PREFERRED BUILDING ORIENTATION

FOR NATURALLY VENTILATED BUILDINGS

by

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ABSTRACT

Determining optimum building orientation for naturally ventilated buildings is an important concept. Obtaining the optimum orientation will determine the success of the performance of a naturally ventilated building.

This project deals with obtaining the preferred building orientation for 10 regional weather stations across the province of Ontario. Different methods were utilized to obtain the preferred building orientation: the average ventilation rate method, the percentage of ventilation rates above and below the minimum summer ventilation rates, and the consecutive hours method, ie. the number of weather events that are below the minimum summer design ventilation rate for a specific building configuration. The analysis involves six building orientations (0°, 30°, 60°, 90°, 120°, and 150°) with respect to North, and exterior temperatures greater than or equal to 20°C, 25°C, or 30°C.

Optimizing building orientation, to minimize the number of weather events where the ventilation rates are below the summer design ventilation rate is the general goal of this research work.

A statistical analysis was carried out based on the results obtained from the data for the frequency of ventilation rates versus the ventilation rates below the summer design ventilation rate, for all 10 Ontario weather stations, for temperatures greater than or equal to 20°C, and all six building orientations. The output of the statistical analysis showed that for the above mentioned temperature range, that there is a relationship between the ventilation rates below the design summer ventilation rate and building orientation.

RÉSUMÉ

Déterminer l'orientation maximale d'un bâtiment en fonction de la ventilation naturelle des bâtiments demeure un concept important. En obtenant une orientation maximale celle-ci déterminera le succès de la performance de la ventilation naturelle d'un bâtiment.

Ce projet traîte sur la façon d'obtenir la meilleure orientation d'un bâtiment en fonction de dix stations météorologiques régionales situées à travers la Province de l'Ontario. Differentes méthodes furent utilisées afin d'obtenir une meilleure orientation: la méthode pour obtenir un degré moyen de ventilation, la fréquence de la ventilation versus les degrés de ventilation et la méthode des heures consécutives, ie. le nombre de cas qui se situe sous le taux minimum de ventilation en rapport à une ventilation estivale pour une configuration spécifique d'un bâtiment. Les analyses comprennent six orientations de bâtiment (0°, 30°, 60°, 90°, 120°, et 150°) en rapport avec le nord, et les températures extérieures équivalentes ou au dessus de 20°C, 25°C, ou 30°C.

Maximiser l'orientation d'un bâtiment, afin de minimser le nombre de cas où les taux de ventilation sont inférieurs au taux de ventilation estivale proposé est le but générale de cette recherche.

Une analyse statistique a été faite et basée sur la fréquence des taux de ventilation versus le taux de ventilation minimum requis en été pour toutes les dix stations météorologiques de l'Ontario, pour des températures au dessus ou égales à 20°C et les six orientations de bâtiment. Le rendement de l'analyse statistique démontre, pour les différentes températures ci-haut mentionnées, qu'il y a un lien certain entre les taux de ventilation qui se situent au dessous du taux minimum de ventilation requis en été et l'orientation d'un bâtiment.

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A	- total effective areas of openings, m^2
A_j	- area of the opening j
Cd_j	- discharge coefficient of the jth opening
Cp_i	- internal pressure coefficient
Cp_j	- pressure coefficient at any point j, Pa
C_Q	- coefficient of ventilation efficiency
E_{ij}	- expected frequency, ij
g	- acceleration due to gravity, 9,8 m/s^2
h	- height from inlets to outlets, m
O_i	- observed frequency, i
P_{static}	- static pressure of undisturbed airstream, Pa
P_{tap}	- measured pressure at each tap, Pa
ΔP_j	- pressure difference across the jth opening
Q	- ventilation rate, L/s
Q_j	- ventilation rate through the jth opening
T_i	- inside temperature, K
T_o	- outside temperature, K
V	- external wind speed, m/s
V_{ref}	- reference wind speed, m/s
θ	- ratio of flow with heat and friction losses to theoretical flow, usually = .3 - .5

ρ - air density, 1.2 kg/m^3

χ^2 - chi-square variable

1.0 INTRODUCTION

Modern farm operations are becoming more and more costly, because of the competition which exists in agricultural production. Farmers are now searching for more cost efficient means of operating their farms while decreasing their overhead costs. One such method is the use of natural ventilation in livestock housing. Natural ventilation dates back to early civilizations. The application of natural ventilation techniques has been observed about 2000 B.C. under the 12th dynasty in ancient Egypt, Aynsley et'al. (1977). The design of early canadian settlements were also influenced by natural ventilation especially during the harsh winters. It can also be presumed that early livestock shelters were built using natural ventilation concepts and that these concepts have been improved over the years until the recent introduction of electrical power in the agricultural field, Barrington (1991).

Today, energy suppliers such as Ontario Hydro, for example, who produce power via thermal or hydrological processes, are studying ways and means of reducing the demand within the agricultural sector. The ventilation of farm buildings is one area which has drawn interest. The gradual replacement of mechanical ventilation by natural systems will be cost beneficial to the farmer in that energy consumption will be reduced. The energy supplier will also benefit, in that it will reduce the demand for electricity in this field, and redistribute this energy elsewhere.

Natural ventilation can be adapted to various types of livestock buildings such as beef, dairy, horse, poultry, sheep , and swine. For swine operations, natural ventilation is not recommended in farrowing and in nursery units, because winter ventilation rates cannot be adequately controlled, Choinière et al. (1988). Nevertheless for growing and finishing pigs, wider temperature fluctuations can be tolerated and naturally ventilated systems are quite adequate.

Natural ventilation also falls within the concepts of sustainable agriculture since sustainable agriculture requires a minimum amount of energy input to produce maximum outputs. Natural ventilation can easily fulfil this requirement since there is practically no energy needed to operate the system. It has been noted that a dairy farmer could annually save $12.00/cow (at $0.10/Kwh) using natural instead of mechanical ventilation, Choinière and Munroe (1990). Furthermore, natural ventilation systems require less energy and are quieter than mechanical ventilation systems.

Natural ventilation is governed by the wind forces and by the thermal forces of the air inside the building, Aynsley et al. (1977), Bruce (1977), Vickery et al. (1983), DeShazer et al. (1988), and van't Ooster and Both (1988). Because natural ventilation is powered mainly by the wind, especially during the summer, proper building orientation is important if maximum ventilation rates are to be met most of the time.

Emphasis will therefore be placed on optimizing building orientation with respect to summer ventilation rates using natural systems.

1.1 Objectives

Using the meteorological data obtained from Environment Canada, a prediction model was conceived and used to simulate ventilation rates for a naturally ventilated agricultural building positioned at various orientations. The meteorological data are from

10 weather stations of the Province of Ontario, and cover a period of 30 years. Because the project was limited to summer ventilation, the weather selected corresponded to conditions during which the temperature was within the following ranges: greater than or equal to 20°C, 25°C, and 30°C. The ventilation rate prediction model was based on air inlet discharge coefficients obtained through wind tunnel experimentation and varying according to the wind angle with respect to the building orientation. From the ventilation rates obtained for the various building orientations, the effect of building orientation versus ventilation rates below the summer design rate was analyzed to obtain the preferred building orientation for all 10 locations, and for temperatures greater than or equal to 20°C.

In order to achieve this main objective the following sub-objectives were introduced:

1- To develop a methodology to use meteorological data during the summer for simulating the ventilation rate for natural ventilation of buildings.

2- To analyze the effect of temperature-related wind events and building orientation on the average ventilation rates as design tool for obtaining the preferred building orientation.

3- To analyze the effect between building orientation and the frequency of ventilation rates below and above the minimum summer design ventilation rate for temperatures greater than or equal to 20°C, 25°C, and 30°C.

4- To study the effect of temperature-related wind events and building orientation on the frequency of consecutive hours when the minimum ventilation rates were below the minimum design summer ventilation rate and to graphically represent the number of consecutive hours.

5- To determine statistically if there is a relationship between building orientation and the frequency of ventilation rates below the minimum summer design ventilation rate via the use of SAS (Statistical Analysis Software).

1.2 Scope

This research project will be limited by the following:

1) the meteorological data analysis is limited to 10 weather stations across the province of Ontario, for temperatures greater than or equal to 20°C, 25°C, and 30°C.

2) the computer model was based on ventilation coefficients developed by Choiniére (1991) through wind tunnel testing.

3) the data used to compute the analysis was obtained from weather stations located in open land areas with no obstructions which is typical of rural areas. These stations are in zones affected by different typical weather regimes and may not necessarily reflect the wind patterns of their region.

4) the ventilation coefficients pertained to a natural ventilation barn of the style identical to the federal plan M-9760 (CPS 1990).

5) the statistical analysis is limited to temperatures greater than or equal to 20°C due to the limitations of Statistical Analysis Software (SAS).

2.0 LITERATURE REVIEW

2.1 History of Natural Ventilation

The concern for wind effects on and around buildings dates back to early civilizations. The planning and design of many ancient villages was influenced by wind effects, Vickery et al. (1983). The application of natural ventilation techniques has been observed in the remains of the town of Kahan, founded about 2000 B.C. under the 12th dynasty in Ancient Egypt. The layout of the town consisted of dividing the town in two sections: the peasants' district in the west, where they lived in small houses and were exposed to the hot desert wind; and the higher class section lived in the north district where people lived in larger houses facing the pleasant north winds.

Early Canadian settlements were also influenced by natural ventilation especially during the winter, Aynsley et al. (1988). Houses near high ridges were sited on the southern side, for protection from the cold northerly winds. More exposed houses on the prairies had doors on the south side to avoid the strong north wind.

The concept of natural ventilation is as old as agricultural buildings. During the early twentieth century, natural ventilation systems consisted of door inlets at the upper level of the walls and of chimneys extending from the ceiling up through the hay loft and the roof. The fresh air would enter through the wall inlets and be drafted through into the long chimneys. The design of natural ventilation systems at this time was mainly based on air buoyancy forces developed through winter temperature differentials, Barrington

(1991).

With electricity becoming more available, farmers were introduced to mechanical ventilation systems. These systems provided more constant ventilation conditions and better air exchanges, probably as a result of poor natural ventilation design, Barrington (1991). But now with increasing energy costs, more environmental awareness and the technological advancements as well as the research that is occurring in the field of natural ventilation, farmers are once again opting for natural ventilation systems.

2.2 Ventilation Systems

Ventilation in livestock facilities is a process of controlling several environmental factors by diluting inside air with fresh outside air. Ventilation systems affect:

1- Air temperature

2- Moisture level

3- Moisture condensation on surfaces

4- Air temperature uniformity

5- Air speed across animals

6- Odour and gas controls

7- Airborne dust and disease organism level

8- Combustion fumes from unvented heaters.

Ventilation systems from an agricultural perspective provide the following advantages for livestock buildings, Gaze (1986):

1- An ideal environment for the animals being housed in the facility, ie. bringing in oxygen to sustain life;

2- Removal of products of respiration e.g. carbon dioxide;

3- Adequate dilution of the odours, gases, and the moisture levels in the facility;

4- Adequate control of the inside temperature, so that the animals are not under any stress and are able to give high returns to the farmer;

5- Removal of contaminants released by the facility and furnishing materials, e.g. radon, formaldehyde;

6- Provide better working conditions for the farm operator.

2.3 Mechanical Ventilation

Mechanical ventilation used in livestock buildings are basically of two types, being either the exhaust or pressure type, ASHRAE (1977), Hellickson and Walker (1983). The exhaust type focuses on drawing the air from within the facility, via fans, to the exterior of the building. The exhaust system is the most popular of the two types. Figure 1 displays one type of exhaust system for buildings that have insulated ceilings. Here the fresh air enters through openings in the gables located in the attic. The air is tempered in this location and then drawn into the building through a continuous slot next to the wall opposite the fan, as shown in Figure 2. After the air passes through the slot it is mixed with the warmer air in the facility and moves slowly across the building to be exhausted by the fan as displayed in Figure 3. During the summer, (temperatures between inside and outside temperatures of 1°C to 3°C. There are cases where the fan air flow is high enough that air displacement in the barn can create 0.5 m/s to 1.0 m/s air velocity around the animals in the building.

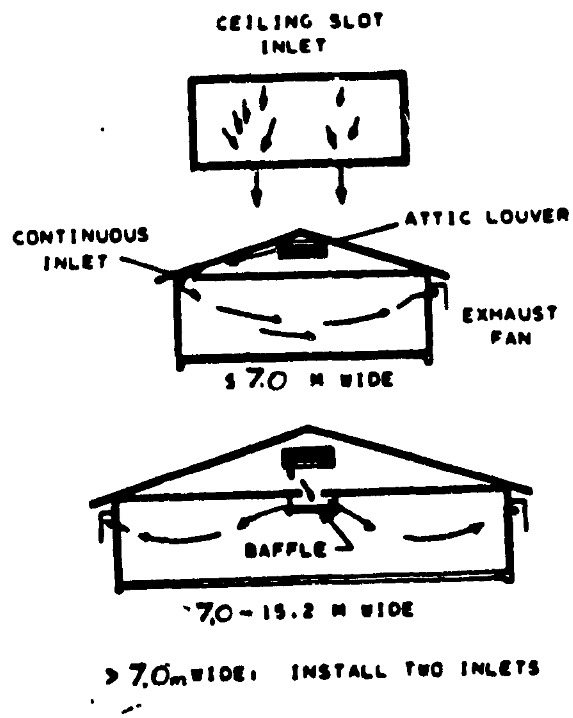


Figure 1 Eave and center ceiling inlets for exhaust systems.

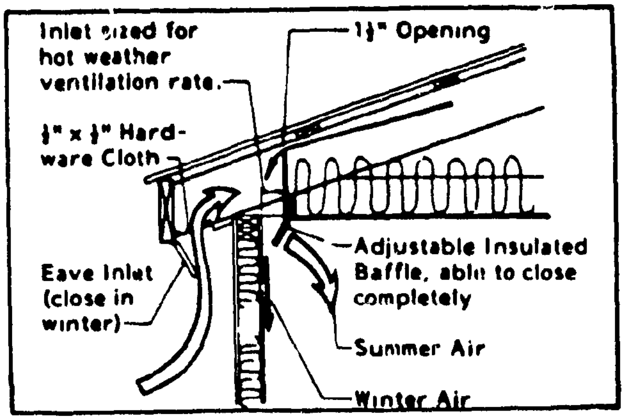


Figure 2 Slot eave inlet for summer and winter use.

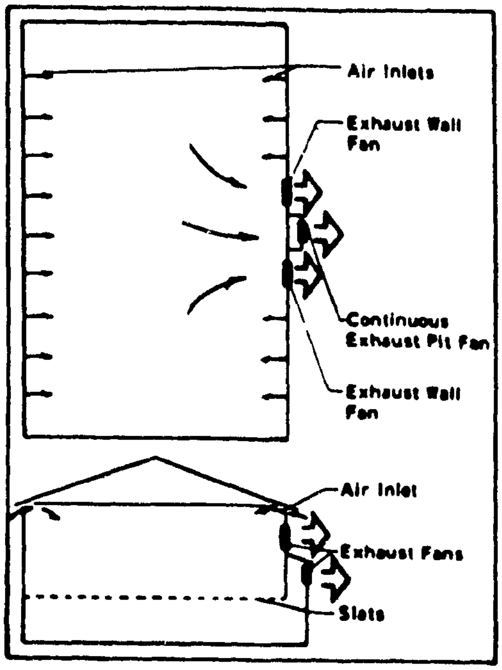


Figure 3 Air movement in exhaust type system.

The location of fans depends upon the size of building, and the type of livestock being housed within the facility, ASHRAE (1977)

The size and number of fans required for a building depends on the maximum amount of air needed to adequately ventilate the interior of the building per each animal unit, Hellickson and Walker (1983). Fans can be one speed, two speed, variable speed, or one fan with a motor controlled shutter, depending on the budget and needs of the farmer.

Air inlets are required for all types of ventilation, including mechanical ventilation, Chandra et al. (1986). Opening doors and windows in addition to the mechanical system should be discouraged because this will result in poor air distribution within the facility during the summer and in the winter can produce serious drafts, Chandra et al. (1986). An air inlet is usually a continuous slot 2.5 cm to 3.8 cm wide in the ceiling, usually next to the wall. It is recommended that for every 472 L/s total fan capacity for maximum winter ventilation, there should be 3.65 m of slot opening. The slot inlet should be located away from the fan at a recommended distance of 4.5 m, Barre et al., (1987). For buildings wider than 7 m, more than one wall slot inlet should be installed to maintain adequate levels of air recirculation, moisture levels, and odour and gas levels. Inlets should also have adjustable openings because different climatic conditions require different size openings.

2.4 Natural Ventilation

2.4.0 Natural Ventilation Systems

Natural ventilation is the movement of air through specific openings resulting from the natural forces produced by temperature differences and wind. The ventilation rate depends on the wind speed and direction, interference of nearby obstructions such as hills or buildings and the size, design and location of outlet and inlet openings. Natural ventilation differs from mechanical ventilation in that the latter requires a mechanical energy input to produce the pressure differential necessary to cause air flow, Hellickson and Walker, (1983).

2.4.1 Natural Ventilation Forces

Naturally ventilated buildings depend upon thermal and wind forces, ASHRAE (1977), Shoda (1951), Caudill et al. (1951). Whereas thermal or buoyancy force predominates during the cooler season, the wind is the main ventilation force in the summer, Shoda (1951). This project will mainly deal with the wind effects because it is concerned with the optimizing building orientation for summer ventilation, though the other effect will be briefly discussed.

2.4.1.1 *Wind Forces*

The flow of air around a building caused by the wind creates pressure gradients between surfaces i.e. transfer of dynamic pressure into static pressure head, Vickery et al. (1983). It is basically the velocity of the wind which determines the magnitude of the pressure exerted on the exterior of a building, Hellickson and Walker (1983). The pressure may be of three types:

1) Positive pressure (generally on the windward side); this pressure pushes air into the building via the sidewall openings.

2) Negative pressure (generally on the leeward side); this pressure sucks air out of the building via end wall, sidewall, and/or ridge openings.

3) Neutral pressure where there is no air movement.

The static pressure which develops over the roof will depend on the kind and style of roof, Hellickson and Walker (1983). Also, pressure effects will depend on the building orientation with respect to the wind direction.

2.4.1.2 *Prediction Model Based on Wind Forces*

The effect of the wind force in moving air through a building varies with the prevailing wind direction, the wind speed, seasonal and daily variation in velocity and direction, local obstructions, and changes in land topography. ASHRAE (1981,1989), Aynsley et al.(1977), Krishnakumar et al. (1985), 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 openings, or if the opening areas are known and one wants to obtain the ventilation rate, the previously mentioned authors presented a simple prediction model for natural ventilation:

$$Q = C_Q \times V \times A \tag{1}$$

where

Q = ventilation rate, L/s

C_Q = coefficient of ventilation efficiency

V = external wind speed, m/s

A = total effective areas of sidewall openings, m^2

The application of the coefficient C_Q to the natural ventilation prediction model, is a method which is used by designers to calculate the ventilation rates of any structure, ASHRAE, (1981), Hellickson and Walker (1983). 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 of the opening , C_d, and the internal and external pressure differences depending on the wind angle, Choiniére, (1991). ASHRAE (1981) and Hellickson and Walker (1983) proposed that C_Q values vary depending upon the wind direction. Also Etheridge and Nolan (1979), Vickery et al. (1983), Vickery and Karakatsanis (1987) and Krishnakumar et al. (1985) stated that any change in the ridge or sidewall opening areas would generate a new C_Q curve.

2.4.1.3 *Prediction Models Based on Thermal Forces*

Thermal forces or thermal buoyancy forces can be considered as being complementary to wind forces in providing air exchange through naturally ventilated buildings. Thermal buoyancy is referred to as being the action of warm air, produced primarily by the animals housed in the facility, rising to the ceiling of the facility and exiting via chimneys in the roof to the outside and replaced by cool air entering at low openings Bruce, (1977, 1978); Hellickson and Walker (1983). This is where thermal buoyancy is also referred to as chimney or stack effect. When the temperature inside the building is significantly higher than outside conditions, and also in the case where that there are negligible wind forces, thermal forces must be relied upon entirely, Munroe and CHoiniére (1986). The ventilation rate due to the thermal forces can be calculated as follows, ASHRAE (1977); Hellickson and Walker (1983):

$$Q=A\times\theta\times(2\times g\times h\times(T_i-T_o)/T_i)^{1/2} \tag{2}$$

where

- Q = ventilation rate, L/s
- θ = ratio of flow with heat and friction losses to theoretical flow, usually = .3 to .5
- g = acceleration due to gravity, 9.8 m/s^2
- h = height from inlets to outlets, m
- T_i = inside temperature in degrees, K
- T_o = outside temperature in degrees, K

2.4.2 Required Openings Used for Natural Ventilation

The design of inlets and outlets is critical to naturally ventilated buildings, ASHRAE (1977), Bruce (1975, 1978), Warren and Webb (1988). Openings in the sidewalls may function as air inlets or outlets depending on the wind direction and exterior temperature, Bruce (1978).

Ridge openings or chimneys are located in the roof and usually act as an outlet only, Bruce (1978). During the coldest days of the year, when the sidewall openings are likely to be completely closed, a minimum ridge opening should be maintained to allow for some ventilation within the facility, Choiniére and Munroe (1990). This practice maintains low ventilation rates while drawing fresh air in a random fashion because of the lack of air tightness of the building, Bruce (1978).

2.4.2.1 *Sidewall Openings*

There are two types of sidewall openings shown in Figure 4. These inlets are used with automatically controlled naturally ventilated warm buildings, Munroe and Choiniére (1986). These openings may be panels that are opened and closed by sliding vertically or the openings may be doors rotating about the inlet. These doors are typically distributed over the full length of both sides of the barn, and generally measure 1.2 m in height, but this dimension can vary depending on the type of building, the door or panel style, the local climate, and the livestock housed, Munroe and Choiniére (1986).

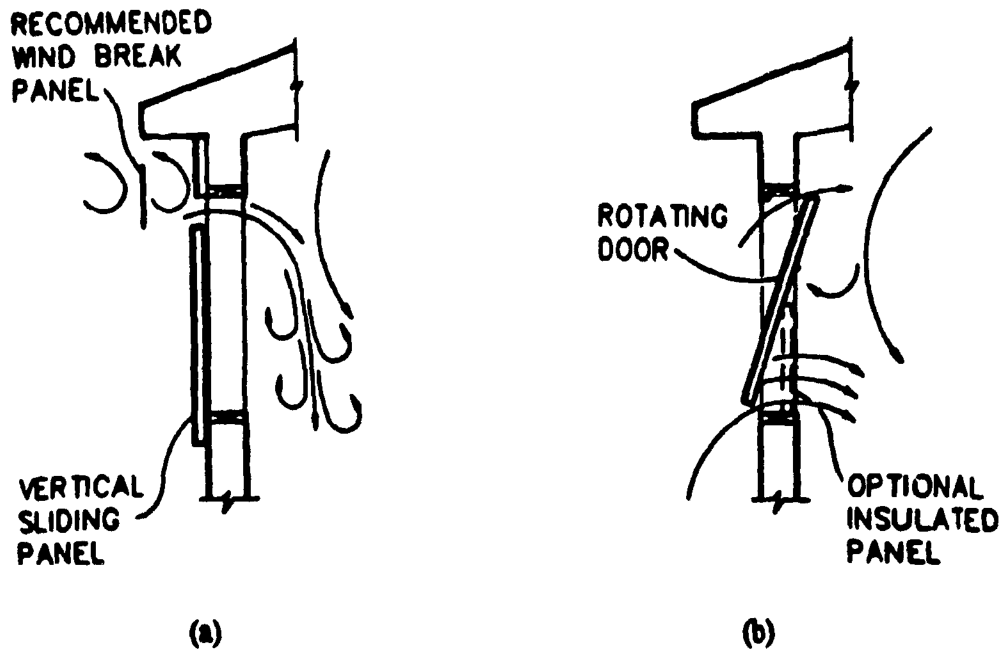


Figure 4 Type of sidewall openings used in a naturally ventilated agricultural building: (a) vertically sliding panels, (b) rotating openings.

2.4.2.2 *End Wall Openings*

It is highly recommended to install adjustable openings in both end walls of the building, Bruce (1978). When the wind is blowing parallel to the building, zones of poor air circulation or stagnation can develop near the ends of the barn, Munroe and Choiniére (1986), Bruce (1978). End wall openings improve air circulation in these areas.

End wall openings are operated manually during the summer and closed for the remainder of the year, Munroe and Choiniére (1986). A typical installation would be tow windows, each 0.9 x 1.8 m, located approximately 2.4 m from the sidewalls as illustrated in Figure 5.

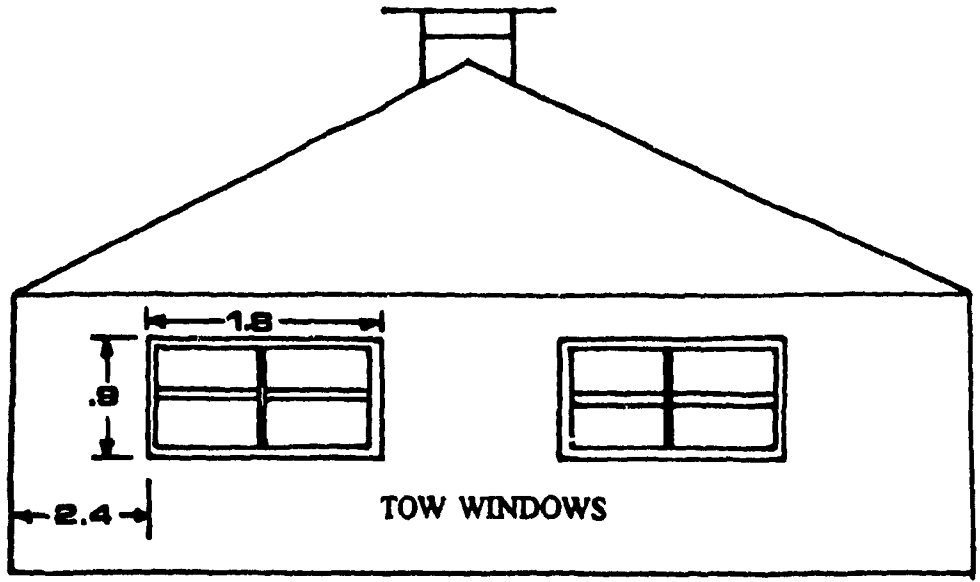
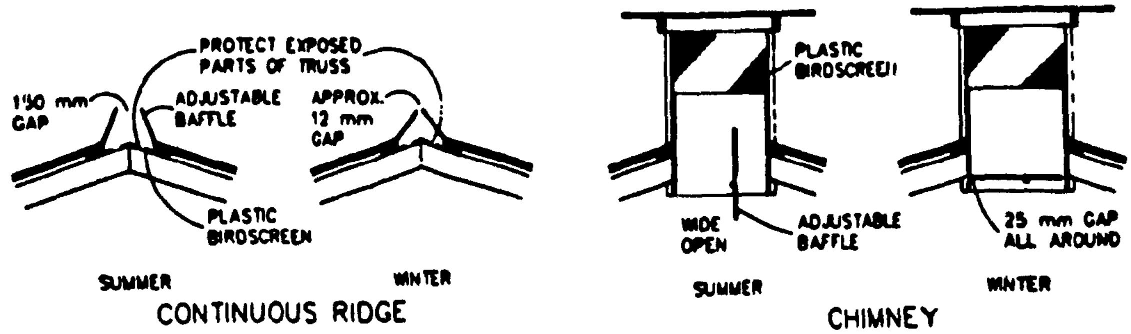


Figure 5 End Wall openings.

2.4.2.3 *Ridge Openings*

Previous research done by Choinière (1989), has proven that the use of a large ridge opening does not present any advantage over a small ridge opening provided sidewall opening area is available for warm summer conditions. Instead of a continuous ridge, the use of intermittent chimneys, like those shown in Figure 6 , is now recommended, Munroe and Choinière (1986). For conventional finishing hog buildings and dairy barns this could be typically 0.6 x 0.6 m chimneys 7.2 m apart to maintain adequate air circulation within the facility.



(a) (b)

Figure 6 Types of roof openings (a) continuous ridge (b) chimney openings

The use of the chimneys presents many advantages over the continuous ridge opening, Munroe and Choiniére (1986). It reduces material as well as construction costs and eliminates any problems of deterioration to the structure of the building, Choiniére (1991). Chimneys are also more convenient for restricting birds entering the building. The hood or cap over the chimney eliminates most of the rain and snow infiltration into the building, Choiniére (1991).

The chimneys should be fully open during warm weather and left partially opened when the average daily temperatures are below the 5 to 10°C range, Choiniére (1991). In Ontario for example, this would typically involve opening the chimneys in

May and partially closing them in September, however this may vary depending upon local climatic conditions. Throughout the year, the automatic control system will take care of opening or closing the large sidewall openings in order to maintain an ideal temperature inside the barn, Choiniére (1991).

2.4.3 Automated Operation of Inlet\Outlet Openings

Airflow requirements or ventilation rates vary with the size of the animal and outside environmental conditions. Naturally ventilated buildings must receive sufficient air to maintain air quality in cold weather conditions as well as maximize airflow rates in the summer to reduce the risk of animal heat stress, Choiniére (1991). Also systems should be designed to prevent birds, rodents and any other undesirable animals coming in contact with the livestock, Choiniére (1991). A demonstration of naturally ventilated systems, meeting such requirements will be discussed in the following section. They will illustrate different ridge and sidewall configurations.

Potential use of automatic control systems is viable in areas where the daily temperatures continually fluctuate. An automatic control system for natural ventilation is one where a thermostat regulates the inside air temperature by opening or closing the sidewall panels according to a selected or targeted temperature, Choiniére et al. (1987); Mitchell and Ross (1977); Ström (1987). For example, during the winter in a warm barn or a very well insulated barn, with an RSI value of 3.5 with a target temperature of 8°C and ±2°C, the thermostats would activate the system to open the panels if the temperature were to rise above 10°C and close the panels if the temperature dropped below 6°C, Choiniére et al. (1987); Milne (1983). Most automatic systems use a timer and there will be a time delay of approximately 3 to 4 minutes to readjust the panels in the case of a temperature fluctuation of ±2°C. Thus the system remains active long enough each time to move the vertical panels if adjustment is necessary to obtain the targeted temperature desired in the building. In a modified environment barn, ie. lightly insulated barn with an RSI value of 0.9, the system would likely be inoperative when the average outside temperature is below -15°C or -10°C, Choiniére et al. (1987). In this case the air temperature within the building would remain at a constant level with reference to the type and number of animals housed, and the size of the building. During this period the sidewall panel would remain at a minimum permanent opening, depending on the type of barn, and also the type of animal being housed within the facility, Choiniére et al. (1987). In a cold barn or an uninsulated barn (RSI of 0.2), the automatic control system would generally remain inactive, meaning the panels would remain closed during January and February due to the extreme cold conditions. The chimneys or ridge opening would act as both the inlet and outlet and remain at a specific opening size to allow moisture, odours, and gases to escape. The panels would remain open during most of the months of June, July and August due to the hot weather conditions. On the other hand the system would remain active during September, October, November, March, April, and May since during these months there are wide temperature fluctuations during a 24 hour period, Choiniére et al. (1987). In each of the three types of buildings the automatic control system can also be overridden by performing manual adjustments. The energy needed to operate the automatic control system is minimal. If a power failure should occur, due to the minimal amount of power needed to operate the system, a battery can be used as a standby generator for the system.

2.4.4 Seasonal Changes In Airflow Patterns

Climatic conditions in many areas in Canada can be basically divided into four temperature ranges: hot (above 20°C), cool (5-20°C), cold (-5 to -15°C), and very cold (below -15°C), Choiniére and Munroe (1990). Airflow patterns within a naturally ventilated building will differ within each of the temperature ranges due to the different ventilation rates required which is directly influenced by size of the openings. Temperature distributions and airflow patterns within the animal facility during each of the four seasons are shown in Figure 7.

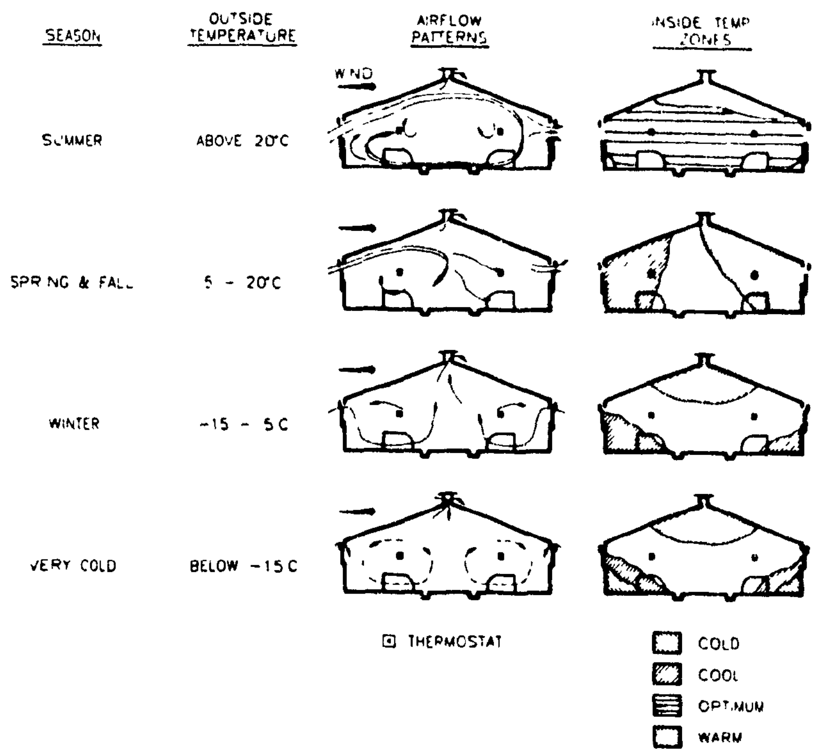


Figure 7 Temperature distributions and airflow patterns in the animal facility for the four different seasons.

2.4.4.1 *Hot (Summer) - Exterior Temperature Above 20°C.*

When the exterior temperature is above the interior temperature the sidewall openings are opened to their maximum. This allows for large volumes of air to enter the facility via the windward side of the building simply due to the wind forces. Since there is very little difference between the exterior and interior temperatures, thermal buoyancy effects are negligible during these periods, Choiniére and Munroe (1990). The incoming air flows across the ceiling and mixes with the inside air, and recirculates toward the windward side near floor level. Animals which are housed within the facility will opt to lie in the areas where there is maximum air circulation.

2.4.4.2 *Cool (Spring, Fall) - Exterior Temperature Range of 5 - 20°C.*

Most animals that can be housed in warm, naturally ventilated buildings perform best in a temperature range of 10 to 20°C, Choiniére (1991). When, for example, the exterior temperature drops below the interior targeted temperature the automatic control system will automatically adjust the opening of the sidewall panel. As a result the volume of air entering the facility will likely reduce, and the airflow pattern will not be the same as for hot summer condition, Choiniére and Munroe (1990). The incoming air tends to fall and recirculate partway across the building. The temperature of the incoming air is slightly cooler than the ambient temperature within the building, but not cold enough for the air to drop immediately upon entering.

2.4.4.3 *Cold (Winter) - Exterior Temperature Range 15 - 5°C.*

The size of the sidewall opening is very small and as a result the wind will have less of an effect in ventilating the building, since the volume of air entering the building is greatly reduced, Choiniére and Munroe (1990). During this period, the thermal effect will become more evident as the difference between the outside and inside temperature increases.

As the cold air enters into the facility, it immediately falls to the floor, but because of turbulence, it mixes with the inside air and warms up within an area of 2 to 3 m from the wall. The mixed air then rises slowly towards the ridge openings in the ceiling and also towards the sidewall openings on the leeward side of the facility.

2.4.4.4 *Very Cold (Winter) - Exterior Temperature Below -15°C.*

In this case the sidewall openings are completely closed. Fresh air enters via the ridge openings in the roof. Airflow rates during this condition are low. In some instances an opening can act as both an air inlet and an outlet depending upon exterior wind conditions as well as thermal effect within the facility, Choiniére et al. (1986). The movement of air within the facility depends on thermal effects caused by the incoming cold air and also on the heat generated by the animals, Choiniére et al. (1986).

2.4.5 Building Orientation

Determining the optimum building orientation for natural ventilation is an important step which should not be overlooked. 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, (CPS 1990). Another criterion which influences building orientation is the number of consecutive hours when the ventilation rate is below the minimum required summer ventilation rate required for the type of livestock being housed within the facility. One should not judge the building orientation relying on the average prevailing winds alone. Hellickson and Walker (1983) state that a designer should keep in mind the local climatic conditions, the geography of the area, and past experiences to determine how to maintain adequate ventilation within the facility.

Hellickson and Walker (1983) explain that there are basically two preferred building orientations. The first is an East-West orientation, where in this case the sidewall openings of the naturally ventilated livestock building 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; however this case would permit the hot sun to penetrate in the morning and the afternoon. Consequently, there are problems with both of these orientations. This is why the project deals with positioning the facility at various orientations to determine which orientation would be the preferred orientation. Figure 8 shows the six building orientations used in this research project, with respect to the cardinal coordinates.

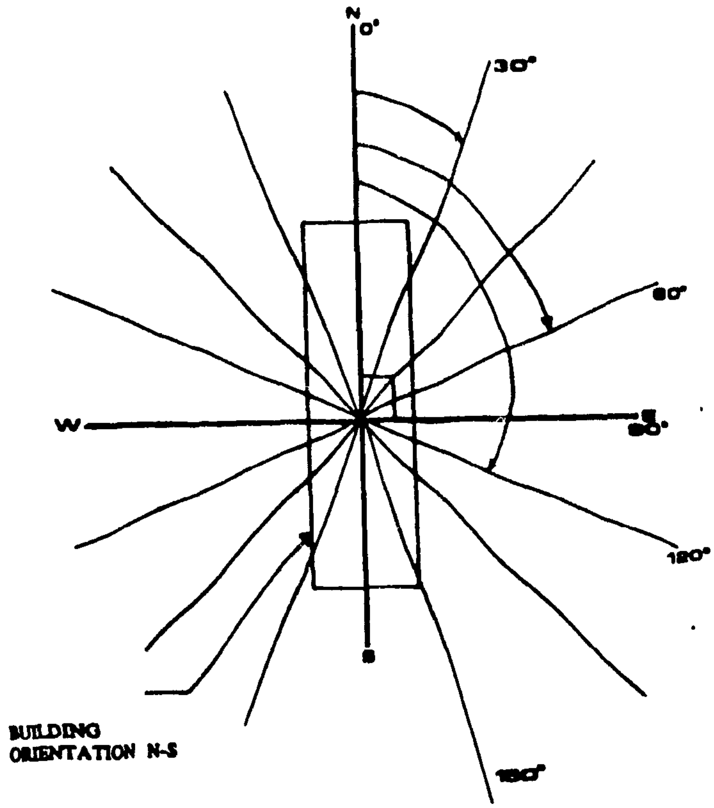


Figure 8. Six building orientations with respect to the North.

2.4.6 Advantages and Disadvantages of Natural Ventilation

The ventilation requirements of livestock buildings are the same for either naturally or mechanically ventilated buildings. Proper ventilation is needed in the summer to prevent excessive temperature rise in the building; the same can be stated for winter conditions to prevent build up of moisture or gas levels. The ventilation requirements are determined by the heat and moisture production of animals. During the summer months, in the mechanically ventilated barns, the ventilation rate is limited by the number and size of fans, while in naturally ventilated barns, the ventilation rate depends upon the size of the sidewall openings, building orientation, wind speed, and the wind direction, ASHRAE (1977). In colder weather, the temperature inside the mechanically ventilated building can be automatically controlled via the use of thermostats, Hellickson and Walker (1983). These are used to turn the fans on or off, and as a result vary the ventilation rate as required. Similarly, the ventilation rate in the naturally ventilated barn can be varied by using thermostats to automatically adjust the size of the sidewall openings, Choiniére et al. (1987). As with mechanical ventilation systems there are advantages and disadvantages in using natural ventilation, as listed below. The advantages and disadvantages listed below are based on different tests done by Choiniére at Brooks barn, Alfred Ontario.

Advantages

1- Reduced operating costs. Since fans are not used, replacement and maintenance of motors, as well as electricity costs are virtually eliminated.

2- Reduced noise levels. Stress levels are lower for both the livestock and the workers. Any unusual animal sounds as well as conversations between workers are easily heard making working conditions safer.

3- Odour test results displayed that, compared to some mechanical systems,there was improved odour and humidity control with the use of naturally ventilated systems. It is important to note that the ventilated system must be properly designed, otherwise poor air quality may develop.

4- Ventilation still functions in the event of a power failure. All openings remain at their settings if the power fails. The panels can be operated manually or, if electricity driven, can be operated with standby power ie battery.

5- Daylight makes these building brighter. This makes them more comfortable to work in.

6- Summer ventilation rates are high. During the summer with any amount of breeze the ventilation rates obtained in naturally ventilated buildings can easily be above one air change per minute due to the size of the sidewall openings.

Disadvantages

1- Birds. They can penetrate into the building and be a nuisance if no bird screens are used.

2- Dripping beneath the ridge opening. No animals should be housed below ridge openings or chimneys since some rain infiltration and/or condensation can occur.

3- More temperature fluctuations in the barn compared with mechanical systems. This can be especially experienced during the winter months.

4- Orientation of the building, and its location relative to other buildings greatly influences wind effects on the ventilation rates.

5- Fluctuations in summer ventilation rates.

2.4.7 Guidelines for Natural Ventilation

There are some basic rules and guidelines which a designer must be aware of when planning a naturally ventilated facility for a farmer, Barre et al. (1987); Milne (1983).

1- Buildings should not be oriented for one particular wind direction, since very few places have a dominant prevailing wind.

2- Inlet openings should not be obstructed by buildings, trees, or any other form of obstructions.

3- Maximum ventilation rates are obtained by using inlet and outlet openings of nearly equal areas.

4- Openings in the proximity of neutral pressure zones are the least effective for ventilation.

5- Opening areas which have been made larger than necessary work well during hot weather conditions. However, this may lead to possible overcrowding of animals near the opening area.

2.4.8 Cost Savings Using Natural Ventilation

A model based on ventilation rates was prepared to evaluate the energy requirements for mechanical ventilation for different types of livestock. Table 1 summarizes the cost per head and energy consumption for mechanical ventilation.

Table 1. Cost per head and energy consumption for mechanical ventilation.

Production	Total Energy		Total Costs	
	per animal produced (kWh)	per group per annum ($kWh \times 10^6$)	per animal produced $	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

A study done by, (Choiniere and Munroe 1990), concluded that for Ontario there is a potential energy savings of approximately 194 million kWh per year if natural ventilation were used instead of mechanical ventilation. This would represent a cost reduction of approximately $9.2 million for Ontario farmers. For swine farmers alone, the savings would be in the range of $4 million.

3.0 THEORETICAL ANALYSIS

There are two methods of obtaining ventilation rates within a naturally ventilated facility. The first is the pressure difference method which utilizes differences between inside and outside air pressures at various openings. The second method is the use of the prediction model based on wind effects. This method relies on the wind speed obtained from weather data, the total effective sidewall opening areas, and a ventilation coefficient which varies according to the wind direction as well as the configuration of the inlet/outlet sidewall opening areas of the naturally ventilated facility. Different configurations in sidewall openings will generate a different ventilation coefficient. Both methods will be discussed, though the prediction model based on wind effects will be the method used in this project to obtain the ventilation rates within the naturally ventilated facility.

3.1 Pressure Difference Method

In order to predict the ventilation rate of a low-rise building, the theory of the pressure coefficient method has been presented by Bruce (1974, 1975, 1977). He proposed a computer program which would calculate the wind-induced ventilation rates for livestock facilities. Brockett and Albright (1987), Down et al. (1985) and Zhang et al. (1988) used the pressure coefficients obtained by Bruce (1977) to produce models for natural ventilation with wind-induced ventilation in addition to thermally induced ventilation. Aynsley et al. (1977) discussed the theory of the pressure coefficient method applied in nonagricultural applications. Aynsley et al. (1977) stated advantages and disadvantages of applying this method. They are:

1)"Ability to make use of the growing sources of wind pressure distribution data associated with load research."

2)"Estimates of natural ventilation made without resorting to the wind tunnel studies while still providing suitable pressure distribution and discharge coefficients are known."

3)"When openings through a building are in excess of 20% of the wall area, it becomes increasingly difficult to determine the effective pressure difference responsible for airflow through the openings from the pressure distribution on solid models."

The first part of the pressure coefficient method described by Bruce (1974,1975,1977), Aynsley et al. (1977), Vickery et al. (1983), Bottcher et al. (1987) and Swami and Chandra (1987) consists of obtaining the external wind pressure coefficient at any point, Cp_j, and is shown in the following equation:

$$Cp_j = \frac{2 \times (P_{tap} - P_{static})}{\rho \times V_{ref}^2} \quad (3)$$

where

Cp_j = pressure coefficient at any point j

P_{tap} = measured pressure at each tap, Pa

P_{static} = static pressure of the undisturbed airstream, Pa

ρ = air density, 1.2 kg/m^3

V_{ref} = reference wind speed

The values of the external wind pressure coefficient that are located around the naturally ventilated building are then applied to predict the ventilation rates according to the various opening areas and the wind angles.

Vickery and Karakatsanis (1987) discussed theoretical estimates of airflow rates can be calculated using the external pressure distribution around the scaled model of a naturally ventilated facility, assuming that:

1)"the internal flow does not disturb the external pressure fields",

2)"the configuration of the external wall openings and internal partitioning is known", and

3)"the flow rates through a given opening can be calculated from the following relationship:"

$$Q_j = Cd_j \times A_j \times (2\times\Delta P_j/\rho)^{1/2} \tag{4}$$

where

Q_j = airflow through the opening j

Cd_j = discharge coefficient of the opening j

A_j = area of the opening, m^2

ΔP_j = pressure difference across the opening j, Pa

ρ = air density, 1.2 kg/m

To obtain the volume of air flowing into and around the facility, the internal pressure coefficient, Cp_i, is required. This value is obtained via computer iterations, based on the assumption that the outflow of air is equal to the inflow of air. The iteration stops when the difference between the predicted inflows and outflows is 0.001 L/s, Suchorski-Tremblay et al. (1990). The relationship is:

$$Q_j = Cd_j \times A_j \times V_{ref} \times \frac{Cp_j - Cp_i}{|Cp_j - Cp_i|^{1/2}} \tag{5}$$

The sign of $(Cp_j - Cp_i)$ determines the direction of the airflow at the j^{th} opening. A positive sign would imply that the flow of air would be inward. On the other hand, if the value is negative this would imply that the flow would be outward. The interior pressure coefficient is assumed to be uniform within the ventilated airspace of the facility, as explained by Aynsley (1977), Swami and Chandra (1987), and Vickery et al. (1983).

3.2 Ventilation Rate Method Based On Wind Effects

The effect of wind force in moving air through a building is dependant on a number of parameters previously mentioned. Examining meteorological data, wind speeds are usually lower in the summer than in the winter, and the wind direction also varies accordingly with seasons, (ASHRAE 1989). The equation used to obtain the ventilation rates by wind forces is:

$$Q = C_Q \times V \times A \tag{6}$$

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 coefficient C_Q varies from .25 to .35 for winds parallel to the building and C_Q varies from .50 to .60 for winds that are perpendicular to the building, Hellickson and Walker (1983).

3.3 Coefficient of Ventilation Efficiency

Suchorski-Tremblay et al. (1990) and Choiniére (1991), developed a computer program to produce coefficients of ventilation efficiency, C_Q values for specific sidewall opening area, versus the wind angles of incidence. This same program was used to generate the C_Q values used in this project. Figure 9 shows the typical C_Q curve for a symmetric building located in open land areas, with sidewall opening area of 17.63 m^2. C_Q values can be obtained for a complete circle, for wind angles from 0° to 360° at one degree intervals.

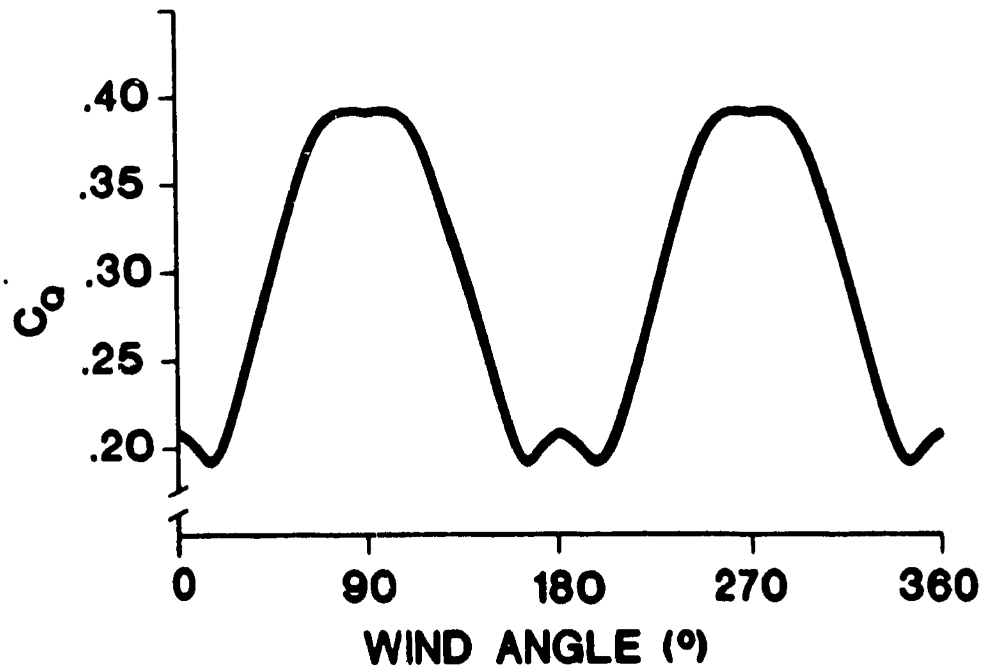


Figure 9 Typical C_Q curve for a symmetric building located in open land areas.

4.0 MATERIALS and METHODS

4.1 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 has a 4/12 slope, with a cathedral ceiling and a 30 cm eave overhang. The building has ten windows on both sidewalls and two windows on both end walls. The sidewall windows remained open to maintain a continuous opening of 80 cm high over the total length of the building. The total area of the sidewall openings represented 27% of the entire sidewall surface. The roof of the building featured four intermittent chimneys, each 60 cm x 60 cm to respect the minimum ridge opening areas suggested by Choiniére et al. (1988, 1989) and Choiniére (1991).

The facility can contain up to 340 hogs, with a given ventilation rate of 40 L/s per hog. The minimum summer design ventilation rate was determined by using the VENT program, designed by the Ontario Ministry of Agriculture and Food to obtain a minimum allowable ventilation rate during the summer 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 minimum summer design ventilation rate was calculated to be 13 600 L/s.

4.2 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. 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. Table 2 displays the weather stations used for Ontario.

Table 2 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. Catherines	2.3
Toronto	34.5
Trenton	34.4
Waterloo	21.4
Windsor	34.5

A set of computer programs were written in quickBASIC 4.5, to sort the weather data according to the three temperature ranges, and also according to the six building orientations previously mentioned. Figure 10 is a flow chart of the computer instructions used in this research project. Appendix A contains the actual programs written in quickBASIC 4.5.

PROGRAM 1: SORTING WEATHER DATA WITH RESPECT TO THE THREE TEMPERATURE RANGES

↓

PROGRAM 2: CALCULATING AVERAGE VENTILATION RATES FOR THE SIX BUILDING ORIENTATIONS AND THREE TEMPERATURE RANGES

↓

PROGRAM 3: CALCULATING VENTILATION RATE FREQUENCIES FOR EACH BUILDING ORIENTATION AND TEMPERATURE RANGE

↓

PROGRAM 4: OBTAINING THE CONSECUTIVE HOURS EVENTS FOR EACH BUILDING ORIENTATION AND TEMPERATURE RANGE

↓

PROGRAM 5: OBTAINING THE MAXIMUM NUMBER OF CONSECUTIVE HOURS FOR EACH BUILDING ORIENTATION, AND TEMPERATURE RANGE

Figure 10. Flow chart of computer programs.

A problem occurred in the computer output, 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 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 is no data for 1 km/h (0 to 1 mph). This rounding and the metric conversions also affected wind speeds ranges, 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 was replaced by an average of 0.5 mph, corresponding to 0.8 km/h (0.22 m/s).

4.3 Ventilation Rate Calculations and Consecutive Hours

Ventilation rates were calculated using for the C_Q versus wind angles of incidence values, and the total area of the sidewall openings using the wind weather data. 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 4.5, where 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.

Frequencies for each 1000 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.

4.4 Average Ventilation Rate Method

Average ventilation rates and their respective standard deviations were obtained for each of 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). The ventilation rates were summed, and the total was divided by the total number of events that occurred for a particular building orientation and temperature range, which gave the average ventilation rate.

4.5 Statistical Methods

A nonparametric statistical analysis via the use of SAS (Statisical Analysis Software) was carried out using the generated ventilation rates below the summer design ventilation rate versus the frequencies of these ventilation rates, for all 10 Ontario weather stations, and for temperatures greater than or equal to 20°C. Appendix B contains a sample SAS program. The analysis consisted of determining if there was a relationship, for the previously mentioned temperature range, between the frequencies of ventilation rates below the minimum summer design rate and the six building orientations, to determine the optimum building orientation.

The SAS procedure that was used was PROC FREQ (procedure frequency). In order to use this procedure a program was written using quickBASIC 4.5 to produce a file that contained ventilation rates below the summer design rate calculated using equation [1], and the frequency of these ventilation rates which are the statistical variables. The PROC FREQ procedure displays the results in tabular form. Horizontally across the top of the table are the six building orientations, vertically are the generated ventilation rates below the summer design rate, and within each cell of the table there are the respective values for the observed frequency, expected frequency, the deviation between the observed and expected frequency, the cell chi-square value, the percent value, the row percent, the column percent, and finally the cumulative column percent.

Only the cell chi-square, percent , row percent, and column values will be discussed in the results, since these values will determine the optimum building orientation.

5.0 RESULTS

Ventilation rates were calculated using the prediction model based on wind forces, for all ten Ontario weather stations, for temperatures greater than or equal to 20°C, 25°C, and 30°C , and 0°, 30°, 60°, 90°, 120°, and 150° building orientations. Due to the limitations regarding the length of the thesis only one weather station will be analyzed in detail to obtain the preferred building orientation. The remaining nine weather stations will be summarized in tabular form, to obtain the preferred building orientation. The weather station chosen at random for the result analysis is the Ottawa weather station.

The results will be presented in four (4) sections:

1) the average ventilation rate method;

2) the ventilation rate frequency curves;

3) the consecutive hour curves and

4) the statistical analysis based on frequencies of ventilation rates below the minimum summer design ventilation rate.

5.1 Average Ventilation Rate Method

A computer program was written in quickBASIC 4.5, where the program would read from the weather data file, the wind speed and the wind direction for each temperature range. The program would also read from another file the ventilation coefficient C_Q, that would correspond to a particular wind direction. For buildings oriented at angles other than 0° (North) correction needed to be made with respect to the wind direction and ventilation coefficient. For example, if a building was oriented at 150° off North and the wind direction was 220°, the corrected wind direction with respect to the building orientation would be 70°, and therefore the ventilation coefficient corresponding to this corrected wind direction would be used. The above mentioned corrected wind direction is obtained by taking the absolute difference between the wind direction and the building orientation. Knowing the effective sidewall opening areas of the building, the ventilation rate can be calculated using the prediction model based on wind forces. Once the ventilation rates have been calculated for each temperature range and building orientation, the rates are summed and divided by the total number of events that occurred within a specified temperature range, and by building orientation, to obtain the average ventilation rate. The standard deviation was also calculated for each temperature range and building orientation. However the standard deviation has no significance in determining the preferred building orientation. Table 3 displays average ventilation rates and corresponding standard deviations, for the Ottawa weather station, for each temperature range, and the six building orientations.

Table 3. Ottawa weather station's average ventilation rates and standard deviations for temperatures greater than 20°C, 25°C, and 30°C for all building orientation angles off 0° North-South.

Building Orientation (Angle off North)	Average Ventilation Rate (L/s)	Standard Deviation
Temperature ≥ 20°C		
0	20 364	13 311
30	19 102	12 428
60	19 237	12 166
90	19 997	12 781
120	21 226	13 478
150	21 668	13 680
Temperature ≥ 25°C		
0	23 057	13 525
30	20 699	11 924
60	20 785	11 730
90	22 399	13 174
120	24 542	14 368
150	25 164	14 375
Temperature ≥ 30°C		
0	27 700	13 368
30	24 190	11 843
60	22 651	10 553
90	23 864	11 853
120	27 377	13 427
150	29 441	13 675

The average ventilation rate for temperatures greater than or equal to 20°C is highest for a building orientation of 150° off North. For temperatures greater than or equal to 25°C, the average ventilation rate is highest for a building orientation of 150°. Finally, for temperatures greater than or equal to 30°C, the average ventilation rate is also highest for a building orientation of 150°. The table also shows that as temperatures increase from 20°C to temperatures above 30°C, the average ventilation rates also increase for all building orientations. From the results obtained, the building orientation that would be chosen for the Ottawa weather station based on 34.4 years of weather data would be 150° off North. The only problem with the average ventilation rate method is that it does not take into effect the times when the ventilation rates are below the minimum summer design ventilation rate (consecutive hours of low ventilation rates), or the distribution of the ventilation rates above or below the minimum design summer ventilation rate for this type of building configuration. The previously mentioned concepts are important aspects of proper design of sidewall, end wall and ridge opening areas, and also in obtaining the preferred building orientation.

5.2 Frequency of Ventilation Rates

Frequency histograms for each of the ten Ontario weather stations and three temperature ranges were plotted. Each graph displays the distribution of the number of events, or frequency versus the ventilation rates for all six building orientations. The ventilation rate along the horizontal axis starts at 3000 L/s and ranges up to 100,000 L/s. The ventilation rates between 0 L/s and 3000 L/s, are not represented in Figures 11 to

13, because those rates are biased estimates, due to the sensitivity of the anemometer not accurately recording low wind speeds. Ventilation rates were cut off at 100,000 L/s, because the frequency of higher ventilation rates is very minimal or zero, as can be observed by the frequency of rates between 75,000 L/s and 100,000 L/s, for the Ottawa weather station, for temperatures greater than or equal to 20°C.

A statistical analysis was carried out, via the use of SAS to determine whether or not the data is normally distributed. If the data is not normally distributed the a test fitting the distribution is used. Knowledge of the type of distribution is required to select the proper statistical test. The statistical variables used in the test, were the ventilation rates and the frequencies of the respective ventilation rates. The results of the statistical analysis showed that the data was not normally distributed at the 0.01 and 0.05 level of significance using the proc UNIVARIATE (procedure univariate) in SAS.

To determine the preferred building orientation from the frequency histograms, the percentage of events above and below the minimum summer design ventilation rate was analyzed for the three temperature ranges, and the six building orientations. The trends for the Ottawa weather station showed that as temperatures increased for different building orientations, the percentage of events below the summer design ventilation rate generally decreased, as shown in Table 4.

Table 4. Percentages above and below the minimum summer design ventilation rate (13600 L/s) for all three temperature ranges, and the six building orientations.

Building Orientation (Angle off North)	Percentage Ventilation Rates Below 13600 L/s	Percentage Ventilation Rates Above 13600 L/s
Temperature ≥ 20°C		
0	26.89	73.11
30	28.26	71.74
60	27.38	72.72
90	26.45	73.55
120	23.44	76.56
150	23.24	76.76
Temperature ≥ 25°C		
0	20.07	79.93
30	21.52	78.48
60	20.56	79.44
90	20.03	79.97
120	17.52	82.48
150	17.58	82.42
Temperature ≥ 30°C		
0	10.51	89.49
30	11.35	88.65
60	12.06	87.94
90	13.15	86.85
120	11.09	88.91
150	9.93	90.07

Also, as temperatures increased from 20°C to temperatures above 30°C the percentage of events above the summer design ventilation rate (13,600 L/s) increased. When analyzing the percentages with reference to the six building orientations, a 150° off North building orientation always had the highest percentages of ventilation rates above the summer design ventilation rate for all temperature ranges. This same building orientation had the lowest percentages of events below the summer design ventilation rate for all temperature ranges, as compared to the other building orientations. Based on the results obtained from the ventilation rate frequency histograms (Figures 11 to 13) and the results shown in Table 4, a building orientation of 150° off North would be the preferred orientation, for the Ottawa weather station.

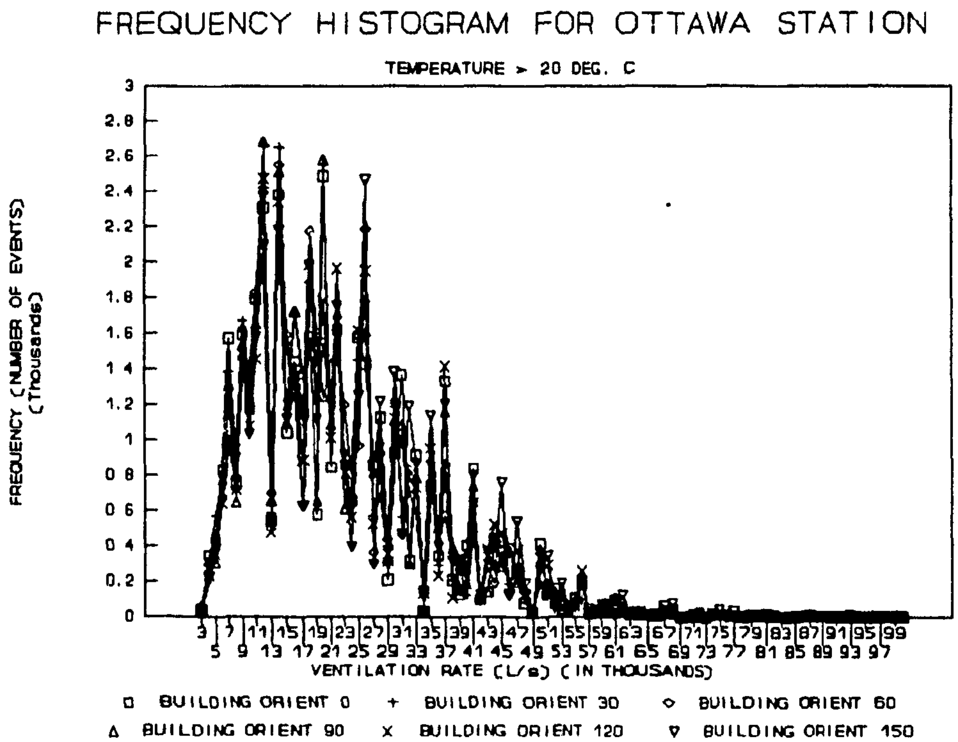


Figure 11. Frequency Histogram for Ottawa weather station for temperatures greater than or equal to 20°C, for all building orientations.

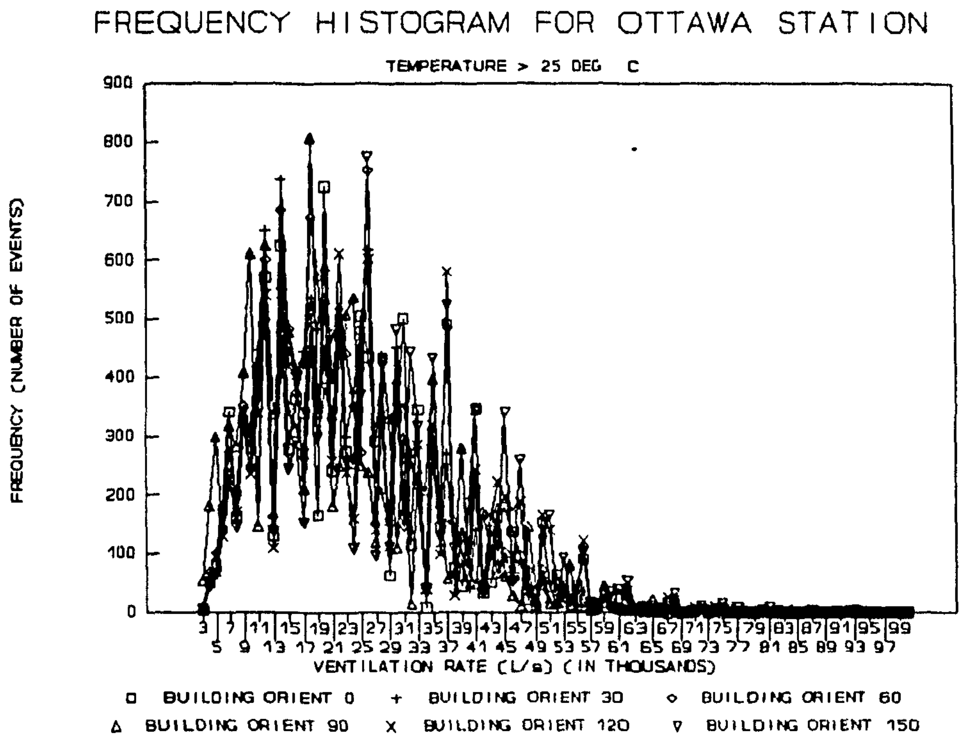


Figure 12. Frequency Histogram for Ottawa weather station for temperature greater than or equal to 25°C, and all building orientations.

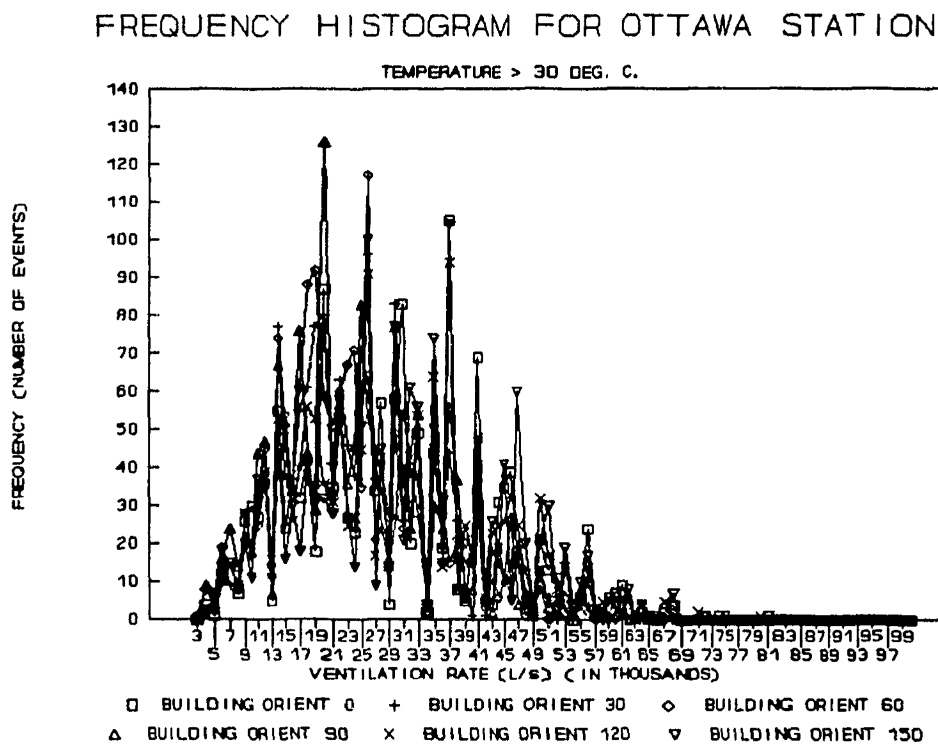


Figure 13. Frequency Histogram for Ottawa weather station for temperatures greater than or equal to 30°C, and all building orientations.

5.3 Consecutive Hour Method

The analysis of consecutive hours below the minimum summer design ventilation rate, which in this case was 13600 L/s, is essential in determining the preferred building orientation. The objective of the consecutive hour method is to orient the building to minimize the times when the ventilation rates are below the summer design ventilation rate. Successfully achieving this, will decrease the level of heat stress on the animals housed within the facility when the atmospheric conditions become unfavourable.

The consecutive hours were obtained via the use of a computer program written in QUICKBasic 4.5. The program would read from a file containing ventilation rates for a particular temperature and building orientation. The ventilation rates would then be compared to the minimum summer design rate, and if the rate was lower than the design rate this would become a one hour event. If the subsequent ventilation rate read from the file was also below the minimum summer design rate this would become a two hour consecutive event. Table 5 displays the analysis of consecutive hours in more detail.

For the Ottawa weather station, consecutive hour curves were obtained for each temperature range, and all building orientations appearing on the same graph. The results will be explained with reference to the effect of temperature and also the effect of building orientation.

5.3.1 Effect of Temperature

Table 5 shows the effect of temperature on initial values of single hours for each building orientation. As the temperature rises the number of single one hour events decreases. Referring to Figures 14 to 16 the same can be stated for the other consecutive hour periods. The longest period of consecutive hours also decreases as the temperature increases. For example, for temperatures greater than or equal to 20°C the longest period of consecutive hours is 43 hours, meaning that for 43 consecutive hours the ventilation rate within the facility was below the minimum design ventilation rate, and when temperatures increase to greater than or equal to 30°C the longest period of consecutive hours is 10 hours.

Table 5. Number of single hours and average number of hours per year based on 34.5 years of weather data that are below the minimum summer design ventilation rate for all building orientations, and three temperature ranges, for the Ottawa weather station.

Building Orientation (Angle off North)	Number of Single Hours	Average Number of Hours/y
Temperature ≥ 20°C		
0	5556	161
30	5821	169
60	5983	174
90	5805	169
120	5357	156
150	5204	151
Temperature ≥ 25°C		
0	1591	46
30	1755	51
60	1733	50
90	1638	48
120	1452	42
150	1414	41
Temperature ≥ 30°C		
0	146	4
30	169	5
60	171	5
90	175	5
120	142	4
150	123	4

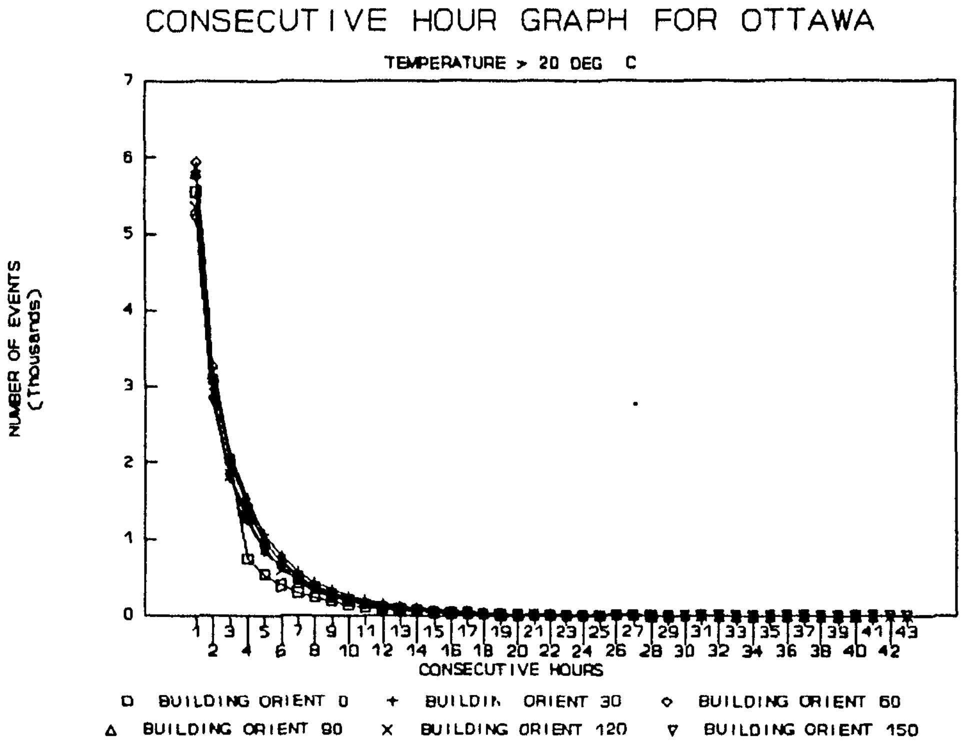


Figure 14. Consecutive hour graph for the Ottawa weather station for temperatures greater than or equal to 20°C, and all building orientations.

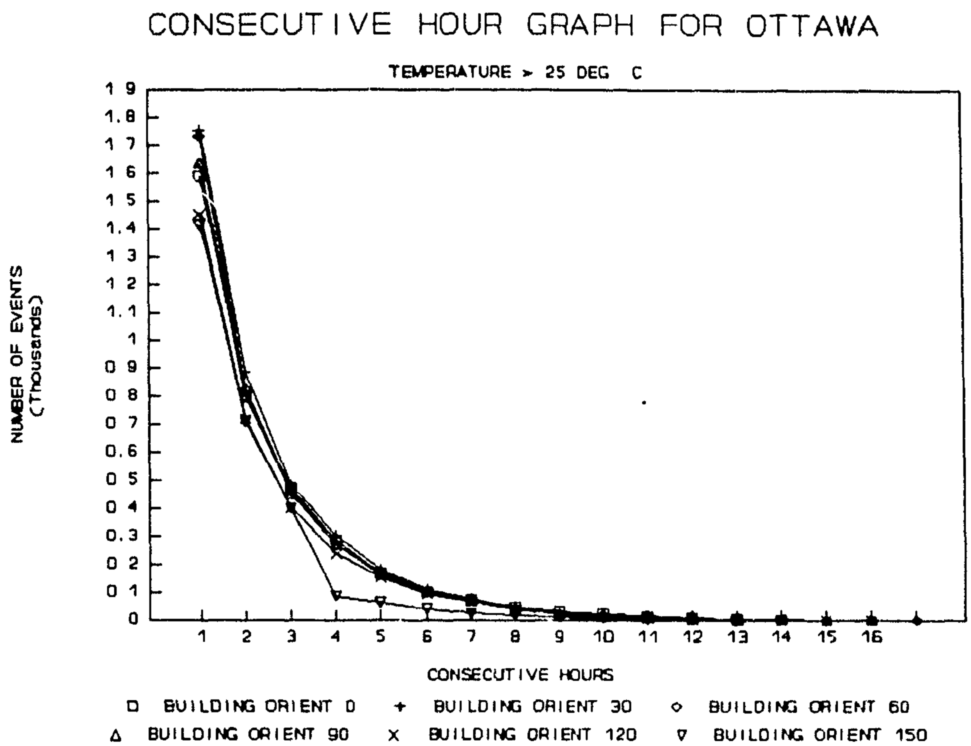


Figure 15. Consecutive hour graph for the Ottawa weather station for temperatures greater than or equal to 25°C, and all building orientations.

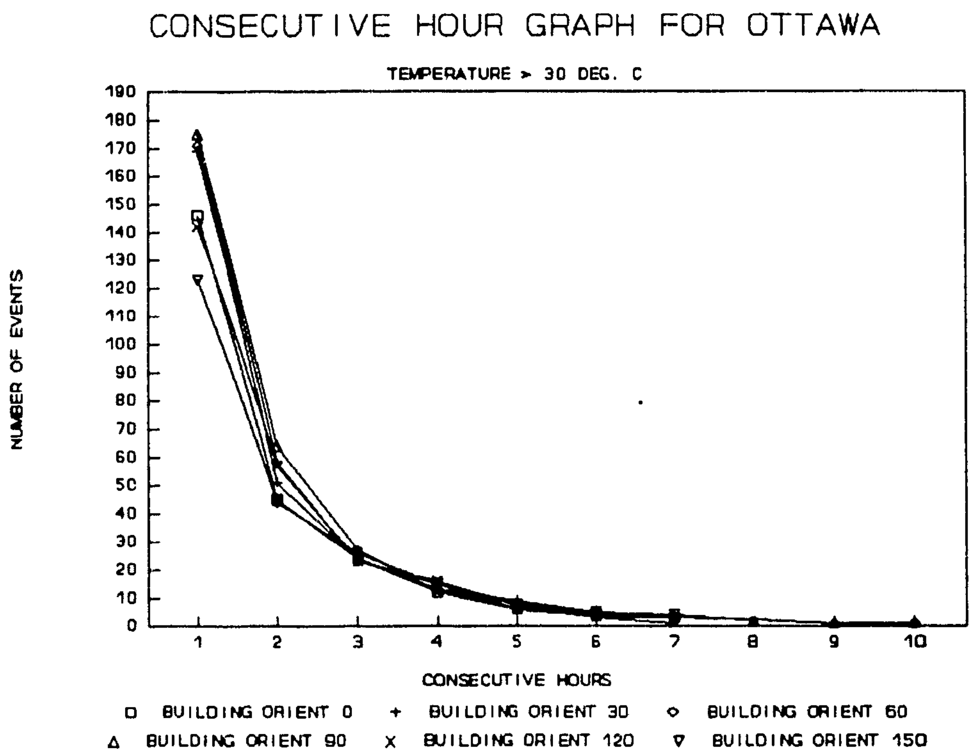


Figure 16. Consecutive hour graph for the Ottawa weather station for temperatures greater than or equal to 30°C, for all building orientations.

5.3.2 Effect of Building Orientation

Referring to Figures 14 to 16, there is an effect of building orientation with respect to consecutive hours for each of the temperature ranges. As temperatures increases, the different building orientations show different results with reference to the number of events for each consecutive hour. For example, at temperatures greater than or equal to 20°C a building orientation of 150° shows fewer one hour events than a building orientation of 60°. The same can be stated for the other temperature ranges, and also for the longest period of consecutive hours.

A building orientation of 150° would be chosen, for the Ottawa region, since this orientation displayed the least number of single hour consecutive events for all three temperature ranges. This orientation also showed the shortest period of consecutive hours for temperatures greater than or equal to 30°C.

5.4 Statistical Analysis Based on the Frequencies of Ventilation Rates Below the Minimum Summer Design Ventilation Rate versus Building Orientation.

A nonparametric statistical analysis was carried out on the frequencies (number of events) of ventilation rates below the minimum summer design ventilation rate (13600 L/s) versus the six building orientations (0°, 30°, 60°, 90°, 120°, 150°), at temperatures greater than or equal to 20°C to determine whether or there is a relationship betweenthe ventilation rates below the minimum summer design rate and the six building orientations. The analysis was only carried out at temperatures greater than 20°C because at higher temperatures the frequencies of ventilation rates below the minimum design ventilation rate are low, and the frequencies at higher temperatures are also incorporated within temperatures greater than or equal to 20°C. The statistical analysis was carried out via the use of SAS using the procedure "proc FREQ" (frequency). The output of this procedure is displayed in tabular form. The information generated for each ventilation rate below the minimum summer design rate and building orientation was: the observed frequency, the expected frequency, the deviation between the observed frequency and the expected frequency, the chi-square value for each ventilation rate and building orientation, the percentage (ratio of observed frequency to the overall total observed frequency) for each ventilation rate and building orientation, the row percent (ratio of observed frequency to the total row observed frequency) for each ventilation rate and building orientation, the column percentage (ratio of observed frequency to total column observed frequency), and the cumulative column percentage (the percent for each ventilation rate summed for each building orientation). This procedure also gives statistical results for the entire table, the chi-square value with corresponding degrees of freedom, and the probability associated with the chi-square value.

The hypothesis that is being tested is whether or not there is a relationship between ventilation rates below the minimum summer ventilation rates and building orientation. Observing the table chi-square value and the probability associated with this value, the probability is smaller than 0.01. Therefore referring to our hypothesis, the conclusion is that there is a relationship between the ventilation rate and building orientation.

The cell chi-square and percent values will be used to study the trends of ventilation rates below the minimum summer ventilation rate versus building orientation.

The results will be presented in three sections: the first in terms of the chi-square values second the percent values, and thirdly the row percents.

5.4.1 Statistical Analysis in Terms of Chi-Square Values

Table 6 displays the calculated chi-square values for each ventilation rates versus the six building orientations. The chi-square values are calculated in SAS using the observed frequency value and the expected frequency for each ventilation rate and building orientation. The formula to obtain the chi-square value Steele and Torrie (1980)

$$\chi^2=\sum\frac{(O_i-E_{ij})^2}{E_{ij}} \tag{7}$$

where

χ^2	- chi-square variable
O_i	- observed frequency, i
E_{ij}	- expected frequency, ij

Table 6. Chi-square values for ventilation rate versus building orientation for Ottawa weather station, for temperatures greater than or equal to 20°C.

Ventilation Rates (L/s)	Building Orientation					
	0°	30°	60°	90°	120°	150°
3000	1.883	0.443	0.443	1.883	0.387	1.424
4000	3.368	0.121	0.121	3.368	10.491	6.180
5000	21.155	6.329	6.329	21.155	5.383	9.104
6000	1.914	2.138	2.138	1.914	6.873	23.607
7000	19.801	1.264	1.264	19.801	22.671	15.127
8000	23.870	16.554	16.554	23.870	0.587	1.440
9000	0.034	0.489	0.489	0.034	0.055	1.291
10 000	0.071	1.178	1.178	0.071	0.380	7.723
11 000	0.856	3.339	3.339	0.856	18.721	3.419
12 000	4.711	25.690	25.690	4.711	22.558	9.267
13 000	0.003	0.515	0.515	0.003	9.338	1.609
14 000	0.514	2.408	2.408	0.514	18.855	2.786
Overall Chi-Square Value is 476.567 Probability < 0.01						

The preferred building orientation of 150° that was obtained from the average ventilation rate method, frequency of ventilation rated, and consecutive hour method was straightforward. Obtaining the preferred building orientation from the statistical analysis based on the chi-square variable is more difficult since there does not appear to be a trend in the chi-square variable with respect to the ventilation rates and building orientation. There is a large variation in the chi-square values, which is due to the differences between the expected and observed frequencies. As a result for the Ottawa weather station, a preferred building orientation cannot be selected based on the chi-square values.

5.4.2. Statistical Analysis in Terms of Percent Values

Table 7 displays the percent values for each ventilation rate below the minimum summer design ventilation rate and building orientation, and column percent for each building orientations, for the Ottawa weather station for temperatures greater than 20°C. The percent values were calculated by taking the observed frequency and dividing it by the overall observed frequency of the table. The column percent is obtained by summing the percent values for each ventilation rate, for each building orientation. The preferred building orientation is chosen based on the minimum percent values for each ventilation rate below the minimum summer design rate and building orientation, and also the minimum column percent value for each building orientation.

Table 7. Percent values for ventilation rates below the minimum summer ventilation rate and all building orientations, for the Ottawa weather station, for temperatures greater than or equal to 20°C.

Ventilation Rate (L/s)	Building Orientation					
	0°	30°	60°	90°	120°	150°
3000	0.06	0.08	0.08	0.06	0.04*	0.05
4000	0.44	0.42	0.42	0.44	0.17*	0.19
5000	0.43	0.64	0.64	0.43	0.37*	0.39
6000	1.08	1.12	1.12	1.08	0.52	0.47*
7000	1.84	1.62	1.62	1.84	0.76*	0.82
8000	0.90	1.29	1.29	0.90	0.65*	0.69
9000	2.15	2.27	2.27	2.15	1.24	1.24
10 000	1.74	1.86	1.86	1.74	1.03	0.93*
11 000	2.31	2.55	2.55	2.31	1.18*	1.49
12 000	3.75	3.34	3.34	3.75	2.33	2.30*
13 000	0.92	0.98	0.98	0.92	0.45*	0.58
14 000	3.50	3.56	3.56	3.50	2.28	2.20*
Total Column %	19.11	19.71	19.71	19.10	11.02	11.35
Overall Percent Value for the Table = 100%						

The preferred building orientation based on the percent values shown in table 7 would be 120°, since this orientation displayed the lowest percent values for the majority of the ventilation rates below the minimum summer design ventilation rate. This same building orientation would also be selected based on the column percent values, since this orientation showed the lowest column percent value compared to the other building orientations.

5.4.3 Statistical Analysis in Terms of Row Percent

Table 8 displays the row percent for each ventilation rate below the minimum summer design ventilation rate and building orientation for the Ottawa weather station for temperatures greater than or equal to 20°C. The preferred building orientation is chosen based on the lowest percentage obtained for each ventilation rate.

Table 8. Row percent values for ventilation rates below the minimum summer design ventilation rate and all building orientations, for the Ottawa weather station, for temperatures greater than or equal to 20°C.

Ventilation Rate (L/s)	Building Orientation						Total Row %
	0°	30°	60°	90°	120°	150°	
3000	15.38	21.54	21.54	15.38	12.31	13.85	100
4000	21.19	20.11	20.11	21.19	8.23	9.18	100
5000	14.69	22.16	22.16	14.69	12.72	13.58	100
6000	20.08	20.75	20.75	20.08	9.62	8.72	100
7000	21.60	19.07	19.07	21.60	9.00	9.67	100
8000	15.77	22.53	22.53	15.77	11.42	11.98	100
9000	19.01	20.05	20.05	19.01	10.94	10.93	100
10 000	18.96	20.30	20.30	18.96	11.28	10.20	100
11 000	18.67	20.57	20.57	18.67	9.50	12.01	100
12 000	19.92	17.77	17.77	19.92	12.38	12.24	100
13 000	19.06	20.25	20.25	19.06	9.30	12.08	100
14 000	18.83	19.11	19.11	18.83	12.27	11.84	100

The row percent were obtained by dividing the observed frequency of each ventilation rate, for each building orientation by the total row observed frequency for the respective ventilation rate. The preferred building orientation for the Ottawa weather station, based on the values of the row percents would be 120°, since this orientation displayed the lowest row percentages for all ventilation rates below the minimum summer design ventilation rate, for temperatures greater than or equal to 20°C.

5.6 Comparison Among Methods

The preferred building orientation selected using the average ventilation rate method, the frequency of ventilation rates above and below the minimum summer ventilation rate method, the consecutive hour method, and the statistical analysis all yielded similar results. The advantage of using all of the previously mentioned methods is that they verify during the summer when most occurrences of unfavourable atmospheric conditions within the facility occur. They also display information that is necessary for designing proper sidewall, end wall, and ridge, or chimney openings. Although these methods showed the same results for the Ottawa region, different results may arise in other regions of Ontario, due to the differences in climatic conditions, as will be shown in Tables 9 to 15.

Table 9. Preferred building orientations obtained using the average ventilation rate method for all 9 remaining weather stations for the province of Ontario.

Ontario Weather Station	Average Ventilation Rate (L/s)	Preferred Building Orientation (Angle off North)
Temperatures ≥ 20°C		
Barrie	18 601	60°
London	22 908	120°
North Bay	25 160	120°
Simcoe	24 252	150°
St. Catherines	29 564	150°
Toronto	23 061	120°
Trenton	26 320	150°
Waterloo	24 195	150°
Windor	25 301	120°
Temperature ≥ 25°C		
Barrie	18 941	30°
London	26 105	120°
North Bay	29 585	150°
Simcoe	28 088	150°
St. Catherines	33 474	150°
Toronto	27 571	150°
Trenton	30 624	150°
Waterloo	2[illegible] [illegible]41	150°
Windsor	[illegible]	120°
Temperat[illegible] 3[illegible]°C		
Barrie	25 681	0°
London	29 489	150°
North Bay	34 660	150°
Simcoe	28 507	0°
St. Catherines	35 339	150°
Toronto	33 739	150°
Trenton	34 567	0°
Waterloo	30 454	150°
Windsor	32 667	150°

Table 10. Preferred building orientation based on percentage of events above and below the minimum summer design ventilation rate in reference to the frequency of ventilation rates, for all three temperature ranges, and for all 9 remaining Ontario weather stations

Ontario Weather Station	Percentage of Events Above 13 600 L/s	Percentage of Events Below 13 600 L/s	Preferred Building Orientation (Angle off North)
Temperatures ≥ 20°C			
Barrie	42 6	57 4	60°
London	31 5	68 5	120°
North Bay	24 0	76 0	120°
Simcoe	27 0	73 0	150°
St Catherines	19.0	81 0	150°
Toronto	30.4	69 6	120°
Trenton	24 5	75 5	150°
Waterloo	30 4	69 6	150°
Windsor	25 4	74 6	120°
Temperatures ≥ 25°C			
Barrie	38 8	38 8	30°
London	22 6	77 4	120°
North Bay	15 1	84 9	150°
Simcoe	17 9	82 1	150°
St Catherines	12 2	87 8	150°
Toronto	18 8	81 2	150°
Trenton	15 1	84 9	150°
Waterloo	22 9	77 1	150°
Windsor	18 9	81 1	120°
Temperatures ≥ 30°C			
Barrie	19 0	81 0	0°
London	14 5	85 5	150°
North Bay	11.0	89 0	150°
Simcoe	14 1	85 9	0°
St Catherines	8 2	91 8	150°
Toronto	10 0	90 0	150°
Trenton	9 2	90 8	0°
Waterloo	13 4	86 6	150°
Windsor	11 9	88 1	150°

Table 11 Preferred building orientation based on single hour events and average number of hours per year, for all three temperature ranges, and for all 9 remaining Ontario weather stations

Ontario Weather Station	Number of Single Hours	Average Number of Hours/Year	Preferred Building Orientation (Angle off North)
Temperatures ≥ 20°C			
Barrie	879	135	90°
London	5609	163	120°
North Bay	2528	74	120°
Simcoe	883	164	150°
St Catherines	146	63	0°
Toronto	5356	155	60°
Trenton	4615	134	120°
Waterloo	1701	79	150°
Windsor	6073	176	120°
Temperature ≥ 25°C			
Barrie	252	39	60°
London	1423	41	150°
North Bay	325	9	150°
Simcoe	184	34	150°
St Catherines	41	18	0°
Toronto	1448	42	120°
Trenton	829	24	120°
Waterloo	461	22	150°
Windsor	1900	55	120°
Temperature ≥ 30°C			
Barrie	8	1.0	30°
London	102	3.0	150°
North Bay	9	< 1.0	150°
Simcoe	14	3.0	0°
St Catherines	3	1.0	0°
Toronto	123	4.0	150°
Trenton	29	< 1.0	150°
Waterloo	23	1.0	0°
Windsor	224	6.0	120°

Table 12. Preferred building orientation based on the minimum longest period of consecutive hours, for all three temperature ranges, and for all 9 remaining Ontario weather stations

Ontario Weather Station	Minimum Longest Period of Consecutive Hours	Preferred Building Orientation
Temperatures ≥ 20°C		
Barrie	27	90°
London	36	120°
North Bay	21	120°
Simcoe	15	120°
St.Catherines	6	150°
Toronto	18	90°
Trenton	22	120°
Waterloo	11	150°
Windsor	34	120°
Temperatures ≥ 25°C		
Barrie	8	60°
London	10	150°
North Bay	11	150°
Simcoe	7	30°
St.Catherines	3	90°
Toronto	9	120°
Trenton	10	120°
Waterloo	7	0°
Windsor	12	150°
Temperature ≥ 30°C		
Barrie	2	30°
London	5	150°
North Bay	3	120°
Simcoe	4	0°
St Catherines	1	150°
Toronto	4	60°
Trenton	5	150°
Waterloo	3	0°
Windsor	7	0°

Table 13. Preferred building orientation based on the total column percent values obtained from the statistical analysis, for temperatures greater than or equal to 20°C, and for all 9 remaining Ontario weather stations.

Ontario Weather Station	Total Column Percent Values*	Preferred Building Orientation (Angle off North)
Temperatures ≥ 20°C		
Barrie	15.09	60°
London	16.12	120°
North Bay	13.47	150°
Simcoe	14.72	120°
St. Catherines	14.53	90°
Toronto	15.21	60°
Trenton	8.33	150°
Waterloo	16.18	150°
Windsor	13.56	120°

* Total percent value summed for all ventilation rates, corresponding to the preferred building orientation.

Table 14. Preferred building orientation based on row percent values obtained from the statistical analysis, for temperatures greater than or equal to 20°C, and for all 9 remaining Ontario weather stations.

Ontario Weather Station	Preferred Building Orientation (angle off North)
Temperatures $\geq$ 20°C	
Barrie	60°
London	60°
North Bay	120°
Simcoe	120°
Trenton	150°
Waterloo	0°
Windor	120°

Table 15 Summary of preferred building orientations obtained for all 9 remaining Ontario weather station, based on the four methods, for each temperature range

Ontario Weather Station	Preferred Building Orientation Based on the 4 Methods
Temperatures ≥ 20°C	
Barrie	60°, 90°
London	120°
North Bay	120°, 150°
Simcoe	120°, 150°
St Catherines	0°, 90°, 150°
Toronto	60°, 90°
Trenton	120°, 150°
Waterloo	150°
Windsor	120°
Temperatures ≥ 25°C	
Barrie	60°
London	150°
North Bay	150°
Simcoe	30°, 150°
St Catherines	0°, 90°
Toronto	120°
Trenton	120°
Waterloo	0°, 150°
Windsor	120°, 150°
Temperatures ≥ 30°C	
Barrie	30°
London	150°
North Bay	120°, 150°
Simcoe	0°
St Catherines	0°, 150°
Toronto	150°
Trenton	150°
Waterloo	0°
Windor	120°

6.0 CONCLUSION

The prediction model based on wind forces, summer weather data from 10 Ontario weather stations, and C_Q coefficients for particular wind directions were used to obtain ventilation rates within a typical naturally ventilated swine building positioned at six different orientations. The optimum building orientation was obtained for each of the 10 Ontario weather stations using four methods, (the average ventilation rates, the frequency of ventilation rates, the consecutive hours, and a statistical analysis based· of the ventilation rates below the minimum summer design rate).

The following conclusions are drawn from the project:

1) There is an effect of temperature on building orientation. As temperature increases for the various building orientations, the average ventilation rate also increases. The building orientation with the highest average ventilation rate was the preferred building orientation, for each of the te.

2) There is an effect between the percentages above and below of ventilation rates above and below the minimum summer design rate, and building orientation, for the three temperature ranges. The building orientation with the lowest percentage of ventilation rates below the minimum summer design ventilation rate and the highest percentage above, for the three temperature ranges was the preferred building orientation.

3) There is an effect between building orientation and temperature on the number of consecutive hours below the minimum summer design ventilation rate. The building orientation with the least number of consecutive hours, for each of the three temperature ranges was the preferred building orientation. In general, as temperatures increased for all ten Ontario weather stations, for each building orientation, the number of consecutive hours decreased.

4) There is a relationship between ventilation rates below the minimum summer design rate and building orientation. As ventilation rates below the minimum summer design ventilation rate increases, the ratio of the observed frequency to the overall frequency, or percent value increases. Also the building orientation with the lowest overall percent value was the preferred building orientation.

5) There is a relationship between temperature and building orientation. Different temperature ranges displayed different preffered building orientations for all weather stations across the province of Ontario.

7.0 RECOMMENDATIONS FOR FURTHER RESEARCH

1) Since the project dealt with open land areas, with no obstructions, an analysis comparable to the one done in this project should be carried out in areas where obstructions may be found to obtain the preferred building orientation of a naturally ventilated faining the preferred building orientation of only one type of naturally ventilated building is insufficient. Research in the future should be geared toward obtaining the preferred building orientation of other types of building configurations, such as L-shaped naturally ventilated buildings.

3) Research should also be geared towards the development of a computer software package where, if a farmer were interested in constructing a naturally ventilated facility, the program would supply the farmer with all the necessary information with respect to the climatic conditions of the area, the type of livestock being housed, and the number of animals confined within the facility.

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9.0 APPENDIX

PAGE

APPENDIX A

PROGRAM 1: SORTING WEATHER DATA WITH RESPECT TO THE THREE TEMPERATURE RANGES

```
REM Program to split the data for temperature and wind for Ottawa location.
COMMON abbrev$, loc$
CLS
LOCATE 12, 20: PRINT "WHAT IS THE WEATHER STATION DESIRED? ABBREV"
INPUT abbrev$
LOCATE 14, 20: PRINT "WHAT IS THE LOCATION THAT IS DESIRED? LOCATION"
INPUT loc$


REM Preparing the output files, temperature set.
OPEN "c:\" + loc$ + "\" + abbrev$ + ".dat" FOR INPUT AS #1
OPEN "c:\" + loc$ + "\weather\" + abbrev$ + "20" + ".prn" FOR OUTPUT AS #2
OPEN "c:\" + loc$ + "\weather\" + abbrev$ + "25" + ".prn" FOR OUTPUT AS #3
OPEN "c:\" + loc$ + "\weather\" + abbrev$ + "30" + ".prn" FOR OUTPUT AS #4

DO UNTIL EOF(1)
da$ = INPUT$(6, #1)
PRINT da$
INPUT #1, hrs
FOR i = 1 TO hrs
INPUT #1, hstart

REM Splitting the temperature and wind direction.
twind$ = INPUT$(5, #1)
temp = VAL(LEFT$(twind$, 3)) / 10
IF RIGHT$(twind$, 2) <> "**" THEN
windd = VAL(RIGHT$(twind$, 2)) * 10
ELSE
PRINT windd, wspeed
END IF
INPUT #1, wspeed
GOSUB direct
REM Printing to files, temperature sets.
PRINT #2, da$, hstart, temp, wspeed, windd, direct$
IF temp >= 25 THEN
PRINT #3, da$, hstart, temp, wspeed, windd, direct$
END IF
IF temp >= 30 THEN
PRINT #4, da$, hstart, temp, wspeed, windd, direct$
END IF
NEXT i
LOOP
CLOSE #4
CLOSE #3
CLOSE #2
CLOSE #1
CHAIN "c:\QB45\PROGRAMS\STEP14.BAS"
END

REM Subroutine for wind direction.
direct:
IF windd >= 0 AND windd <= 11.25 THEN
direct$ = "N"
ELSEIF windd >= 11.25 AND windd <= 22.5 THEN direct$ = "NNE"
ELSEIF windd >= 22.5 AND windd <= 33.75 THEN direct$ = "NNE"
ELSEIF windd >= 33.75 AND windd <= 45 THEN direct$ = "NE"
ELSEIF windd >= 45 AND windd <= 56.25 THEN direct$ = "NE"
ELSEIF windd >= 56.25 AND windd <= 67.5 THEN direct$ = "NEE"
ELSEIF windd >= 67.5 AND windd <= 78.75 THEN direct$ = "NEE"
ELSEIF windd >= 78.75 AND windd <= 90 THEN direct$ = "E"
ELSEIF windd >= 90 AND windd <= 101.25 THEN direct$ = "E"
ELSEIF windd >= 101.25 AND windd <= 112.5 THEN direct$ = "SEE"
ELSEIF windd >= 112.5 AND windd <= 123.75 THEN direct$ = "SEE"
ELSEIF windd >= 123.75 AND windd <= 135 THEN direct$ = "SE"
ELSEIF windd >= 135 AND windd <= 146.25 THEN direct$ = "SE"
ELSEIF windd >= 146.25 AND windd <= 157.5 THEN direct$ = "SSE"
ELSEIF windd >= 157.5 AND windd <= 168.75 THEN direct$ = "SSE"
ELSEIF windd >= 168.75 AND windd <= 180 THEN direct$ = "S"
ELSEIF windd >= 180 AND windd <= 191.25 THEN direct$ = "S"
ELSEIF windd >= 191.25 AND windd <= 202.5 THEN direct$ = "SSW"
ELSEIF windd >= 202.5 AND windd <= 213.75 THEN direct$ = "SSW"
ELSEIF windd >= 213.75 AND windd <= 225 THEN direct$ = "SW"
```

```
ELSEIF windd >= 225 AND windd <= 236.25 THEN direct$ = "SW"
ELSEIF windd >= 236.25 AND windd <= 247.5 THEN direct$ = "SWW"
ELSEIF windd >= 247.5 AND windd <= 258.75 THEN direct$ = "SWW"
ELSEIF windd >= 258.75 AND windd <= 270 THEN direct$ = "W"
ELSEIF windd >= 270 AND windd <= 281.25 THEN direct$ = "W"
ELSEIF windd >= 281.25 AND windd <= 292.5 THEN direct$ = "NWW"
ELSEIF windd >= 292.5 AND windd <= 303.75 THEN direct$ = "NWW"
ELSEIF windd >= 303.75 AND windd <= 315 THEN direct$ = "NW"
ELSEIF windd >= 315 AND windd <= 326.25 THEN direct$ = "NW"
ELSEIF windd >= 326.25 AND windd <= 337.5 THEN direct$ = "NNW"
ELSEIF windd >= 337.5 AND windd <= 348.75 THEN direct$ = "NNW".
ELSE direct$ = "N" 'windd >= 348.75 AND windd <= 0 THEN direct$ = "N"
END IF
RETURN

REM ******* PROGRAM STEP3.BAS *******
```

PROGRAM 2: CALCULATING VENTILATION RATES WITH RESPECT TO THE SIX BUILDING ORIENTATIONS AND THREE TEMPERATURE RANGES

```
REM program to calculate the ventilation rates using the sorted weather data

DIM degc$(4), angle(40), Cq(40)
COMMON abbrev$, loc$
DATA 20, 25, 30
CLS

LOCATE 12, 20: PRINT "PLEASE ENTER CORRECTLY THE WEATHER STATION THAT IS DESIRED? ABBREVIATION"
INPUT abbrev$

LOCATE 16, 20: PRINT "PLEASE ENTER CORRECTLY THE LOCATION OF THE WEATHER STATION? LOCATION"
INPUT loc$

FOR v = 1 to 3
READ degc$(v)
NEXT v

FOR W = 1 to 3
FOR KK = 0 to 150 step 30

K$ = LTRIM$(STR$(KK))
PRINT " WORKING AT REFERENCE TEMPERATURE NUMBER ====>>> # ";W
OPEN "C:\" + loc$ + "\" + "weather\" + degc$(W) + "degree\" + "calm\" + abbrev$ + degc$(W) + ".prn"
FOR INPUT AS #1

OPEN "C:\SPLINE\" + "OSPLCHPC.PRN" FOR INPUT AS #2

OPEN "C:\" + loc$ + "\" + "weather\" + degc$(W) + "degree\" + "ventrate\" + abbrev$ + K$ + degc$(W)
+ ".prn" FOR OUTPUT AS #3


PRINT #3 "ANGLE DISPLACEMENT FROM ZERO NORTH DEGREES IS ", KK

FOR i= 0 TO 360
INPUT #2, a, b
ii = i / 10
r = a / 10
IF r = INT(ii) THEN
angle(ii) = r
Cq(ii) = b
ELSE
GOTO 4
END IF
4 NEXT i

DO UNTIL EOF(1)

INPUT #1, da, hrs, temp, wspeed, windd, direct$
f = ABS(windd - KK)
g = f / 10
z = INT(g)
FOR j = 0 TO 36
IF j = z THEN
l = 17.63
ws = wspeed / 3.6
c = Cq(j) * ws * l
q = c * 1000
PRINT q
PRINT #3, da, hrs, temp, wspeed, windd, q, direct$
ELSE
GOTO 2
END IF
2 NEXT j
LOOP
CLOSE #3
CLOSE #1
CLOSE #2
NEXT KK
NEXT W
END
```

PROGRAM 3: CALCULATING VENTILATION RATE FREQUENCIES FOR EACH BUILDING ORIENTATION AND TEMPERATURE RANGE

```
REM Program to split the data for temperature and wind for Ottawa location.
DIM count(275), freq(275)
DIM degc$(4)
COMMON ABBREV$, LOC$
10 DATA 20,25,30

REM Preparing the output files, temperature set.
CLS
LOCATE 12, 20: PRINT "What is the location that is desired?abbreviation"
PRINT ABBREV$
LOCATE 14, 20: PRINT "What is the location of the weather station givenn?location"
PRINT LOC$


RESTORE 10
FOR u = 1 TO 3
READ degc$(u)
NEXT u
FOR w = 1 TO 3
FOR KK = 0 TO 150 STEP 30
K$ = LTRIM$(STR$(KK))
PRINT "WORKING ON OBTAINING FREQUENCY DATA FOR TEMPERATURE NUMBER ==>> #"; w
OPEN "c:\" + LOC$ + "\" + "weather\" + degc$(w) + "degree\" + "maxvent\" + ABBREV$ + K$ + "mv" +
".prn" FOR INPUT AS #2
OPEN "c:\" + LOC$ + "\" + "weather\" + degc$(w) + "degree\" + "ventrate\" + ABBREV$ + K$ + degc$(w)
+ ".prn" FOR INPUT AS #4
OPEN "c:\" + LOC$ + "\" + "weather\" + degc$(w) + "degree\" + "fre\" + ABBREV$ + K$ + degc$(w) +
".prn" FOR OUTPUT AS #3

INPUT #2, dum, maxvent, gtcount
CLOSE #2
PRINT gtcount
r = maxvent / 1000
l = INT(r)
FOR i = 0 TO l
count(i) = 0
NEXT i

FOR n = 1 TO gtcount
z = 0
DO UNTIL EOF(4)
INPUT #4, da, hstart, temp, wspeed, windd, q, direct$
z = z + 1
t = q / 1000
p = INT(t)
FOR m = 0 TO l
'PRINT m, p
IF p = m THEN count(m) = count(m) + 1
NEXT m
PRINT z

LOOP
NEXT n
freqtot = 0
FOR j = 0 TO l
freq(j) = count(j) / gtcount * 100
freqtot = freq(j) + freqtot
PRINT freqtot
PRINT USING "###.#"; freqtot
PRINT #3, j, count(j), gtcount, USING "###.###"; freq(j); freqtot

NEXT j

CLOSE #3
CLOSE #4
NEXT KK
NEXT w
CHAIN "C:\QB45\PROGRAMS\STEP026.BAS"
END
```

PROGRAM 4: OBTAINING THE CONSECUTIVE HOUR EVENTS FOR EACH BUILDING ORIENTATION AND TEMPERATURE RANGE

```
REM program to obtain consecutive hours of low ventilation rates

DIM DEGC$(4)
DIM jour(2), heur(2), date(2), journ(2), heu(2)
DIM b(24), c(24), d(24), e(24), f(24), g(24), h$(24)

COMMON abbrev$, loc$

10 DATA 20, 25, 30

CLS

LOCATE 12, 20: PRINT "WHAT IS THE WEATHER STATION TANT IS DESIRED ? ABBREVIATION"

PRINT abbrev$

LOCATE 16,20: PRINT "WHAT IS THE LOCATION OF THE WEATHER STATION ? LOCATION"

PRINT loc$

RESTORE 10
FOR V = 1 TO 3
READ DEGC$(V)
NEXT V
FOR w  = 1 TO 3
FOR kk = 0 TO 150 STEP 30
k$ = LTRIM$(STR$(kk))
PRINT " WORKING ON REFERENCE TEMPERATURE NUMBER ====>>>> # "; w

OPEN "C:\" + loc$ + "\" + "WEATHER\" + DEGC$(w) + "DEGREE\" + "VENTRATE\" + abbrev$ + k$ + DEGC$(w)
+ ".prn" FOR INPUT AS #11

OPEN "C:\" + loc$ + "\" + "WEATHER\" + DEGC$(w) + "DEGREE\" + "CONSEQHR\" + abbrev$ + k$ + DEGC$(w)
+ ".prn" FOR OUTPUT AS #5

m = 0
FOR l = 1 to 3

1 DO UNTIL EOF(11)

INPUT #11, da, hrs, temp, wspeed, windd, q, direct$
PRINT q
date(l) = da
hour(l) = hrs
IF q > 13600 THEN
m = 0
da = date(l)
hrs = hour(l)
GOTO 1
ELSEIF m >= 1 THEN
journ(l) = date(l)
heu(l) = hour(l)
GOTO 3
ELSE
m = 0
jour(l) = date(l)
heur(l) = hour(l)
GOTO 2
END IF

3 IF jour(l) = journ(l) and heu(l) - heur(l) = 1 THEN
da = jour(l)
jour(l) = journ(l)
hrs = heur(l)
heur(l) = heu(l)
GOTO 2
ELSE
m = 0
da = journ(l)
hrs = heu(l)
da = jour(l)
hrs = heur(l)
```

```
GOTO 1
END IF

2 m = m + 1
PRINT m
b(m) = heur(l)
c(m) = heu(l)
d(m) = temp
e(m) = wspeed
f(m) = windd
g(m) = q
h$(m) = direct$
PRINT #5, da
PRINT #5, m
FOR j = 1 to m
PRINT g(j)
PRINT #5, b(j), d(j), e(j), f(j), g(j), h$(j)
NEXT j
LOOP
NEXT l
CLOSE #11, #5
NEXT kk
NEXT w
END
```

PROGRAM 5: OBTAINING THE MAXIMUM NUMBER OF CONSECUTIVE HOURS FOR EACH BUILDING ORIENTATION AND TEMPERATURE RANGE

```
REM Program to split the data for temperature and wind for Ottawa location.
DIM DEGC$(4)
COMMON abbrev$, loc$
DATA 20,25,30
REM Preparing the output files, temperature set.
CLS
LOCATE 12, 20: PRINT "WHAT IS THE WEATHER STATION DESIRED? ABBREV"
PRINT abbrev$
LOCATE 14, 20: PRINT "WHAT IS THE LOCATION THAT IS DESIRED? LOCATION"
PRINT loc$
FOR u = 1 TO 3
READ DEGC$(u)
NEXT u
FOR x = 1 TO 3
FOR KK = 0 TO 150 STEP 30
K$ = LTRIM$(STR$(KK))
OPEN "c:\" + loc$ + "\weather\" + DEGC$(x) + "degree\" + "consechr\" + abbrev$ + K$ + DEGC$(x) +
".prn" FOR INPUT AS #1
OPEN "c:\" + loc$ + "\weather\" + DEGC$(x) + "degree\" + "maxhr\" + abbrev$ + K$ + "mv" + ".prn" FOR
OUTPUT AS #2

maxhr = 1
gtcount = 0
DO UNTIL EOF(1)
REM PRINT da$
INPUT #1, dum
INPUT #1, a
IF a > 1 THEN
FOR i = 1 TO a
INPUT #1, dum, dum, dum, dum, dum, dum$
NEXT i
ELSE
INPUT #1, dum, dum, dum, dum, dum, dum$
END IF
PRINT a
maxhr = INT(maxhr)
gtcount = gtcount + 1
PRINT gtcount
IF a > maxhr THEN maxhr = a
'gtcount = gtcount + 1
LOOP
PRINT #2, maxhr, gtcount
CLOSE
NEXT KK
NEXT x


CHAIN "C:\QB45\PROGRAMS\STEP027.BAS"
END
```

APPENDIX B

SAMPLE SAS PROGRAM USED FOR STATISTICAL ANALYSIS FOR OTTAWA WEATHER STATION

```
OPTION PS=60 LS=132;

DATA  OTF200;

INFILE 'OTF200.PRN';

INPUT VR; ORIENT=O;

DATA OTF2030;

INFILE 'OTF2030.PRN';

INPUT VR; ORIENT= 30;

DATA OTF2060;

INFILE 'OTF2060.PRN';

INPUT VR; ORIENT=60;

DATA OTF2090;

INFILE  'OTF2090.PRN';

INPUT VR; ORIENT=90

DATA OTF20120;

INFILE 'OTF20120.PRN';

INPUT VR; ORIENT=120;

DATA OTF20150;

INFILE 'OTF20150.PRN'

INPUT VR; ORIENT=150;

DATA ALL;

SET OTF200 OTF2030 OTF2060 OTF2090 OTF20120 OTF20150;
```

```
PROC FREQ;

PROC FREQ; TABLE VR*ORIEN/CELLCHI2 EXPECTED CHISQ DEVIATION
CUMCOL;

RUN;
```