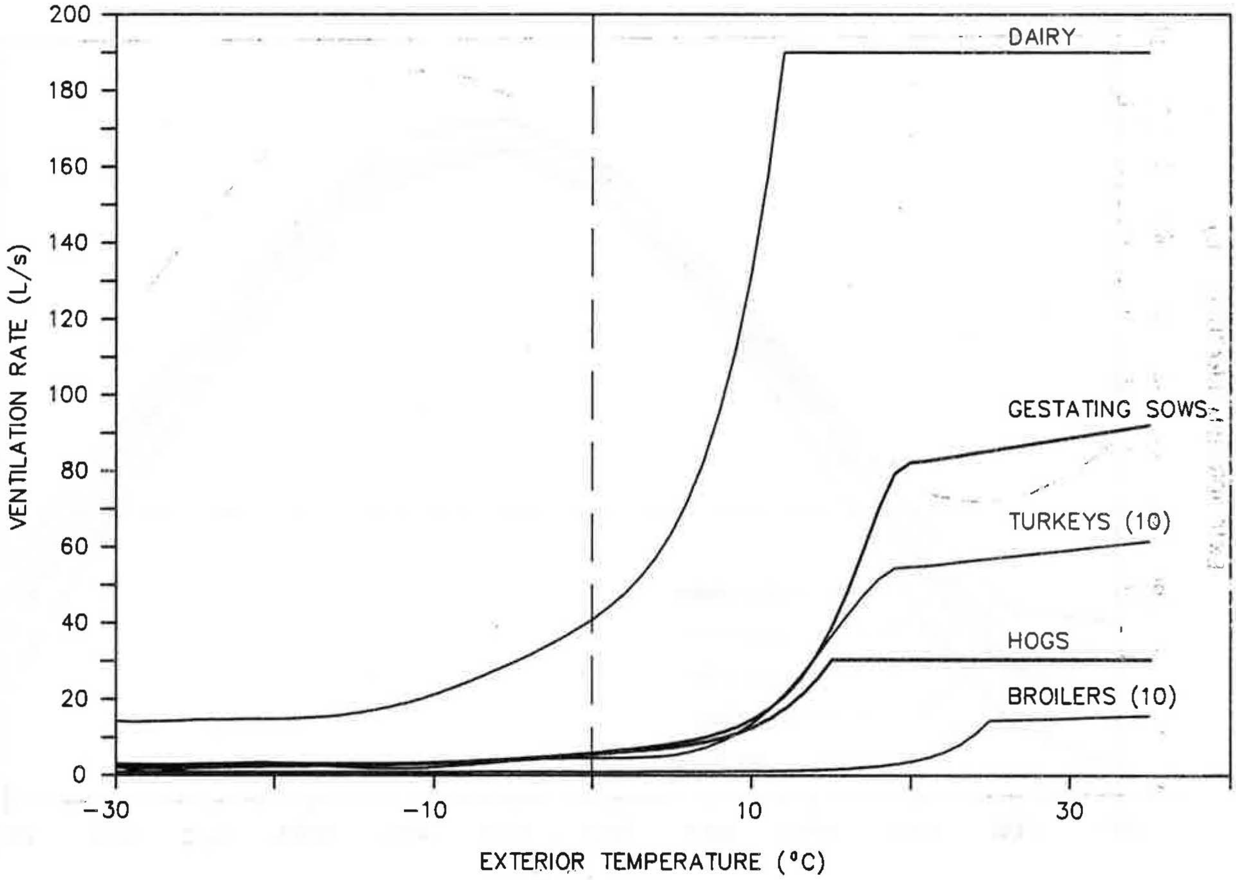

Fig. 3 Recommended ventilation rates for: dairy animals, gestating sows, turkeys (per 10 birds), growing/finishing hogs, and broiler chickens (per 10 birds) over an exterior temperature range of -30 - 35°C.

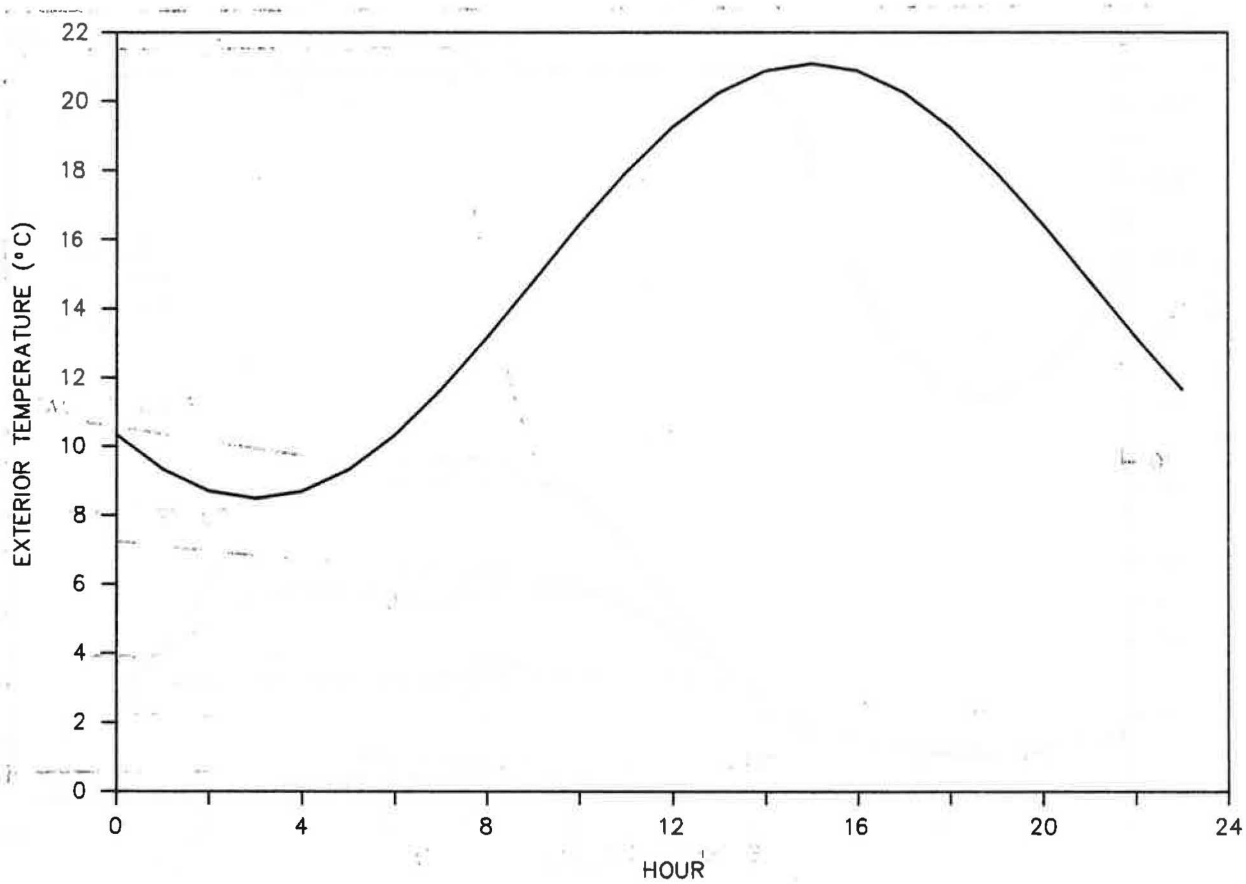

Fig. 4 The hourly temperatures generated for May 24 using a minimum temperature of 8.5°C and a maximum temperature of 21.1°C.

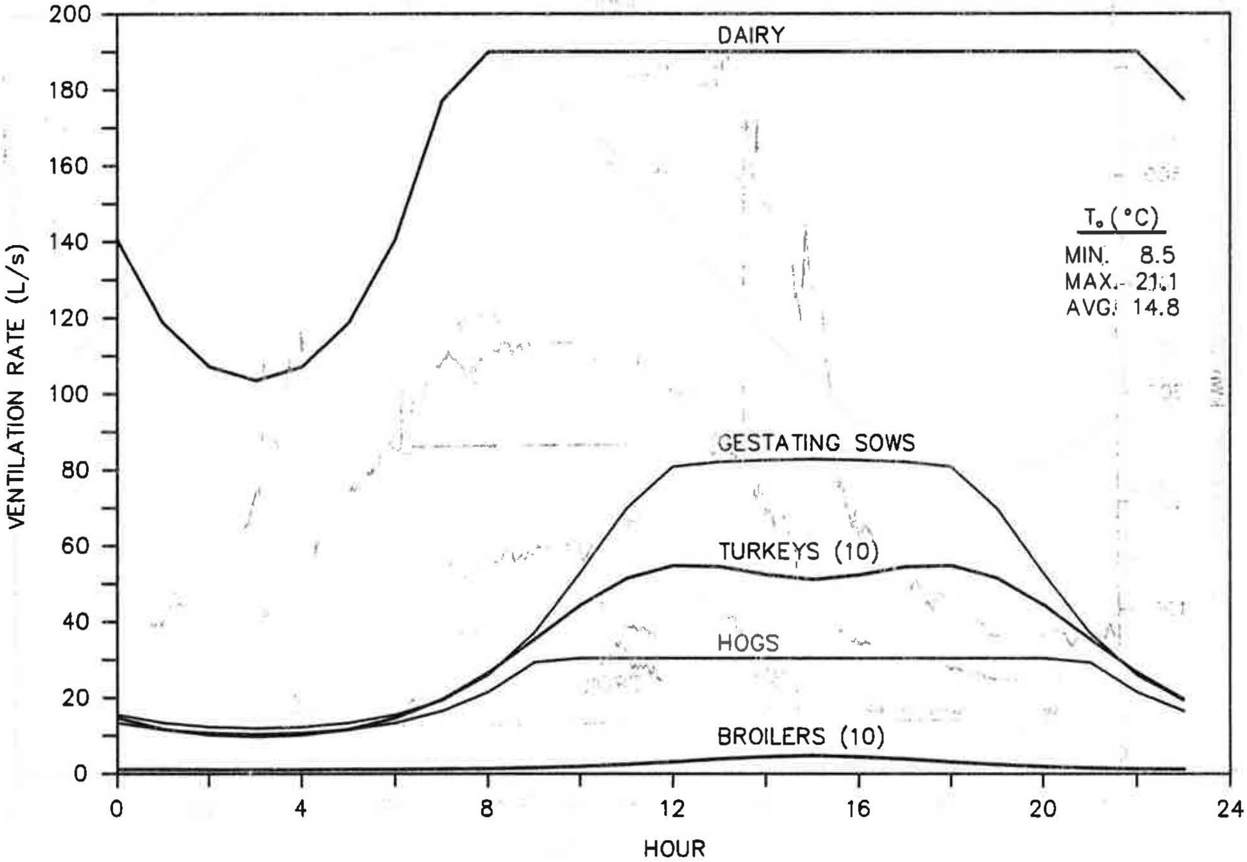

Fig. 5 A typical spring day (May 24) showing the ventilation rates for: dairy cattle that remain indoors year-round, gestating sows, turkeys (per 10 birds), growing/finishing hogs, and broiler chickens (per 10 birds).

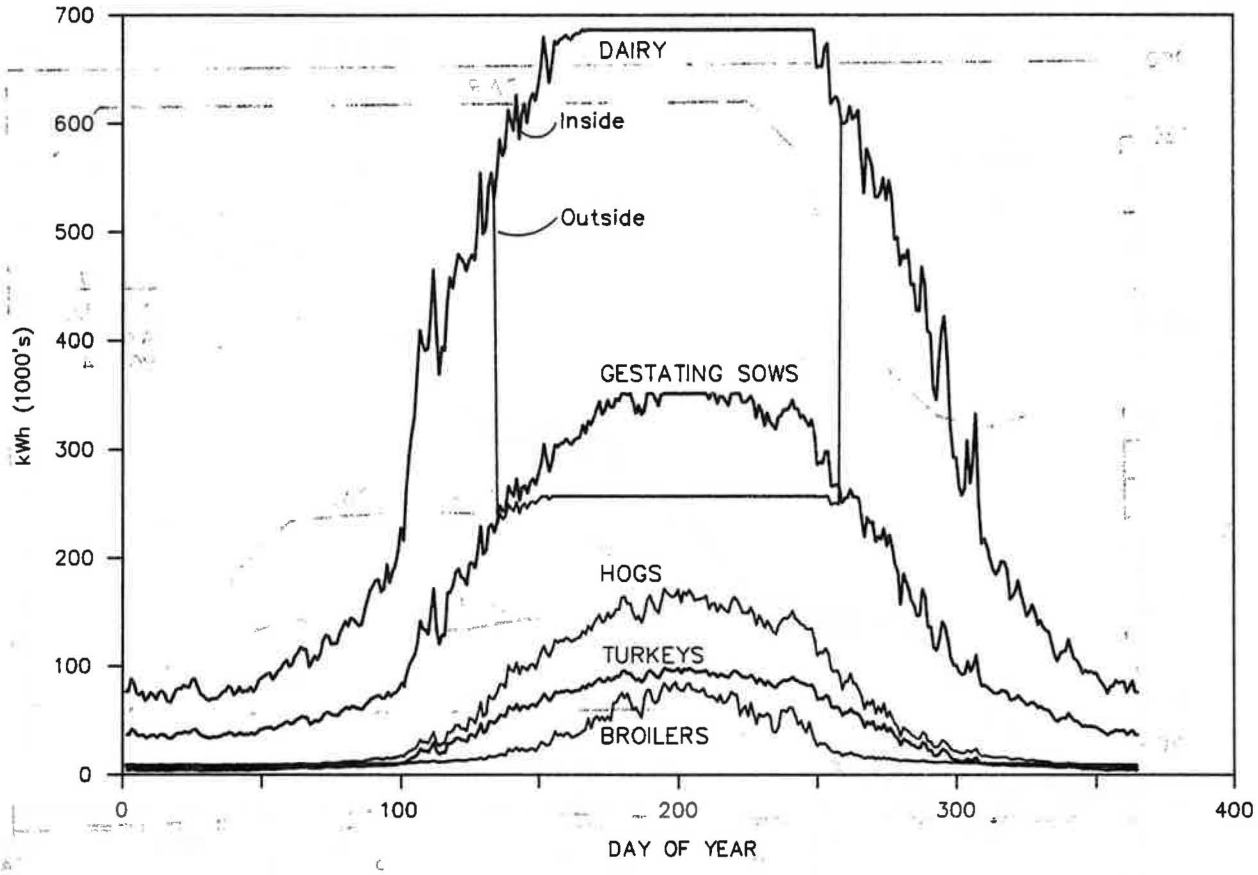

Fig. 6 The total energy required for all the animals in a production group calculated on a daily basis for the year.

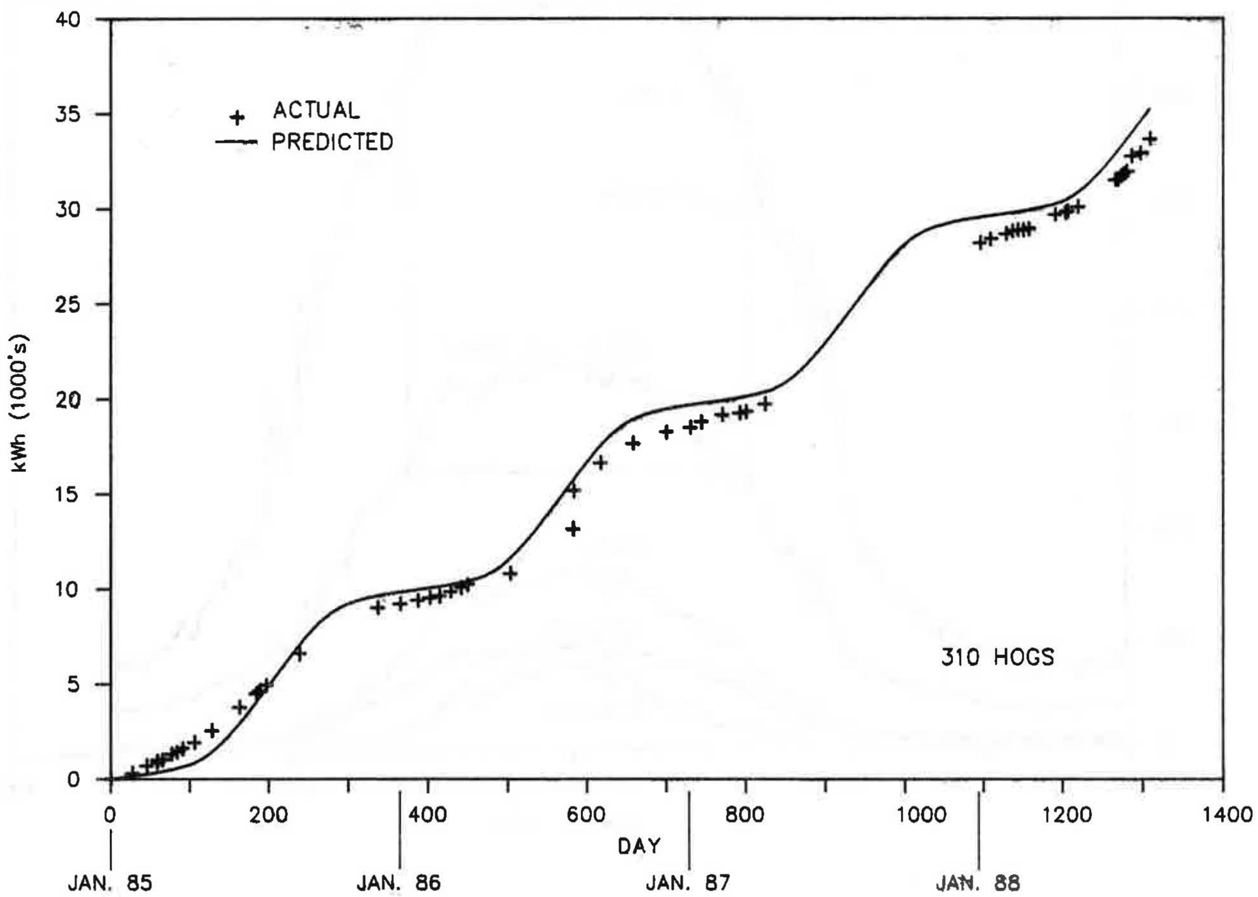

Fig. 7 Daily accumulated energy requirements for a barn with an average of 310 hogs over a 1309-day period.