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OPTIMUM BUILDING ORIENTATION FOR NATURAL VENTILATION

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ABSTRACT: This paper describes three methods to obtain the preferred building orientation, for the Ottawa area, for a typical swine barn using natural ventilation. The three methods used were: the prevailing wind method or windroses, the average ventilation rate method, or the frequency of the ventilation rate was below the minimum summer ventilation rate for a given number of consecutive hours. The analysis involves building orientations of 60° and 150°, and outside temperatures greater than or equal to 20°C, 25°C, and 30°C.

In general, the same results were obtained with each method. The preferred building orientation for a typical naturally ventilated swine barn, for the Ottawa region is 150°.

RÉSUMÉ

Le présent document décrit trois méthodes permettant de définir l'orientation optimale d'un bâtiment à ventilation naturelle servant à l'élevage de porcs dans la région d'Ottawa. Ces trois méthodes sont : a) la rose des vents et les Normales Climatiques au Cananda; b) les taux moyens de ventilation; c) le nombre d'heures consécutives où la ventilation naturelle est inférieure au minimum requis en été. L'analyse est basée sur deux orientations du bâtiment, 60° et 150°, et sur trois temperatures extérieures, 20, 25 et 30 °C.

En général, les trois méthodes ont donné le même résultat: l'orientation optimale d'un bâtiment d'élevage porcin à ventilation naturelle situé dans la région d'Ottawa est de 150° à nímporte laquelle des températures.

INTRODUCTION

Natural ventilation is governed by both wind forces and thermal forces,(Aynsley et al. (1977), Bruce (1977), Vickery et al. (1983)). However, during the summer, when exterior temperatures become warm, naturally ventilated buildings depend mainly on wind forces. Naturally ventilated buildings must be oriented to maximize ventilation rates, preferrably for the facility, maintaining the required minimum summer ventilation rate, and to minimize the consecutive hours of low ventilation rates. A wind induced natural ventilation model has been used for predicting the ventilation rates inside a typical naturally ventilated barn for swine or dairy production. The model was used with 34.4 years of weather data for the Ottawa area in order to select the preferred building orientation.

LITERATURE REVIEW

Prediction models for natural ventilation

There are two predominant natural forces that a designer has to work with when planning a naturally ventilated facility. These are wind forces and thermal buoyancy forces (ASHRAE 1977). The effect of the wind force in moving air through a building varies with the prevailing wind direction, the wind speed, seasonal and daily variations in velocity and direction, local obstructions, and changes in land topography (ASHRAE 1981). Aynsley et al.(1977), Choinière et al.(1989), Choinière (1991), Vickery et al.(1983) and numerous other authors have demonstrated how buildings can be ventilated during the summer via these wind forces. To obtain an optimum opening size for the sidewall and ridge opening, these authors presented a simple prediction model for natural ventilation:

$$Q = C_Q \times V \times A$$

where

Q = ventilation rate (L/s)
C_Q = coefficient of ventilation efficiency
V = external wind speed (m/s)
A = effective areas of sidewall and ridge openings(m^2)

The ventilation efficiency coefficient, C_Q, varies from .25 to .35 for winds parallel to the building, and from .50 to .60 for winds that are perpendicular to the building, (Hellickson et al. 1983). Agreement with these values was obtained from a scale model study carried out in a wind tunnel, (Choinière, 1991).

The ventilation rates for this scale model study were determined using the pressure difference method for building orientation angles of 0° to 90°, and a C_Q curve for 360° based on Suchorski-Tremblay et al. (1990) and Choinière (1991).

Ventilation rate coefficient

The application of the coefficient C_Q to the natural ventilation prediction model, (ASHRAE, (1981), Hellickson et al., (1983)) is a method which is used by designers to calculate the ventilation rates of any structure. For each different building orientation and wind direction there is a corresponding C_Q value. C_Q can be regarded as being a combination of the discharge coefficient, C_d, and the internal and external pressure differences, (Choinière, 1991). ASHRAE (1981) and Hellickson et al. (1983) proposed that C_Q values varied depending upon the wind direction. This method is very easy to apply, but not very precise.

Suchorski-Tremblay et al. (1990) and Choinière (1991), used a computer program to produce C_Q values versus the wind angles of incidence. This same program was used to develop the C_Q values which will be used in this paper.

Building orientation

From a non-agricultural perspective, housing developments are oriented depending on the geographical location so that the residents will live in thermal comfort throughout the year. Unfortunately, in the past this was not the case. In ancient Egypt poor people lived in houses which faced the hot desert wind: and the rich people lived in the northern district, their houses facing the pleasant north winds, (Aynsley et al. (1977)).

Determining the optimum building orientation for natural ventilation is an important step and obtaining a proper building orientation contributes greatly to the performance of the system. The general guideline to follow is to align the length of the facility perpendicular to the prevailing winds (Hellickson et al. (1983), Choinière and Munroe (1990)). Hellickson et al. (1983) state that a designer should keep in mind the local climatic conditions, the geography of the area, and past experiences in determining how to maintain adequate ventilation within the facility.

Hellickson et al. (1983) explained that there are basically two preferred building orientations: The first is an East-West orientation in which the sidewall openings are closed. This orientation maximizes the heat gain from the low winter sun and minimizes the penetration of the high summer sun. The second is a North-South orientation where the sidewall openings remain open for maximum summer ventilation, but the hot sun does penetrate in the morning and in the afternoon. Consequently, there are problems with both of these orientations as reported by Choinière (1989).

Another criteria which influences building orientation is the number of consecutive hours in the summer when the ventilation rate is below the minimum summer ventilation rate recommended for the type of livestock being housed. The preferred building orientation should not be based on the wind direction or speed only, but rather also on their combination and frequency.

Previous studies

An analysis was carried out by Choinière (1989) for an Ottawa area site using two hundred hours of meterological data for temperatures above 20°C, 25°C, and 30°C. The aim of the project was to develop a methodology for predicting ventilation rates based on the effects of the weather and the consecutive hours of low ventilation rates. He concluded that there is a relation between the average ventilation rates obtained and building orientation. Also, he found that a North-South orientation showed higher ventilation rates for exterior temperatures above 20°C, 25°C, and 30°C, than an East-West orientation.

Suchorski-Tremblay et al. (1990) also carried out an analysis of average ventilation rates for building orientations based on weather data. The results were based on thirty years of weather data from various location within the province of Ontario for temperatures of above 20°C, 25°C, and 30°C, and also for a symmetrical building oriented at different angles from 0° (North) to 150°, at 30° intervals. They tested a typical naturally ventilated swine building with an 80 cm high continuous sidewall opening, or intermittent chimneys spaced at 7.2 m apart, for all three of the temperature ranges. A ranking scheme was developed based on a number of parameters including: average ventilation rate, frequencies of different ventilation rates, and consecutive hours of low ventilation rates. From their results they concluded that for the province of Ontario, 30° West off North building orientation was most frequently recommended.

This ranking system does not take into account the statistics for the frequencies of different ventilation rates or the consecutive hours of low ventilation in determining if there is a significance between the building orientation chosen with the ranking method and the other building orientations.

OBJECTIVES

The summer weather data for the Ottawa area was used with a wind-based prediction model for a typical naturally ventilated building. The objectives of this study are:

1) To determine the effect of exterior temperatures on the wind direction frequencies (windroses) and on the selection of the preferred building orientation based on the prevailing wind method.

2) To determine the effect of three exterior temperature ranges and two building orientations on the ventilation rate frequency curves and on the number of consecutive hours when the ventilation rates are below the minimum recommended summer ventilation rate.

3) Compare the preferred building orientation obtained, based on the three different methods.

METHODS AND PROCEDURE

Building description

The building used in the analysis is a typical gabled roof swine barn measuring 12.2 m wide by 24.4 m long, with 2.7 m high sidewalls. The barn's roof had a 4/12 slope, with a cathedral ceiling and a 30 cm eave overhang. The building had ten windows on both sidewalls and two windows on both end walls. The sidewall windows remained open to simulate a continuous opening of 80 cm high over the total length of the building- an area 27% of the entire sidewall surface. The roof of the building featured four intermittent chimneys, each 60 cm x 60 cm to respect a minimum ridge opening areas obtained by Choinière et al. (1988, 1989) and Choinière (1991).

The facility can contain up to 340 hogs at a time, with a given ventilation rate of 40 L/s per each hog. The recommended ventilation rate was determined by using the VENT program, (House and Hoffman, 1987) designed to obtain ventilation rates based on the type of livestock housed within the facility, the number of animals, and also the type of building. For this building configuration, the recommended minimum summer ventilation rate was calculated to be 13 600 L/s.

Weather data processing

Weather data for different locations in the province of Ontario were obtained from the Land Resource Research Center of Agriculture Canada in Ottawa. The original data was collected by Environment Canada. The weather stations were selected based on three criteria:

1)preferably, the stations collected data for at least 30 years,

2)the wind direction data were measured within the sixteen quadrants of the compass and,

3)they were near major pork production regions.

Table 1 displays the weather stations used for Ontario.

In order to study the temperature effects on the wind direction and speed, the 30 years of weather data, were sorted according to three temperature sets; equal to or greater than 20°C , 25°C, or 30°C.

From the original weather data, a problem occurred when the wind speed decreased below the sensitivity of the anemometer (wind speed sensor). The recorded wind speeds and wind directions were reported at 0 mph and 0° (North) respectively. This problem had to be corrected since it is impossible to have zero wind speed, always occurring from one particular direction. The wind direction of 0° was corrected by checking previous recorded wind directions with a measured wind speed, and adopting that direction until the wind speed picked up and generated a wind direction again.

Originally, the wind speed data were recorded in miles per hour, with the lowest value being one. When Agriculture Canada switched from imperial to the metric system the 1 mph, or 1.6 km/h were rounded to 2 km/h. Consequently, there are no data for 1 km/h (0 to 1 mph). This rounding and the metric conversions also affected wind speeds, such as 4 km/h (2 to 3 mph), 7 km/h (4 to 5 mph), 9 km/h (5 to 6 mph), etc...

Since a wind speed of 0 km/h is not possible, the zero data were replaced by an average of 0.5 mph, corresponding to 0.8 km/h (0.22 m/s).

Windroses

Windroses were obtained for each of the temperatures greater than or equal to 20°C, 25°C, and 30°C. The weather data was sorted for each of the 16 quadrants (N, NNE, NE, NEE, E, SEE, SE, SSE, S, SSW, SW, SWW, W, NWW, NW, and

NNW) and a computer program was written to obtain the frequency of the events that occurred within each quadrant. The total number of the events for a specific quadrant was divided by the total number of events for that weather station, and put in percent form. The calm periods were also accessed and displayed as a frequency. Reference was made to the Canadian Climate Normals for the Ottawa station, where the average frequency for the months of June, July, and August were obtained for each of the 16 quadrants. The windroses were then plotted with Autosketch. The windroses obtained from the weather data files and from the Canadian Climate Normals were then compared.

Prevailing wind method

An attempt was made to select the preferred building orientation based on the prevailing wind method. The percentage of winds from a specific direction were summed for each direction. The preferred building orientation would have the maximum percent of wind interception.

Ventilation rate calculations

Ventilation rates were then calculated using for the C_Q versus wind angles of incidence values, and the total area of the sidewall openings. The number of consecutive hours below the minimum designed summer ventilation rate for the three temperature ranges and for each of the six building orientations (0°, 30°, 60°, 90°, 120°, 150°) were also obtained. A set of computer programs were written in QuickBASIC, by which the number of consecutive hours were obtained. This was done by comparing the ventilation rate calculated to the minimum summer ventilation rate, 13 600 L/s. The program then counted the events that were below the targeted ventilation rate. Table 2 presents an example of the methodology to calculate the number of consecutive events of low ventilation.

Average ventilation rates and their respective standard deviations were obtained for each the six (0°, 30°, 60°, 90°, 120°, 150°) building orientations for each of the three temperature ranges above (20°C, 25°C, or 30°C). For this paper the best (150°) and worst (60°) building orientations were analyzed

Frequencies for each 100 L/s ventilation rate were calculated and, using Lotus 1-2-3, graphically displayed in a bar graph format which could then be used for further analysis.

Finally, the number of consecutive hours below the minimum required ventilation rate were obtained for each of the six building orientations and each of the three temperature ranges and plotted.

RESULTS AND DISCUSSION

All of the results are based on the weather data obtained from Environment Canada, for the Ottawa International Airport weather station for the past 30 years and for temperatures greater than or equal to 20°C, 25°C, or 30°C, and for the building configuration explained in this report. For the purpose of this report, only two out of the six building orientations will be analyzed: 60° and 150°.

Windroses

One area of interest in the analysis of windroses, is the effect of temperature on the prevailing wind frequencies obtained for the temperature ranges tested. For the Ottawa International Airport weather station, and 34.4 years of weather data analyzed, there were 44 707 hours where the temperature was above 20°C, (yearly average of 1300 hours), 13 080 hours above 25°C, (yearly average of 380 hours), and 1575 hours above 30°C, (yearly average of 45 hours). For all temperatures, most winds range from the South to the West-North-West quadrants. As the temperature increases from 20°C to 30°C, the wind changes from a South-South-West to a West direction. This trend becomes more evident when observing the calculated frequencies for the prevailing winds coming from the West. For example, at 20°C, the frequency obtained for winds coming from the West was 11% (4918 hours out of 44 707 hours); for 25°C the frequency was 12.5% (1635 hours out of 13 080 hours), and for 30°C the frequency was 18.3% (288 hours out of 1575 hours).

The wind direction frequencies obtained from the Canadian Climate Normals, (Environment Canada, 1982) for the months of June, July, and August (Fig. 4) are similar to the frequency data obtained for the windrose at temperatures greater than or equal to 20°C. However, when comparing the windroses obtained for temperatures greater than or equal to 25°C and 30°C, the frequency of Northern and Eastern winds are greater for the Canadian Climate Normals.

As shown in Figures 1 to 4, when the temperature increases, the frequency of calm periods decreases from 5.48% at 20°C to 1.52% at 30°C. This means that as the temperature increases the occurrence of low wind speeds is minimal. For the months of June, July, and August, the Canadian Climate Normals showed the highest calm periods (7.13%) compared to the other windroses, (Fig. 1 to 3).

Table 3 shows the cumulative prevailing wind frequency data for temperatures greater than or equal to 20°C, 25°C, and 30°C, and for the Canadian Climate Normals for the months of June July, and August, for specific building orientations. This cumulative frequency is obtained by adding the wind frequency data for a 90° wide quadrant perpendicular to the building orientation, on both sides of the building, (Fig. 5). A NW-SE orientation is preferred for temperatures greater than or equal to 20°C, 25°C and the Canadian Climate Normals since the cumulative frequency is highest in these cases 74.8%, 78.8%, and 66.1% respectively. However, for temperatures greater than or equal 30°C the preferred building orientation would be a NNW-SSE, since the cumulative frequency for this direction is highest at 85.7%. A trend develops, in that as temperature increases the cumulative frequency of prevailing winds also increases Table 3.

From the results, temperature does have an effect in obtaining a preferred building orientation with respect to windroses. For temperatures below 30°C, the building orientation obtained from wind data compared to the Canadian Climate Normals is the same. As the temperature increases over 30°C, the preferred building orientation differs from the one obtained using the Canadian Climate Normals. Therefore, determining preferred building orientation solely on windroses is biased at extreme temperatures ($T \geq 30°C$).

Ventilation rate method

Figures 6 to 11 show the distribution of the ventilation rates for the two building orientations, 60° and 150°, at temperatures greater than or equal to 20°C, 25°C, and 30°C. The graphs shown in Fig. 6 to 9 have distributions that are very similar. In Figures 10 and 11, the data is more spread out and the graph tends to characterize another type of distribution.

In Fig. 6 to 11, the high peaks that occur from 200 L/s to 400 L/s are due to the correction for the calm periods. A trend develops with calm periods with respect to temperature. As the temperature increases from 20°C to 30°C, the percent of calm periods, or the times when the ventilation rates are below the required summer ventilation rate (13 600 L/s) decreases from 38.2% to 14.4%.

<u>Effect of temperature</u>

The distribution of the ventilation rates changes as temperature increases from 20°C to 30°C. At 60°, and temperatures increasing from 20°C to 30°C and above, the frequency that the ventilation rates are above the required summer ventilation rate (13 600 L/s) increases from 61.8% to 80.8%, (Fig. 6, 8,and 10). Also, the average ventilation rates increase on average by 8.0% as temperatures increase, (Table 4). The maximum ventilation rates decrease from 135 000 L/s for temperatures greater than 20°C to 71 000 L/s at a temperatures greater than 30°C. In terms of the frequency when the ventilation rates are below the required summer ventilation rate, the percentage decreases from 38.2% for temperatures greater than 20°C to 19.2% for temperatures greater than 30°C.

Similarly, the same trends occur for a building orientation of 150°. The frequency that the ventilation rates are above the required summer ventilation rate (13 600 L/s) increases from 67.2% for temperatures greater than 20°C to 85.6% for temperatures greater than 30°C, (Fig. 7,9, and 11). The average ventilation rates in Table 4 also increases by 14% as temperature increases. The maximum ventilation rates decreased as the temperature increased. For temperatures greater than and equal to 20°C, the maximum ventilation rate is 161 000 L/s, and at a temperature greater than or equal to 30°C the maximum ventilation rate is 80 100 L/s. The frequency when the ventilation rates are below the required summer ventilation rate (13 600 L/s) decreases as temperatures increases. For example at temperatures greater than or equal to 20°C the percent is 32.8% while at temperatures greater than and equal to 30°C the percent is 14.4%, (Figure 7, 9, and 11).

Effect of building orientation

The effect of building orientation with respect to the ventilation rate method showed that as the temperatures increase from 20°C to 30°C, the frequency that the ventilation rate is above the required summer ventilation rate increases by 5% on average for both building orientations, 60° and 150°, (Fig. 6 to 11). The frequency when the ventilation rates are below the required summer ventilation rate, decreases by 5% as temperatures increases from 20°C to 30°C, for both building orientations. At each of the temperature ranges, the maximum ventilation rates were higher for the 150° than for the 60°. Figures 6 to 11 also show higher ventilation rates for a 150° orientation than for a 60° orientation. For example, the maximum ventilation rate at a temperature of 30°C, for a building orientation of 60° is 71 000 L/s compared to 80 000 L/s for a 150° building orientation at the same temperature. Also the number of events are greater, for higher ventilation rates at 150° than for 60° for all three temperature ranges. Average ventilation rates in Table 4 are higher for 150° than 60°. For example, at a temperature of 20°C the average ventilation for a building oriented a 60° is 19 237 L/s as compared to 21 668 L/s for a building oriented at 150°.

Based on the ventilation rate method for temperatures greater than or equal to 20°C, 25°C, and 30°C, a building orientation of 150° from the North would be chosen. This method showed the highest average ventilation rate (Table 4), the highest maximum ventilation rate (Fig. 7, 9, and 11), higher percent of ventilation rates above the required summer ventilation rate, lowest percent of ventilation below the required summer ventilation rate, and the lowest number of calm periods.

Consecutive hours

When analyzing the Ottawa station's exponential graph (Fig. 12) of percentage of events versus consecutive hours, there is a direct relationship between the percentage of events to the frequency of the ventilation rates that are below the required summer ventilation rate. The relationship is, the percentage of one hour events below the minimum summer ventilation rate is equal to the percentage of ventilation rates below the required summer ventilation rate, (Fig. 6 to 11). The graph shows that there is a rapid reduction in the percentage of events as the number of consecutive hours increases. This means that the number of events when ventilation rates are below the required summer ventilation rate declines as the period of time is prolonged. As the graph continues to decay, it levels off to a final point. This point is the maximum number of consecutive hours where the ventilation rate is below the required summer ventilation rate. Figure 13 is the natural log of the exponential curve, (Fig. 12) and behaves as a natural log, allowing for the calculation of the slope to evaluate the rapidity at which the percentage of events are reduced. Table 2 is a sample of hourly weather data, ventilation rate, and methods used for the compilation of the consecutive hours of low ventilation rates (Fig. 12 and 13).

Effect of temperature

Table 5 shows the effect of temperature on the initial values of single hour events. As the temperature rises, the number of initial one hour events decreases. For example, at a temperature greater than or equal to 20°C and an orientation of 150,° the percentage of one hour events is 32.3% (14427 hours out of 44707 hours), and at a temperature greater than or equal to 30°C, for the same orientation, the percentage of one hour events is 14.2% (222 hours out of 1575 hours).

As temperature increases, the longest period of consecutive hours decreases. For example, temperatures greater than or equal to 20°C and an orientation of 150° the longest period of consecutive hours is 43. This means that for 43 consecutive hours the ventilation rate was below the required design summer ventilation rate, and for temperatures greater than or equal to 30°C, and the same orientation, the longest period of consecutive hours is 7.

Figure 13 shows that as temperature increases, the slope of the line increases. Consequently, the percentage of events decreases as the number of consecutive hours increases. For example, at temperatures greater than or equal to 20°C and a building orientation of 150°, the slope of the line is -0.20, at temperatures greater than or equal to 30°C , and for the same building orientation, the slope of the line is -0.65.

Effect of building orientation

The effect of building orientation with respect to consecutive hours shows that as temperature increases the percentage of hours decreases. For temperatures greater than or equal to 20°C and a building orientation of 150°, fewer single hour events of low ventilation rates occur than for a building orientation of 60°, (Fig. 12). However the differences between the two building orientations are small. For the 150° building orientation and temperatures greater than or equal to 20°C, the percentage of single hour events was 32.3%, but for the 60° building orientation the percentage of single hours was 37.1%, resulting in a difference of approximately 5% for 34.4 years. Referring to Fig. 13, for a building orientation of 60°, at temperatures greater than or equal to 20°C, there is a sharper decrease in the percentage of events when the number of consecutive hours increases above 32 when compared to a building orientation of 150°. But as temperatures increase above 25°C there is a sharper decrease in the percentage of events when the number of consecutive hours increases, for a building orientation 150°.

A preferred building orientation of 150° was chosen based on the consecutive hours method because it showed the least number of single hour events, for all temperature ranges, (Table 5). This orientation showed at temperatures greater than 25°C fewer percentage of events as the number of consecutive hours increases , since the slope of the line is steeper in this region.

Comparison among methods

The orientation obtained using the prevailing wind method, or windroses, the ventilation rate method, and the consecutive hour method all yielded similar results. With the windroses we obtained a preferred building orientation of NW-SE for temperature greater than or equal to 20°C, 25°C, and the Canadian Climate Normals were obtained. This orientation would be similar to the 150° building orientation obtained using the ventilation rate method and the consecutive hour method, for all three temperature ranges. The advantage of using the ventilation rate method and the consecutive hour method, is it shows the frequency of events above the minimum summer ventilation rate and the number of single hours, respectively for a particular building orientation and temperatures greater than or equal to 20°C, 25°C, and 30°C. This information is necessary for designing proper sidewall, end wall and ridge or chimney openings. Although the three methods show the same results for the Ottawa region, different results may arise in other regions of Ontario, due to differences in climatical conditions.

SUMMARY AND CONCLUSIONS

Weather data for the Ottawa area was used with a prediction model for a typical naturally ventilated swine building. Two building orientations were chosen (60° and 150°) and analyzed at temperatures greater than or equal to 20°C, 25°C, and 30°C. The selection of the preferred building orientation was based on the prevailing winds or windroses, the ventilation rate method, and finally the frequency of events of a given number of consecutive hours below the design summer ventilation rate. The results showed that:

1- Selection of the preferred building orientation from the windroses would be NW-SE orientation at temperatures greater than or equal to 20°C, NW-SE orientation at temperatures greater than or equal to 25°C, and NNW-SSE orientation at temperatures greater than or equal to 30°C. The preferred building orientation based on the Canadian Climate Normals would be a NW-

SE orientation.

2- At a building orientation of 150°, as the temperature increases from 20°C to 30°C, the average ventilation rate increases by 14%. The frequency at which the ventilation rate was below the required summer ventilation rate decreased from 32.8% at a temperature greater than and equal to 20°C to 14.4% at a temperature greater than or equal to 30°C.

3- Building orientation effects showed that the frequency at which the ventilation rates were above the required summer ventilation rate increased on average by 5%, from 60° to 150° for all temperature ranges.

4- Building orientation effects showed that at an orientation of 60° versus an orientation of 150°, the number single hour events was less for an orientation of 150°, at all temperatures.

FURTHER RESEARCH

Further research is geared toward a statistical analysis being done to test the significance of the building orientation based on the average ventilation rates and also on the consecutive hours of low ventilation rates.

RÉSUMÉ ET CONCLUSION

Les données météorologiques de la région d'Ottawa ont servi, avec un modèle de prédiction, à déterminer l'orientation optimale d'un bâtiment à ventilation naturelle servant à la production porcine. Deux orientations ont été choisies (60° et 150°), et l'analyse porté sur des températures supérières ou égal à 20, 25, et 30 °C. On a choisi l' orientation optimale du bâtiment en fonction des vents dominants (rose de vents), des taux de ventilation et, en fin de compte, du nombre d'heures consécutives où la ventilation naturelle etait inférieure au minimum requis en été. Les résultats montrent que :

1- Si l'on se fie à la rose des vents, l'orientation optimale du bâtiment serait NO-SE à des températures supérieures à 20 °C ou à 25 °C, et NNO-SSE à des températures supérieures à 30 °C. Si l'on se fie plutôt aux Normes Climatiques au Canada, le bâtiment devrait être orienté selon l'axe NO-SE.

2- Lorsque le bâtiment est orienté à 150° et que les températures passent de 20 à 30 °C, la moyenne des taux de ventilation augmente de 14 %. La période où les taux de ventilation est inférieur au minimum requis en été baisse à 32.8% si la température dépasse 20 °C, alors qu'elle chute à 14.4 % lorsque la temperature s'élève à 30 °C et plus.

3- En changeant l'orientation du bâtiment de 150° à 60°, on a prolongé de 5% en moyenne la periode où le taux de ventilation naturelle était supéieur au minimum requis en été, peu importe la température.

4- À toutes les tempéreatures étudiées, le nombre initial d'événements d'une heure seulement était inférieur pour l'orientation de 150°, comparé à celui enregistré à 60°.

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Table 1. Location and number of years of weather data accessed for each weather station.

LOCATION	YEARS OF DATA
BARRIE	6.5
LONDON	34.5
NORTH BAY	34.4
OTTAWA	34.4
SIMCOE	5.4
ST. CATHARINES	2.3
TORONTO	34.5
TRENTON	34.4
WATERLOO	21.4
WINDSOR	34.5

Table 2. Sample of hourly weather data, ventilation rate, and methods used for the compilation of the consecutive hours of low ventilation.

530705 <<-- DATE																
5 <<-- NUMBER OF CONSECUTIVE HOURS						COMBINATIONS OF CONSECUTIVE HOURS BELOW 1 AIR / MIN.										
HOUR	TEMP. °C	WIND SPEED (km/h)	WIND DIR. °	VENT. RATE (L/s)	COORD.	1X5	2X4	2X4	3X3	3X3	3X3	4X2	4X2	4X2	4X2	5X1
12	22	3	180	10352.54	SOUTH											
13	23	2	180	9645.12	SOUTH											
14	22	3	180	10352.54	SOUTH											
15	21	3	180	10352.54	SOUTH											
16	22	2	180	9645.12	SOUTH											

Table 3. Selection of building orientation based on the frequency of prevailing wind interception.

BUILDING ORIENTATIONS	FREQUENCIES FOR EXTERIOR TEMPERATURES (%)			
	T°≥ 20°C	T°≥ 25°C	T°≥ 30°C	CANADIAN CLIMATE
N-S 0°	62.2	64.4	75.6	60.1
NNW-SSE 22.5°	68.2	76.4	85.7*	64.2
NW-SE 45°	74.8*	78.8*	81.0	66.1*
WNW-ESE 67.5°	66.3	69.0	65.3	57.8
W-E 90°	62.4	61.9	52.2	55.6
WSW-ENE 112.5°	56.2	52.2	44.2	52.3
SW-NE 135°	55.0	49.2	48.1	55.1
SSW-NNE 157.5°	49.0	49.2	57.6	53.0

* Best building orientation per temperature range.

Table 4. Ottawa (Ontario) airport weather station's average ventilation rates and standard deviations for temperatures greater than 20°, 25° and 30°C for 60°and 150°.

TEMPERATURE RANGE (°C)	BUILDING ORIENTATION (ANGLE OFF 0° N)	AVERAGE VENTILATION RATE (L/s)	STANDARD DEVIATION
T ≥ 20°	60°	19 237	12 166
	150°	21 668	13 680
T ≥ 25°	60°	20 785	11 730
	150°	25 164	14 375
T ≥ 30°	60°	22 651	10 553
	150°	29 441	13 675

Table 5. Consecutive hour data for the three temperature ranges and two building configurations.

TEMPERATURE RANGE (°C)	BUILDING ORIENTATION (ANGLE OFF 0° N)	NUMBER OF SINGLE HOURS	AVERAGE NUMBER OF HOURS/Y
T ≥ 20°	60°	16564	481
	150°	14427	419
T ≥ 25°	60°	3957	115
	150°	3333	97
T ≥ 30°	60°	284	8
	150°	222	6

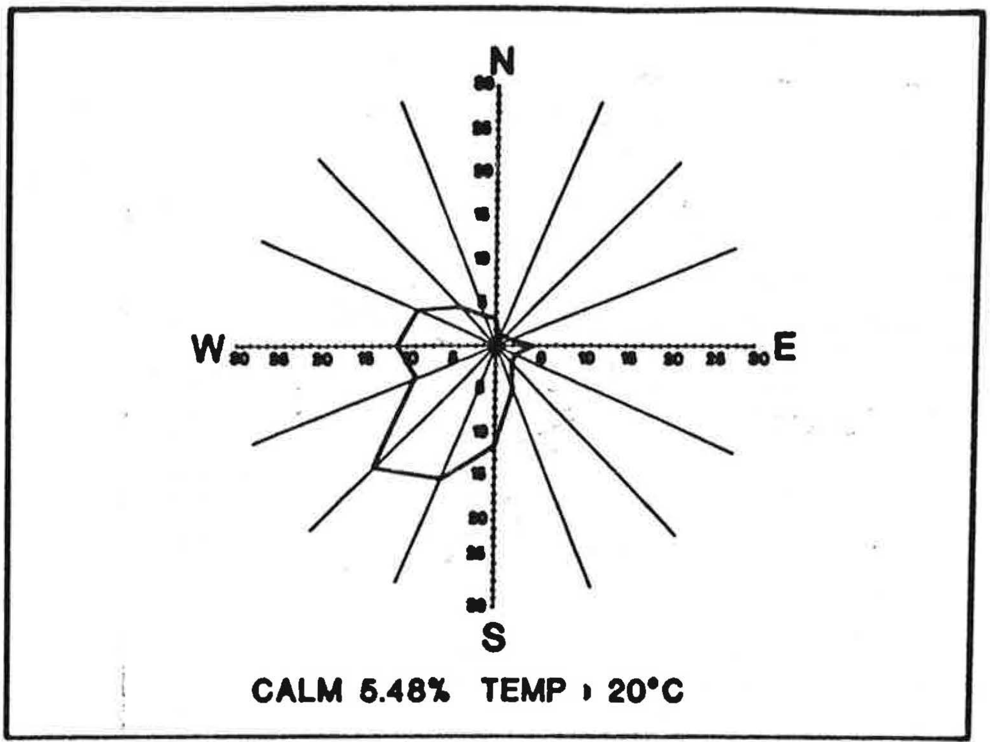

Figure 1. Windrose for Ottawa region, temperature ≥ 20°C.

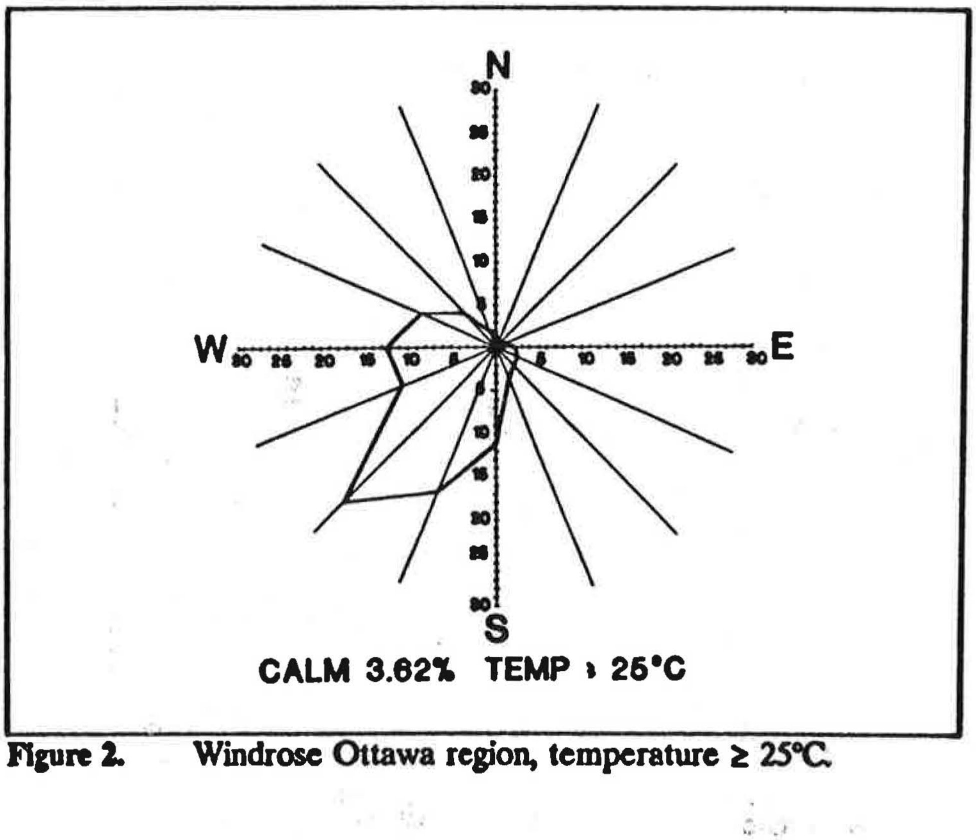

Figure 2. Windrose Ottawa region, temperature ≥ 25°C.

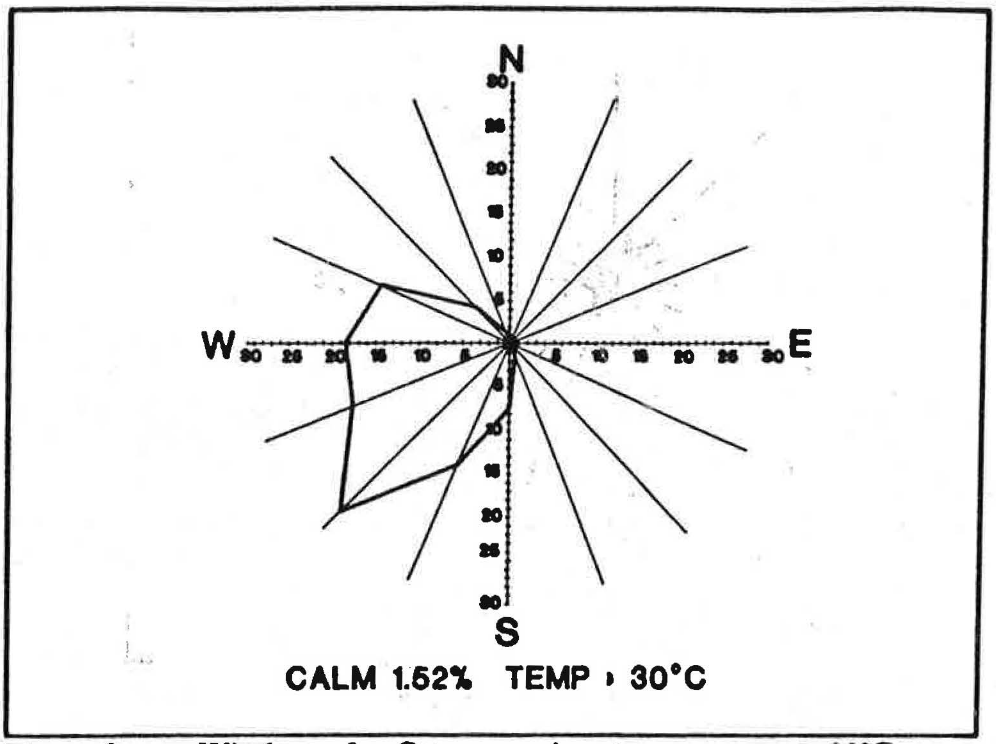

Figure 3. Windrose for Ottawa region, temperature ≥ 30°C.

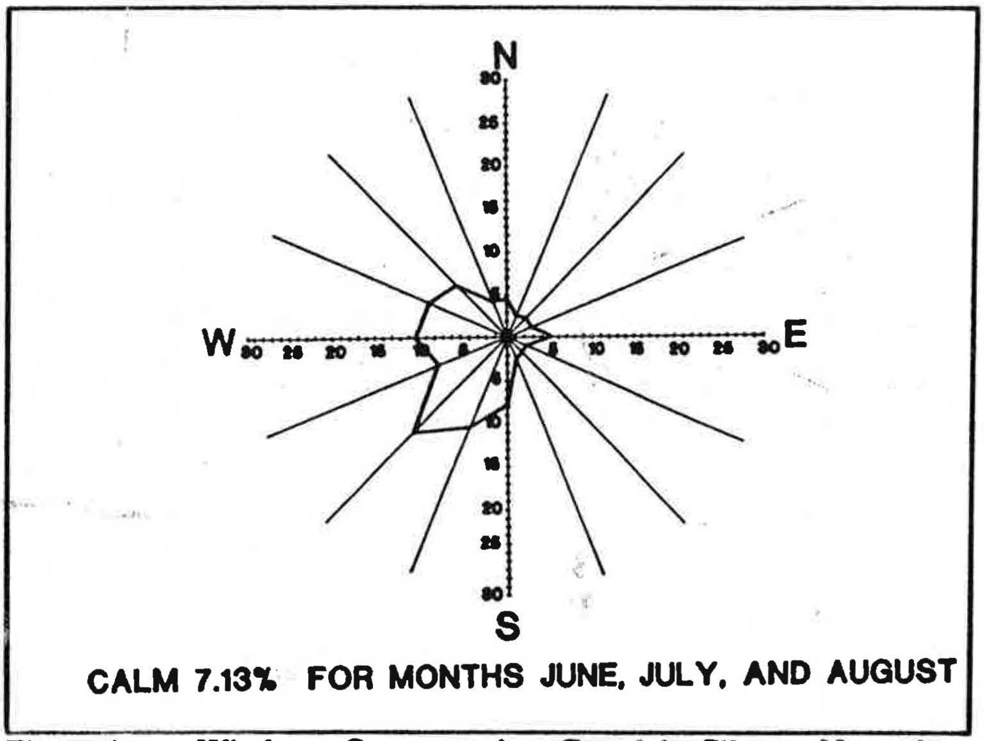

Figure 4. Windrose Ottawa region, Canadain Climate Normals.

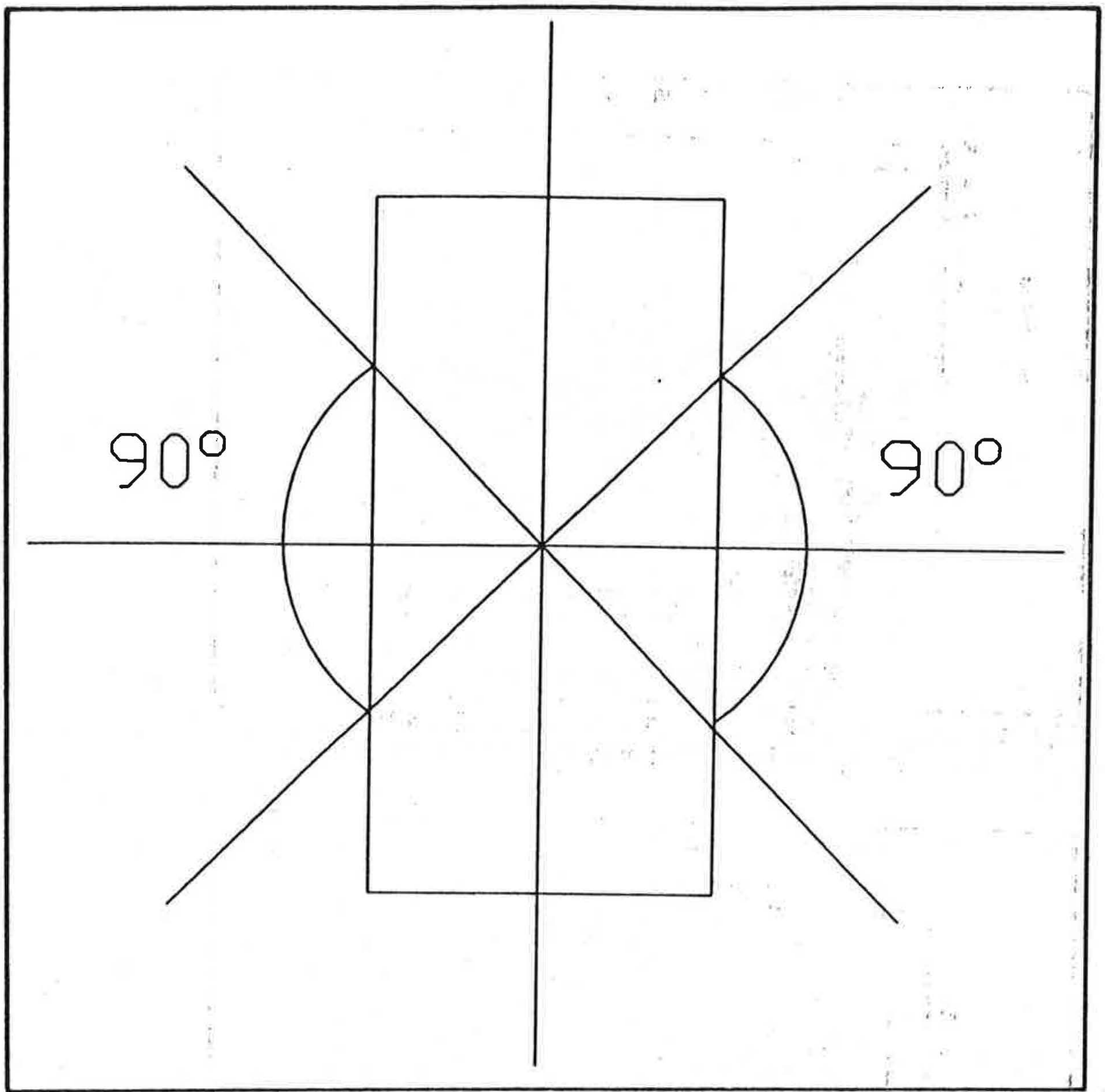

Figure 5. 90° quadrants for building orientation frequency calculations.

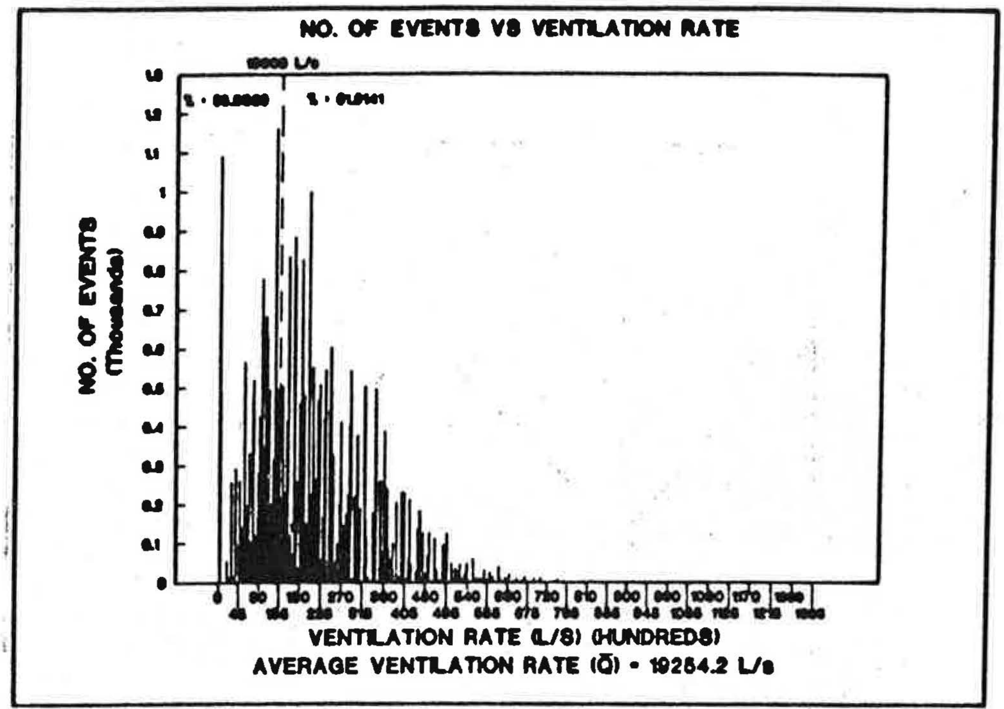

Figure 6. Frequency histogram for Ottawa region, temperature ≥ 20°C, building orientation 60°.

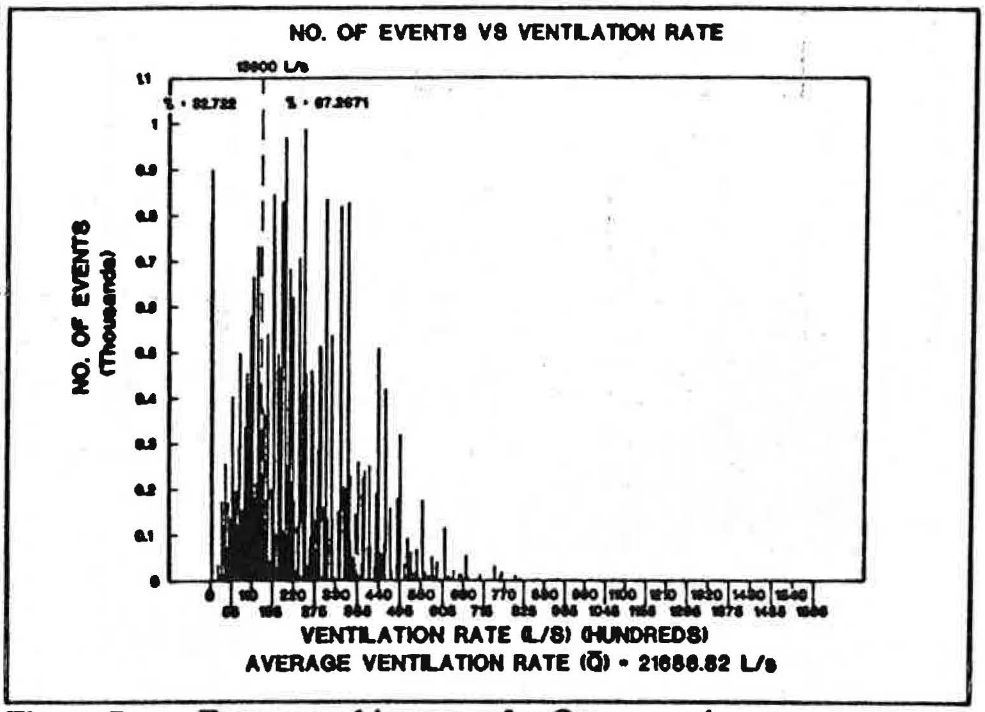

Figure 7. Frequency histogram for Ottawa region, temperature ≥ 20°C, building orientation 150°.

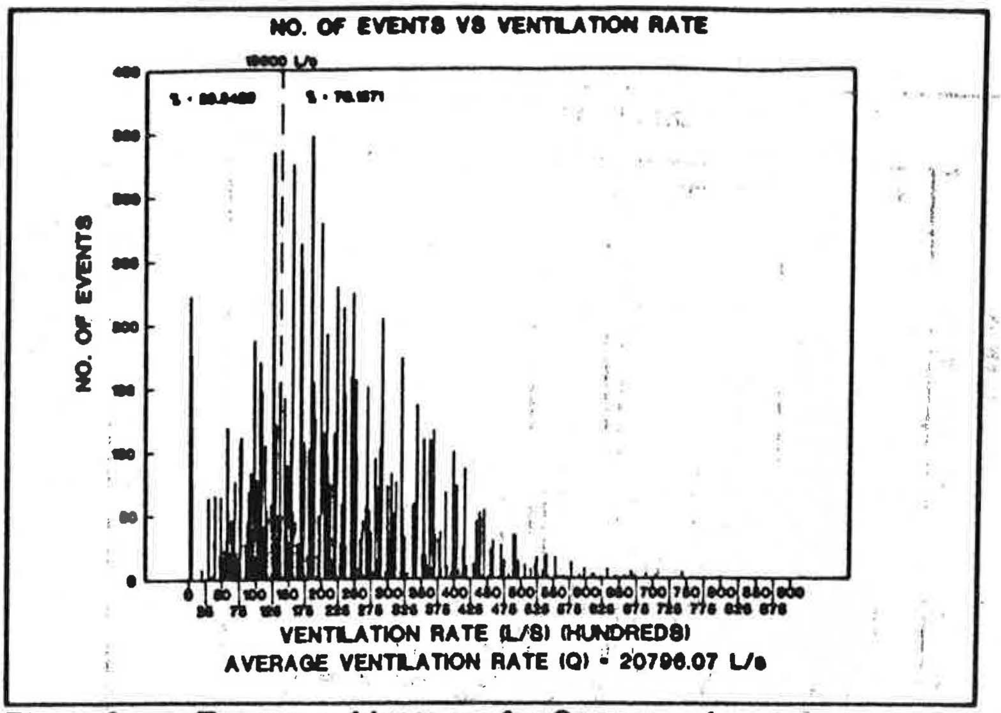

Figure 8. Frequency histogram for Ottawa region, temperature ≥ 25°C, building orientation 60°.

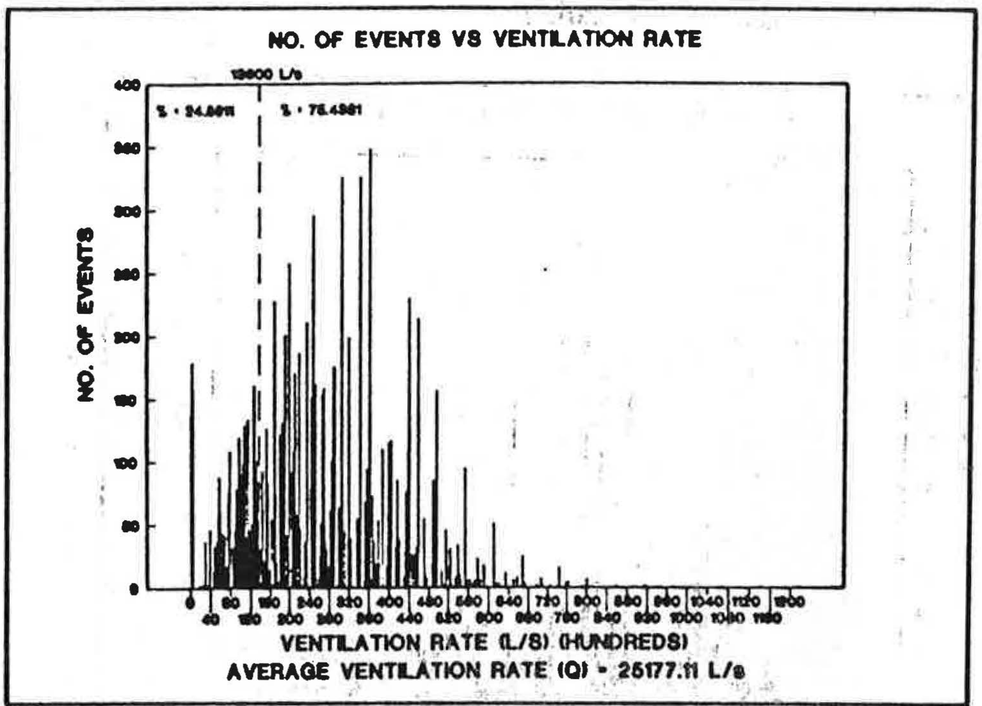

Figure 9. Frequency histogram for Ottawa region, temperature ≥ 25°C, building orientation 150°.

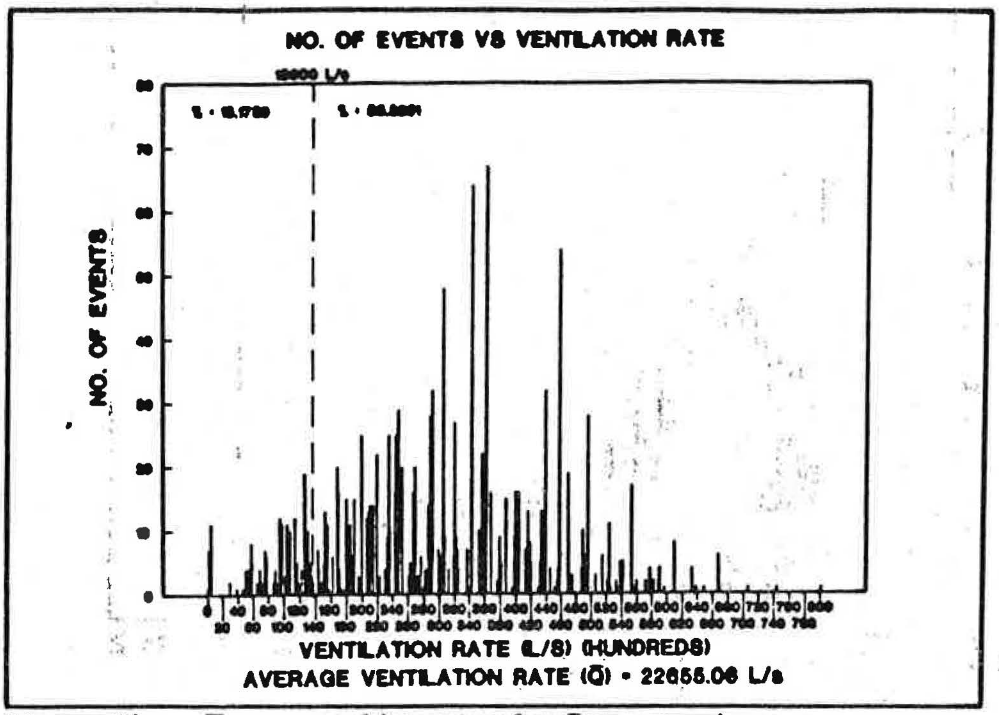

Figure 10. Frequency histogram for Ottawa region, temperature ≥ 30°C, building orientation 60°.

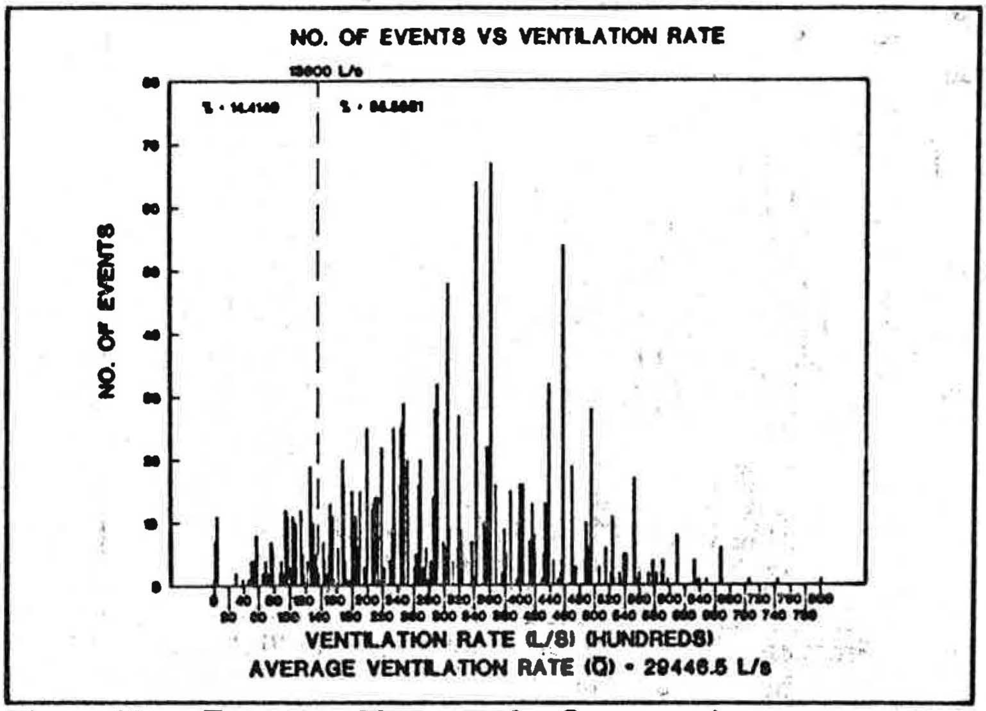

Figure 11. Frequency histogram for Ottawa region, temperature ≥ 30°C, building orientation 150°.

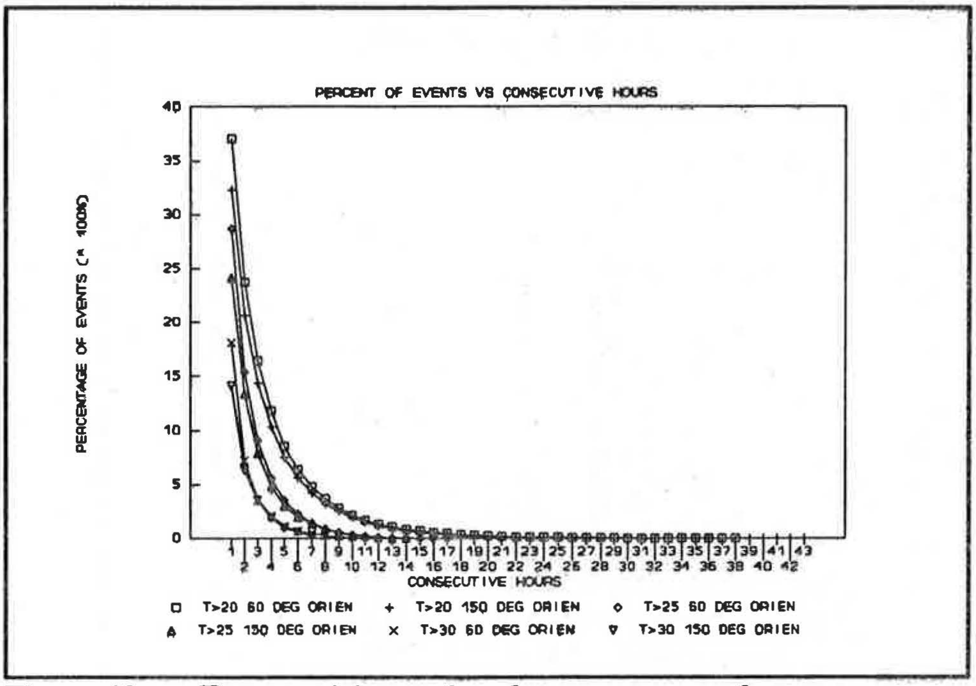

Figure 12. Exponential graph of percentage of events versus consecutive number of hours for Ottawa region.

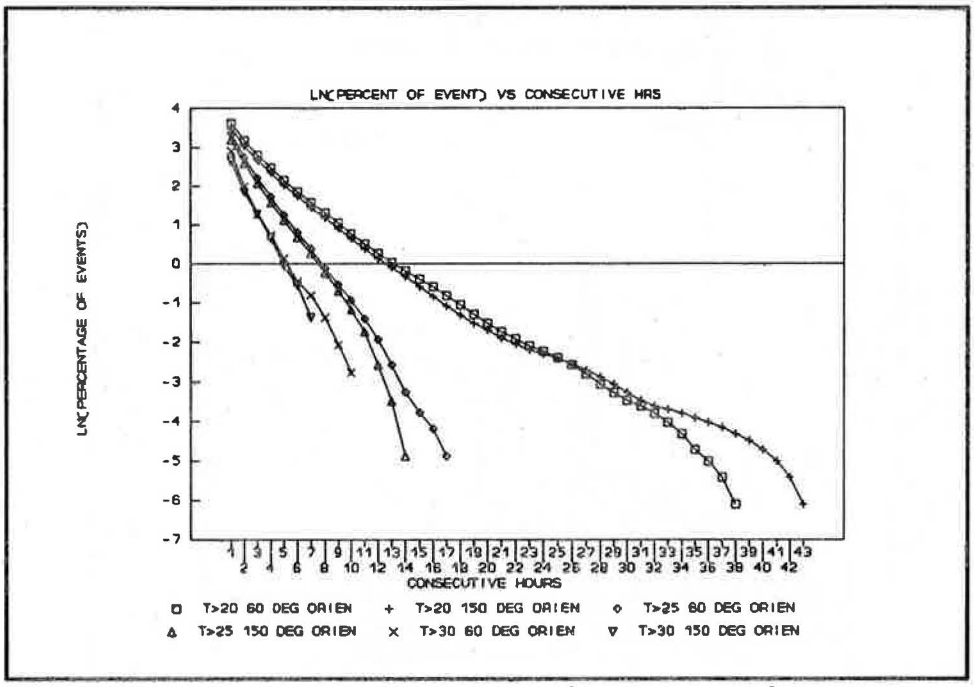

Figure 13. Natural logarithm graph of percentage of events versus consecutive hours for Ottawa region.