



COMPUTER AIDED DESIGN SOFTWARE FOR NATURALLY VENTILATED

LIVESTOCK BUILDINGS

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For presentation to the
CANADIAN SOCIETY OF AGRICULTURAL ENGINEERING
at the Agricultural Institute of Canada Annual Conference
July 29-31, 1991 - Fredericton, New Brunswick

ABSTRACT: This paper describes the user-friendly computer package called NatVent which helps the user design sidewall, end wall, chimney and/or ridge openings for naturally ventilated livestock buildings. It is written in QuickBASIC and is interactive. The user inputs various dimensions and characteristics of the building and NatVent suggests the best building orientation(s) based on design critical temperatures and hourly meteorological data. NatVent uses meteorological data from 30 locations across Canada. The output features the preferred building orientation(s), the percent of time ventilation is below or above the desired summer ventilation rate, the frequency of consecutive hours of low ventilation, and the average ventilation rate.

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RÉSUMÉ

Le présent document décrit le logiciel "NatVent" servant à concevoir les étables à ventilation naturellement. L'utilisateur aura donc un outil pour vérifier l'efficacité des ouvertures pratiquées dans les murs de long du bâtiment, aux extrémités, ainsi que des ouvertures continues au faite du toit ou des cheminées intermittentes. Ce logiciel est interactif et fût produit en "QuickBASIC". Selon les dimensions des ouvertures et du bâtiment, "NatVent" produit la courbe des coefficients de ventilation en fonction de l'angle d'incidence des vents. En utilisant les données météorologiques de vitesse et direction des vents de 30 stations Canadiennes, "NatVent" produit les courbes de fréquence des taux de ventilation, la fréquence des heures consécutives sous le taux requis de ventilation estival et finalement, le programme suggère les orientations privilégiées pour le bâtiment par ordre décroissant d'efficacité.

INTRODUCTION

To create a naturally ventilated livestock building that functions well, a designer has to consider many factors including; building dimensions, opening sizes and positions, building orientation, summer ventilation rate and critical exterior temperatures, among other things. A computerized modelling system was proposed to test different designs for different regions of Canada. NatVent has been created to assist the designer in checking how different building designs behave when they are tested using multiple years of weather data (hourly temperature, wind speed and direction). The program's basic data comes from wind tunnel studies of a scale model of a typical naturally ventilated building. Ventilation rate coefficients (C_Q) were found for various specific angles of wind incidence using the pressure difference method.

LITERATURE REVIEW

Existing designs for warm naturally ventilated swine finishing buildings generally have large sidewall openings and either a continuous ridge opening or chimneys. However, there is a controversy among different authors on the methodology used to design naturally ventilated buildings. Design could be based on thermal buoyancy and wind forces, or on wind forces alone.

Bruce (1975a, 1978), Down *et al.* (1985) and others proposed that the design of the necessary openings for the air inlets and outlets should be based on thermal buoyancy alone. Hellickson *et al.* (1983), Brockett and Albright (1987), DeShazer *et al.* (1988) and van't Ooster and Both (1988) presented different models combining both thermal buoyancy and wind forces. These models were used for designing conventional buildings with various continuous ridge openings.

The results of Choinière *et al.* (1989, 1990a) showed that there are basically no differences between the exterior and interior temperatures, for a building with sidewall openings equal to 30% of the total sidewall area. Barrie *et al.* (1985) obtained similar results when utilizing large sidewall opening areas.

Since the size of the sidewall openings has to be determined so as to maintain sufficient ventilation during the hot summer period, Choinière *et al.* (1989, 1990a) recommended that the sizing of the sidewall opening area should be based on wind only. For the cooler periods of the year, the automatic control system can reduce the opening area of the sidewall to maintain the required interior temperature.

Model for natural ventilation by wind induced forces only

Aynsley *et al.* (1977) summarized the research done to obtain a reliable model for predicting ventilation rates due to the wind.

Bruce (1974, 1975b) presented the theory of the pressure difference method as usual to predict the ventilation rate of a low-rise building. He proposed a computer program that would calculate wind induced ventilation rates for livestock facilities. His results were based on the wind tunnel testing of a sealed scale model of a gable roof barn, having full scale measurements of 22 m by 35 m, and a 12° roof slope. Down *et al.* (1985), Brockett and Albright (1987), Zhang *et al.* (1989), Down and McMahon (1990), and Down (1990) used the pressure coefficients obtained by Bruce (1974, 1975b) to develop a model for natural ventilation with wind induced ventilation, in addition to thermally induced ventilation.

Another wind tunnel study was done for a typical single story poultry building by Bottcher *et al.* (1986). They used the pressure difference method and measurements of air inlet velocities to measure ventilation rates in a 1:25 open scale model.

Shrestha *et al.* (1990) measured the pressure difference over a 1:2 open scale model of a low-rise agricultural building. This building was tested outside, in an open country situation. They reported an inflow of air through the roof ridge opening for wind blowing parallel to the building length. This contradicts Bruce (1974, 1975b), who stated that the ridge opening is always an outlet (based on sealed model tests). In addition, Shrestha *et al.* (1990) presented equations to calculate the ventilation rates based on the pressure difference method.

Ventilation rate coefficient

ASHRAE (1981, 1989), Hellickson *et al.* (1983), Krishnakumar *et al.* (1985), Vickery and Karakatsanis (1987) and Vickery *et al.* (1983) presented a simpler model for wind induced natural ventilation, which is

$$Q = C_Q VA_T$$

where C_Q = flow coefficient
 A_T = total area of sidewall openings, m²

In fact, C_Q contains the combination of the discharge coefficient, and internal and external pressure coefficient differences. ASHRAE (1981, 1989) and Hellickson *et al.* (1983) proposed that C_Q values range from 0.2 to 0.3 for a wind angle of 0°, and 0.5 to 0.6 for a wind angle of 90°. This method is then easy for designers to use, however unprecise.

Etheridge and Nolan (1979), Vickery *et al.* (1983), Vickery and Karakatsanis (1987) and Krishnakumar *et al.* (1985) demonstrated that any change in the opening areas of the sidewall and the ridge produces a different C_Q curve.

Consequently, Swami and Chandra (1987, 1988) developed a computer package to predict wind induced natural ventilation for low-rise domestic buildings.

No literature was found describing computer software based on wind induced natural ventilation using the measurements of pressure coefficients around typical animal housing buildings currently being used in Canada.

OBJECTIVES

The objectives of this project were:

1. To create a computer program to design the necessary openings for various naturally ventilated livestock buildings for different climatic regions in Canada.
2. To use meteorological data (hourly temperature, wind speed and direction) as the testing method for the naturally ventilated buildings in those regions.

PACKAGE DESCRIPTION

General Flowchart

NatVent has been written in QuickBASIC 4.5 (Microsoft QuickBASIC, 1988). It has been constructed in a modular manner using a main program that accesses or calls many subprograms and subroutines to perform its functions. Figure 1 presents the general flowchart. It begins with a welcoming screen and proceeds to ask the User questions to gather input data. It merges this data with a previously stored bank of wind tunnel data and performs calculations. It then merges these results with a bank of User-chosen meteorological data and outputs the results into files in specific formats which the User can organize graphically.

WELCOME Section

The opening screen welcomes the user to the package and states the organization credited for its creation, the Ontario Ministry of Agriculture and Food, and gives a brief package description. The User is warned that the responsibility for using NatVent rests with him/her. NatVent then asks a set of questions to establish what the User wishes to do and which data to use. First it asks:

Do wish to (C)alculate ventilation rates or (W)ork with data?

This question gives the User the option to begin calculation on previously saved input data, or to enter new or change existing data in the data input section. If the User wishes to use existing data and run it through calculations, "C" is the response. Then NatVent guides the User into choosing which one of the fifteen directories to access and begins calculations. If the User wants to handle data, "W" is the response. Next it asks:

Do you wish to use (P)reviously sorted data or Input (N)ew data?

By choosing "P" or "N", the User informs NatVent to expect existing data or be ready to accept new building information. If the User chooses to call up previous data, NatVent needs to know which set. The User can recall a set of existing data by number or can request to see a list of existing data sets which includes the client's name, associated date and a descriptive title.

If the User chooses new data, NatVent will ask him/her which unit system to employ for the whole run, Imperial or Metric (SI). For previous data, NatVent uses the units system of the data already stored. There is a short delay for the chaining procedure from this program to the INPUT Section and the User is asked to wait.

INPUT Section

In this part of the package, the User communicates by answering NatVent's numerous questions. After answering a screenful of questions, NatVent always asks the question:

Do you wish to (C)ontinue, (M)odify the above data or (E)xit NatVent?

If the User approves his/her choices, he/she answers "C" and the next screen appears. If the User wants to change one, a few or all the answers that are on that particular screen, he/she answers "M", enters the question number and proceeds to modify the answer. Modification on a screen can go on indefinitely. The User can always quit the package at any point prior to the end by answering with "E". The data will not saved, however, the User can ask for a hardcopy of the answers prior to leaving NatVent.

The first screen of questions deals with establishing for whom the structure will be built. NatVent requests the client's name, the date, a descriptive title, the production type to be housed, and the required summer ventilation rate. The production type can be one of the following: calves, heifers, dairy cows, beef cattle, growing-finishing hogs, gestating sows, turkeys, poultry or plants in a single-arch greenhouse.

This is followed by a set of screens which ask the User to:

1) Choose one of thirty weather station sites across Canada, which is in the same topographical area as the building site.

2) Choose the number of critical temperatures against which the User wants to test the building, and specify them. The critical temperature is the outside temperature above which the User feels there could be a problem of heat stress with his/her livestock. This limits NatVent's search in the weather station's database for hourly recordings of temperatures as warm as and warmer than the critical temperature.

3) Choose the building orientation that the User wants to consider. The User has a choice of angles beginning at 0° and increasing in increments of 10° , 30° or 60° up to 360° , or specific angles that are multiples of 10° entered by the User. For NatVent's purposes, North is 0° , East is 90° , South is 180° and West is 270° .

The following screen tells the User about certain limitations of NatVent's range of variation. For instance, the building must be in an open country situation and cannot have annexes off the central long axis of the main building (i.e. no 'T' or 'L' shapes). Neither of these limitations prevents the User from making an assessment on a building with these shapes, but the resultant answers may not be accurate. Also, greenhouses must be single buildings with a gable roof. These limitations due to Choinière's (1991) original wind tunnel test model upon which NatVent is based. There is also a practical limitation to the program which states that the maximum number of openings on any surface is 140.

This is followed by a screen which checks if the building consists of two adjoining sections of the same width. If there are two sections, then the User is recommended to run NatVent twice.

The next screen contains questions for general building dimensions, such as length, width, sidewall height, and roof angle in degrees (Fig. 2). Each question provides minimum and maximum limits (see Table 1). The roof angle is used to find the peak height.

NatVent uses the next screen to show the User how to input data in an orderly fashion for each building surface. End walls are numbered 1 and 3 and sidewalls are 2 and 4, as shown in Fig. 3. Measurements and orientations for openings are based on a Cartesian grid with the "0, 0" in the left bottom corner of the surface as viewed by the User standing outside the building, facing that particular surface.

NatVent asks the User what type of openings are to be placed in a particular surface. For example, "END WALL number 1 openings" can have one of three options: intermittent, continuous or none present. This is the same for the other end

wall. Sidewalls 2 and 4 can have either continuous or intermittent openings and the roof can have chimneys, a continuous ridge or an intermittent ridge (Fig. 4).

If an answer for an end wall is "none present", then no measurement is taken and NatVent proceeds to the next screen. This would occur in a building comprised of two adjacent sections. For any surface, an answer of "continuous" would lead to a new screen in which NatVent asks for the width and height of the opening, the distances from the left corner and from the floor to the centre of the opening, and the number and width of posts in the opening. This last items allows calculating how much area is blocked by the vertical posts which detracts from the total opening area.

For any surface, an answer of "intermittent" openings (including chimney and intermittent ridge) leads the User to state how many openings. On the next screen, the User is presented with a table in which he/she is required to enter each opening's width and height, and the distances from the left corner and from the floor to the centre of the opening. The NatVent continues to the next surface. When it finishes with the roof, it has acquired the information it needs to calculate the flow coefficients, C_Q . It then asks the User if the building information is to be saved in a file directory so it can be accessed when the package is run again.

Calculating the Area for Each Opening

As the User inputs the dimensions of the desired openings, NatVent calculates the area. If an opening area is larger than the original model's, it must be divided to accomodate more than one measured coefficient, C_p . This allows for a better representation of the area by using more than one C_p for that particular opening.

The opening areas for the end and sidewalls are checked for sizing that is too large in either length (x-axis) or height (y-axis). The roof is only checked for sizing in the length (x-axis) dimension; the width of the opening is not important in this way because of the physical limitation when building the barn.

Hidden to the User, NatVent takes the continuous openings of any surface and treats them as intermittent locating the posts or roof trusses in positions of equal distance (length of continuous opening/number of posts). The resultant discrete opening areas are then checked for sizing and the correct number of C_p s are assigned. Table 2 shows the types of opening sizes that are considered for.

Selection of Model Data

Data for the NatVent package is based on wind tunnel studies for a typical naturally ventilated buildings. Experiments were performed in the 2 x 3 m low speed wind tunnel of the National Research Council of Canada, located in Ottawa, Ontario (Choinière *et al.*, 1990b, Choinière, 1991). The 1:20 scale model was based on Canada Plan Service's plan M-3433. It represents a typical dairy or swine, gable roof barn, measuring 12.2 m wide by 24.4 m long with 2.7 m high sidewalls and a roof slope of 4/12. It had two openings in either end wall that could be open or closed. Its sidewalls could remain closed, or contain a 800 mm or a 1100 mm high continuous

opening. The roof featured a 150 mm or a 400 mm wide ridge opening running continuously along the roof peak, or four chimney structures each measuring 600 mm by 600 mm. By combining these features, 12 different configurations were studied.

For this model building, Choinière (1991) provides a source of files containing the x-y coordinates for the pressure taps and the associated pressure. Figure 2 shows an example of the required building dimensions for NatVent. It also shows the types of sidewall, end wall and ridge openings that can be considered.

As demonstrated by Choinière *et al.* (1990b) and Choinière (1991), each building configuration has an effect on the pressure coefficient distribution over the building's surfaces. In those experiments, the model was rotated between 0° and 90°, only. With Natvent, a building is rotated for 360°, making windward walls leeward and visa versa. NatVent has to select which data file to use according to the particular surface at its relative position. The specific data file of pressure coefficients used depends on three factors: 1) the type of end wall, 2) the type of roof and 3) the type of sidewall. As shown in Figs. 3 to 5, these files were grouped under different configurations: open versus sealed model, end walls open or closed, sidewalls open to 800 mm or to 1100 mm, and the roof being either chimneys, or a 150 mm, or 400 mm wide ridge opening. Each of the five surfaces of the building is represented by a combination of these configurations.

Methodology for Surfaces

When the tested building is symmetric with respect to its sidewall openings, the data files chosen for the 0° to 90° range are used for the full rotation. However, a nonsymmetrical building may have different sidewall opening heights. Therefore, the two sidewalls are considered as four surfaces when the building is completely rotated. First, a sidewall and end wall face the wind (windward side), and when rotating past 180°, they face away from the wind (leeward side). The roof data is in the middle of the roof surface so it is not affected. The count up to seven surfaces becomes two end walls (2), one roof (3), windward sidewall (4) and leeward sidewall (5), then turn the building and the "windward" sidewall is now leeward (6) and the "leeward" sidewall is now windward (7). After orienting the surfaces, NatVent used a set of priorities to decide which pressure coefficient data to use. The following are the priorities between surfaces:

To decide which end wall and roof type to use:

1. If either end wall has at least one opening, then the open end wall configuration is used.
2. If the roof has chimneys, use the chimney configuration. Likewise, if the roof has a ridge between 100 and 250 mm, use the 150 mm ridge configuration, and if the roof has a ridge between 250 and 650 mm, use the 400 mm ridge configuration.

3. If any sidewall opening height is greater than 900 mm, then use the 1100 mm configuration. Otherwise, use the 800 mm configuration.

To decide which sidewall to use:

4. For the sidewalls themselves, if either sidewall is less than 300 mm, then the sealed configuration is used. If the measurement is between 300 mm and 900 mm, use the 900 mm configuration. If the opening is greater than 900 mm, then use the 1100 mm configuration.

Table 3 illustrates the choice of data files chosen for the example of a building featuring one end wall with an opening and the other end wall closed, the first sidewall with a 700 mm high continuous opening, the other sidewall with a 1000 mm high continuous opening, and the roof with a 200 mm continuous ridge.

Building Additions

Choinière *et al.* (1988) described the qualitative effects of a building addition on the airflow patterns and observed rates of decay of injected smoke. A building addition also has an effect on the pressure distribution along the building surfaces. NatVent is able to accommodate building sections, each with a minimum of 9.14 m lengths (Fig. 6).

Error Checking

NatVent has many data manipulations which remain transparent to the User. Some are as common as error checking for alphanumeric characters. That is, if NatVent knows to expect a number, then it will check the User's answer, character by character, for letters or more than one decimal point. If there is an error, NatVent will inform the User and request a new answer. If NatVent expects non-numerical characters, any letter and number will be admitted without question (such as the date, July 31 1991).

NatVent also checks for errors in opening arrangements in two ways. The first is mathematical. For example, if the summation of openings is greater than the wall's length, or a height of an end wall opening does not fit completely in the surface area, then NatVent will inform the User of the error and reask the question. The second is graphical. For example, when the User enters all the opening dimensions and there are no mathematical conflicts, then an outline of the surface appears in the screen and the openings are marked in blue. If the User does not like the opening placements, he/she can change them.

Using Previously Entered Data

The INPUT section can also handle previously entered data that have been stored in NatVent files. The User can access previous building configuration data and make alterations. NatVent presents the previous data in the same format as they were originally entered, using the same units. NatVent would show the User each screen of questions with the previous answers and the User has the option of continuing to the next screen, thereby accepting those data again, or modifying the data or exiting the package.

If the User wishes to modify the end wall, sidewall or roof configurations (e.g. alter intermittent to continuous), all previous data pertaining to that surface is lost and NatVent assumes that the User is entering new data. This procedure also is employed if the User wishes to maintain the same type of opening, but change specifics. For instance, if an end wall has intermittent openings, but the Users wants to increase their number, NatVent accepts the numerical change and asks the User to input the dimensions and distances per opening as though it was new data. NatVent is not capable of assuming which openings are to be kept as they are, and which are to be removed or added. The User must tell it specifically what he/she wants.

If the User wants a surface to have the same number of windows as before, but the placements of one or more are different, he/she accepts the previous number of openings, When the table of dimensions and distances appears, the User informs NatVent that there are modification to be made on the list. NatVent then asks the User which opening number, thereby providing access to the measurements and the User modifies the appropriate values and NatVent continues.

CALCULATION Section

As shown in Fig. 7, the CALCULATION section contains four programs. First, a specific pressure coefficient, C_{p_i} , has to be associated with each opening, A_i , at its central location (Fig. 8). Second, the pressure difference method is used to calculate the equilibrium internal pressure coefficient and the ventilation rate coefficients, C_Q , for each wind angle. Third, when all C_Q s have been calculated from the available data source, they are interpolated to obtain a C_Q versus wind angle of incidence curve.

Pressure Coefficient Grid over the Building's Surfaces

For each specific opening, A_i , entered into the INPUT section, a C_{p_i} is associated (Fig. 8). A procedure was established to accomodate buildings with different widths and lengths compared to the basic model tested.

Akins (1976) and Akins *et al.* (1979) discussed the effect of building length and width on the distribution of the pressure coefficients over the building's surfaces. For winds flowing perpendicular to the building length, the length effect is minimal on the

pressure distribution. This implies that the end walls or sidewalls could be expanded or shortened without difficulty. However, for wind parallel to the building length, the upwind sections of the sidewalls show large C_p variations for a length approximating the building width. The remainder of the sidewall seems to show a similar C_p distribution along the building.

From the scale model tests of Choinière (1991), there were 26 C_p measurements taken on both sidewalls, 8 C_p s on both end walls, and 20 C_p s over the length of the ridge. As shown in Fig. 9, the C_p s over the first 12 m are assigned to a predetermined location within L_1 while the remaining C_p s are distributed over the entire surface defined by L_2 .

The building model configuration has been defined in a three-dimension grid consisting of length, height and the associated pressure measured for each pressure tap location. If this has not been already done and the file is not stored, NatVent takes the database information for the model building and creates the grid. The method employed for creating this grid is the contour generating program of Kok and Begin (1981). The original data came from rotating the 12.2 m x 24.4 m (full size) building through seven angles: 0°, 10°, 20°, 30°, 45°, 60° and 90° (Choinière *et al.*, 1990b, Choinière, 1991). If the new building is nonsymmetrical, there can be seven surfaces to consider, five standard surfaces and two sidewalls that change source files depending on whether they are on the windward or leeward side. Therefore, for each completely new building configuration, there are at least seven angles times five or seven surfaces for a total of 49 grids to prepare.

The next step takes the x, y coordinates of the new building and fits them to the tested model. The actual barn model scaled up to full size measured 11.76 m wide by 24.24 m long by 2.7 m high due to minute inaccuracies when cutting the plexiglass to size and assembling the building. For the sidewall and roof lengths, if they are less than 24.4 m, there is no transformation of the x coordinate. If these lengths are greater than 24.4 m, the first 12.2 m remain the same and the remainder is scaled up or down linearly with the following formulas:

$$x(j, i) = (x(j, i) - 12.12) / xfactor + 12.12$$

$$xfactor = (blength - 12.12) / 12.12$$

where, x = location of opening centre, length (m)
 j = surface number
 i = opening number on j surface
 $blength$ = barn length (m)
 12.12 = half the actual length of the scaled up model building
 $xfactor$ = multiplier, defined above

For end walls, the coordinates are scaled up or down with reference to the building's width (Fig. 10). For example, if the new building width is 24.4 m, then the x coordinates are scaled down by a factor of two. The same principle, if not the same factor is used for the y coordinate of the end wall and the sidewall height.

These x, y, and z coordinates are already known for the seven angles between 0° and 90°. In this step, the building is rotated and coordinates are calculated for the angles between 90° and 360° to determine the pressures operating on each building opening for each wind angle tested. The total number of angles considered is 24.

Ventilation Rate Coefficients Curve

The pressure difference method is used to calculate the internal pressure coefficient and the ventilation rate coefficients for the 24 available wind angles of incidence. The building's internal pressure coefficients, $C_{p_{in}}$, has been found by iterating to a difference of 0.0001, so that $Q_{in} = Q_{out}$. The C_Q values associated with each mirrored angle between 0° and 360° are used (0°, 10°, 20°, 30°, 45°, 60°, 90°, 120°, 135°, 150°, 160°, 170°, 180°, 190°, 200°, 210°, 225°, 240°, 270°, 300°, 315°, 330°, 340°, and 350°) to find the equation coefficients defining the smooth curve(s). The cubic spline interpolates the C_Q values for all intermediate angles. Figure 11 shows a typical example of a C_Q curve. NatVent sorts the numbers and returns values for every ten degrees, starting at 0° and ending and 350°. This particular part of the package originated from Forsythe *et al.* (1977).

METEOROLOGICAL Section

NatVent can read many years of weather data stored in files that have been modified to contain the date, number of hours/day with a temperature $\geq 20^\circ\text{C}$, hour, dry bulb temperature $\geq 20^\circ\text{C}$ (68 F), wind speed (km/h), and wind direction (multiples of 10°). It adjusts the anemometer's sensitivity problem with calm periods: 0 km/h, 0° (north) (Zemanich *et al.*, 1991) by checking the previous wind speeds and directions, and adopting those directions until the windspeed increases again. For the User's chosen critical temperature(s) and building orientation(s), NatVent calculates average ventilation rates with their standard deviations, the number of events of consecutive hours of low ventilation rates, and the percent of ventilation rates within established ranges.

A modification of the reading of weather data was introduced to eliminate the condition of zero wind speed, since wind never dies down to zero. The original weather data gathered by Environment Canada's stations were in units of miles per hour. Therefore, a sensitivity of 1 mph equals 1.6 km/h and is rounded to 2 km/h. When the anemometer could not perceive a wind speed (< 1 mph), the 0 value was adopted in either units. By assuming that the 0 value could also reflect 0.5 mph (0.8 km/h), then these instances could be redistributed over the first few ventilation rates, depending upon the building orientation (Zemanich *et al.*, 1991).

The weather stations chosen for the overall project for Canada were chosen by three criteria:

- 1) preferably, the stations collected data for at least 30 years,
- 2) the wind direction data were measured within the sixteen quadrants of the compass and
- 3) they were near major pork, dairy, beef, poultry, and greenhouse production regions.

For the User to decide which weather station data set to use, boundary lines for different regions across Canada were mapped. Each resultant area contained one representative weather station. Suchorski-Tremblay *et al.* (1990) explained the methodology for this mapping. The maps considered for the divisional boundaries are a relief map and a topographical profile. The information from these maps aided in locating potential barriers or directors of air movement, such as mountains and valleys. Additional map data help choose the location of cities for NatVent. Table 4 lists the Canadian cities chosen.

RANKING Section

After the METEOROLOGICAL section is completed, NatVent transfers the following information to the RANKING section. Suchorski-Tremblay *et al.* (1990) presented the methodology used for the RANKING section in order to obtain a preferred building orientation. For each building orientation and critical temperature, the package calculates: 1- the number of events of consecutive hours of low ventilation rates (below the User-established ventilation rate) and 2- the average ventilation rate according to a procedure established by Choinière (1989). NatVent calculates the slope, x- and y-intercepts of equations of the natural logarithm of the number of events of low ventilation versus their consecutive hours. It then asks the User to choose a ranking scheme, based on those calculations. NatVent can take into consideration a variety of values involved in the ranking system:

- 1) the average ventilation rate, R_a ;
- 2) the initial number of hours for one event of low ventilation rate, R_h , also y-intercept;
- 3) the maximum number of hours of consecutive low ventilation rates, R_t , also x-intercept; and
- 4) the slope of the curve of the natural logarithm of the number of events of low ventilation rates versus consecutive hours, R_s .

For all the possible ranking systems that the User can use, the assignment of points are:

- R_a : the greater the average, the higher the point;
 R_h : the lower the number of 1-hour events, the higher the point;
 R_s : the steeper the slope, the higher the point; and
 R_t : the lower the number of consecutive hours, the higher the point.

The default ranking scheme is

$$RANK = \frac{1}{2}Ra \times \frac{1}{2} \left(\frac{1}{3}Rh + \frac{1}{3}Rs + \frac{1}{3}Rt \right)$$

However, NatVent gives the User the option of creating his/her own ranking scheme by asking the User what value to give to each of the four ranking variables, Ra, Rh, Rs and Rt, in the form of percentages. The User is reminded that the sum of the percents must equal 100% to make sense at the end. To enter in values such as 1/3 as percentages, put at least two numbers after the decimal place.

OUTPUT Section

NatVent's OUTPUT Section consists of two types of results: a table containing results and a collection of .PRN files which the User imports into LOTUS 1-2-3 (Lotus, 1989) to generate graphic representations.

The .PRN files the User imports into LOTUS 1-2-3 are the following: the percent frequency for each 1000 L/s (1000 cfm) ventilation rate are calculated as a histogram, and the number of events of less than the required ventilation rate for a given number of consecutive hours. The latter can also be graphed as an exponentially declining curve. When the natural logarithm of the number of consecutive events is taken, the curve becomes a straight line.

The proposed output contains the preferred building orientation for the selected climatic zone, the expected average ventilation rate, and the percentage of time the ventilation rate is above the desired summer ventilation rate. Also, it is planned that a future program may be able to tell the User if the amount of opening is adequate according to the general level of satisfaction from the agricultural producers.

EXIT Section

NatVent asks the User if the information from the Input section is to be printed on paper before the package ends. Then the User exits out of NatVent.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge G. Garland, P.Eng., Head of the Engineering Resources Unit, Resources Management Branch; V. Spencer, P.Eng., Manager of the Resources Management Branch, Guelph, Ontario; K. Boyd, P.Eng., Education and Research Fund, Ontario Ministry of Agriculture and Food, AgriCentre, Guelph, Ontario; C. Weil, P.Eng. Head of the Agricultural Engineering Department, Alfred College; M. Paulhus, P.Ag., Principal, Alfred College of Agriculture and Food Technology, Alfred, Ontario; and Dr. E. Lister, Director, Animal Research Centre, for their support and funding.

Special thanks are addressed to Denis Chaput of the Land Resources Institute, Agriculture Canada, for supplying the weather data. Thanks are extended to Rick Pella, draftsman, ARC, Agriculture Canada, for his extensive help and contribution.

The financial support provided by Ontario Hydro, Technical Services and Development for Agriculture, Canadian Electrical Association, Utilization, Research and Development, and by the Ontario Pork Producers Marketing Board, Ontario Ministry of Agriculture and Food, Education and Research Division, Sun-North Systems Ltd., Seaforth, and Faromor Inc., Shakespeare, Ontario, were greatly appreciated.

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Table 1. Building dimension limitations.

Measurements	Minimum		Maximum	
	Imperial	Metric	Imperial	Metric
Building Length	30 ft.	9.14 m	1000 ft.	304.80 m
Building Width	20 ft.	6.10 m	90 ft.	27.43 m
Sidewall Height	8 ft.	2.44 m	16 ft.	4.88 m
Roof Angle	14°		22.6°	

Table 2. Four types of opening dimensions manipulated by NatVent.

Width (w)	Height (h)	Manipulation
$w \leq 2.24$ m	$h \leq 1.10$ m	Standard opening size, leave as is.
$w > 2.24$ m	$h \leq 1.10$ m	Divide opening equally into sub-openings, each new opening having a width ≤ 2.24 m.
$w \leq 2.24$ m	$h > 1.10$ m	Divide opening equally into sub-openings, each new opening having a height ≤ 1.10 m.
$w > 2.24$ m	$h > 1.10$ m	Divide opening equally into sub-openings, each new opening having a width ≤ 2.24 m and a height ≤ 1.10 m.

Table 3. Example of data source files for building example.

Surface Description	End Wall & Roof Files	Sidewall Files For Windward	Sidewall Files For Leeward
End walls, open & closed	open end wall	open end wall	open end wall
Roof, 200 mm	roof 150	roof 150	roof 150
Sidewall, 700 mm		sidewall 800	sidewall 1100
Sidewall, 1000 mm	sidewall 1100	sidewall 1100	sidewall 800

Table 4. List of cities in Canada chosen for NatVent's meteorological database.

Alberta	British Columbia	Manitoba
Calgary	Hope	Brandon
Edmonton	Kamloops	Winnipeg
Grande Prairie	Penticton	
Lethbridge	Vancouver	
Red Deer		
New Brunswick	Nova Scotia	Ontario
Moncton	Truro	Barrie
		London
Prince Edward Island	Québec	North Bay
Summerside	Montréal	Ottawa
	Québec City	Saint Catharines
	Rivière du Loup	Simcoe
	Sherbrooke	Toronto
		Trenton
Saskatchewan		Waterloo
Estevan		Windsor
Prince Albert		
Regina		
Saskatoon		

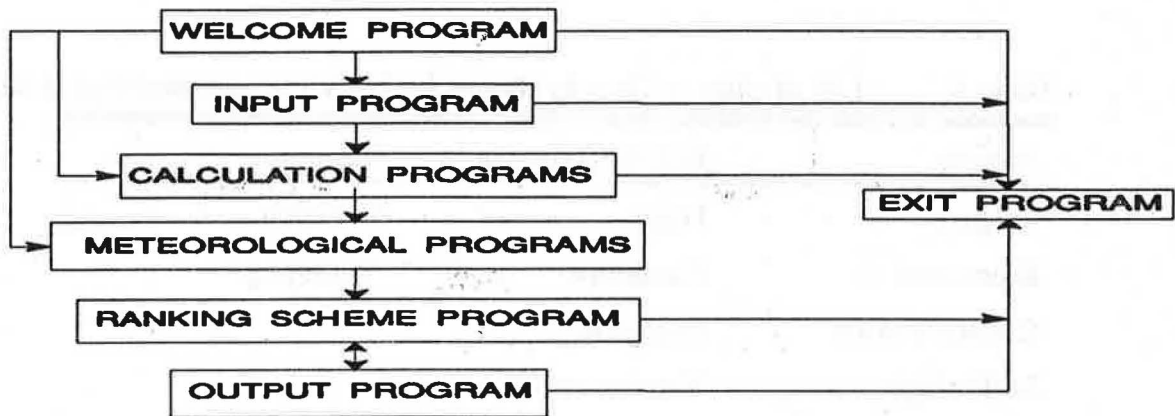


Figure 1. Flowchart for NatVent.

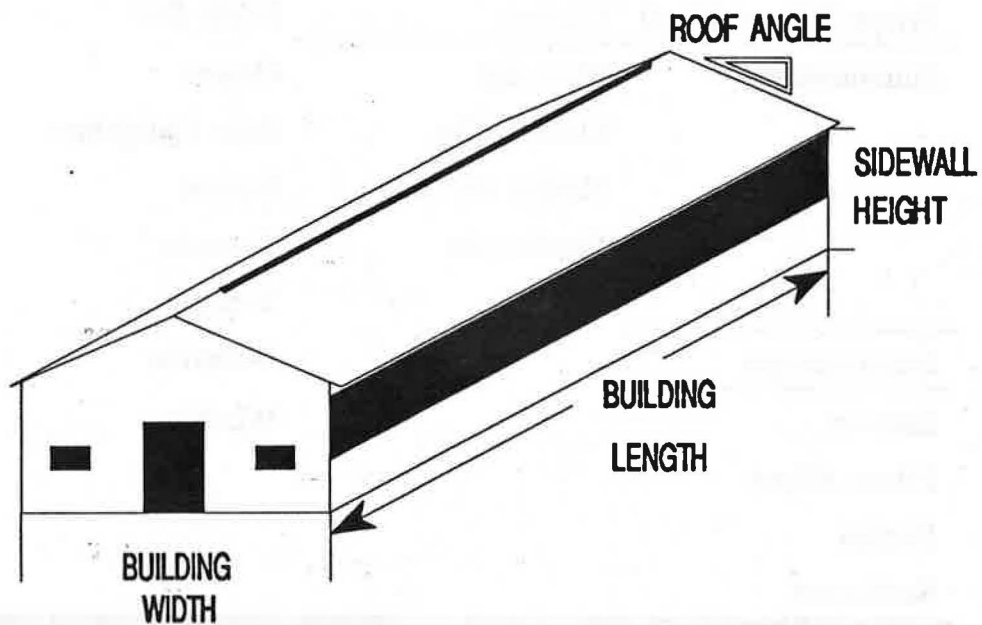


Figure 2. Building dimensions and openings required for NatVent.

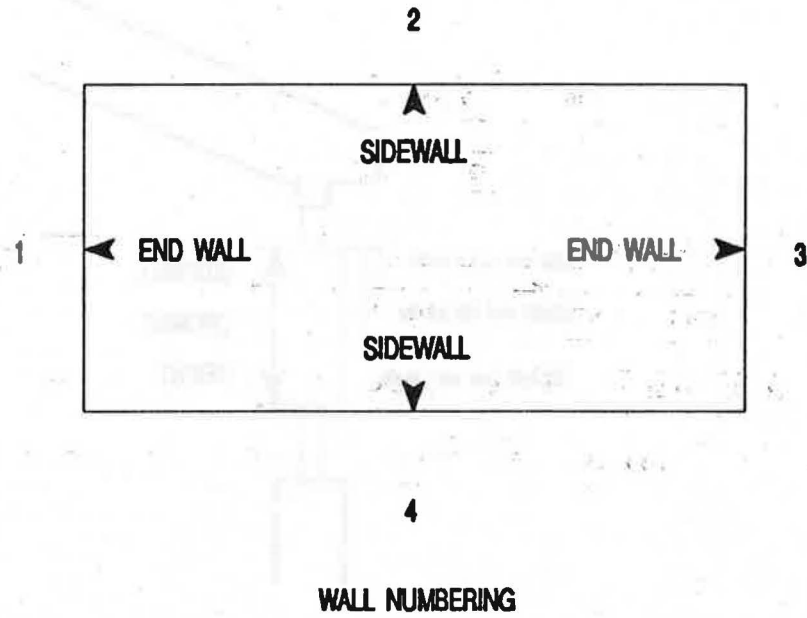


Figure 3. Sidewall and end wall identification.

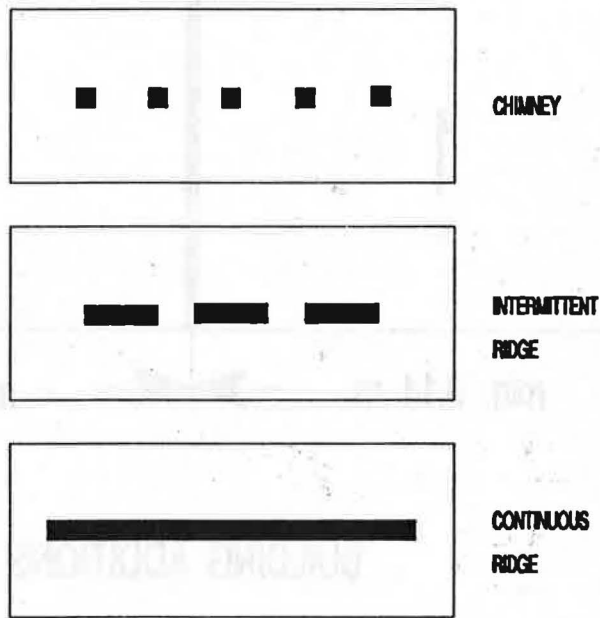


Figure 4. Types of roof openings.

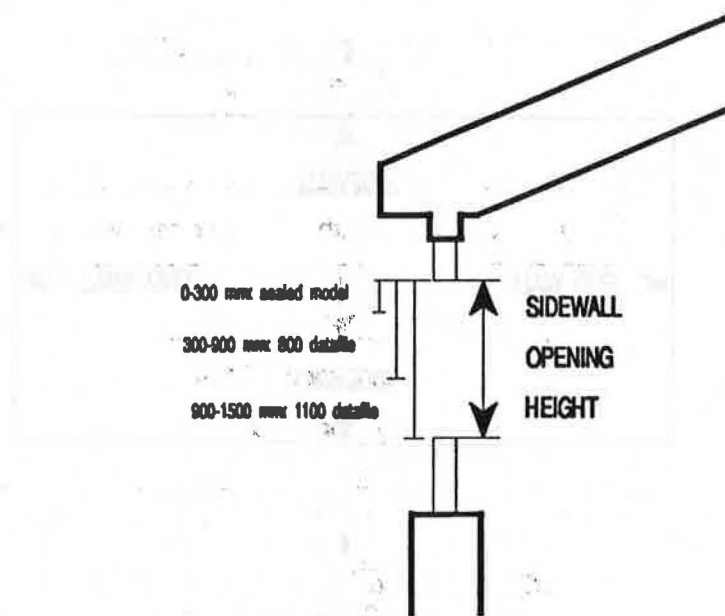


Figure 5. Datafiles used for different sidewall opening heights.

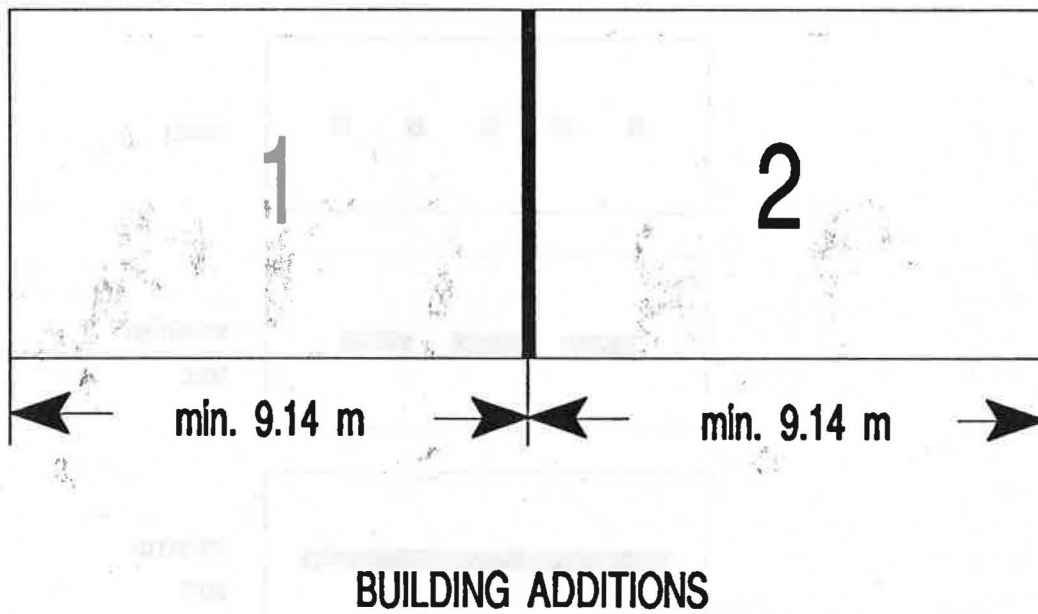


Figure 6. Building additions with NatVent.

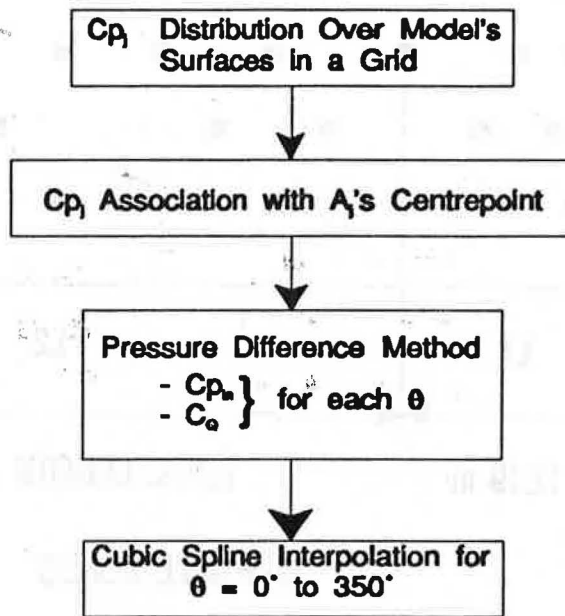


Figure 7. Flowchart for CALCULATION section.

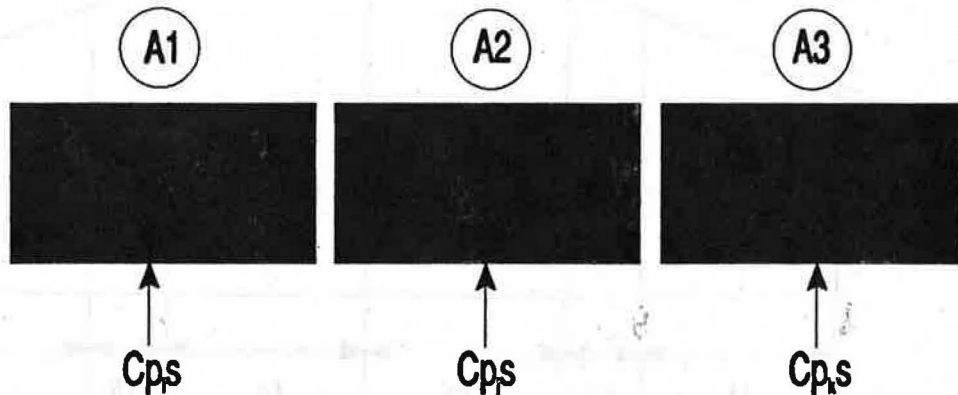


Figure 8. Association of pressure coefficients to specific opening areas.

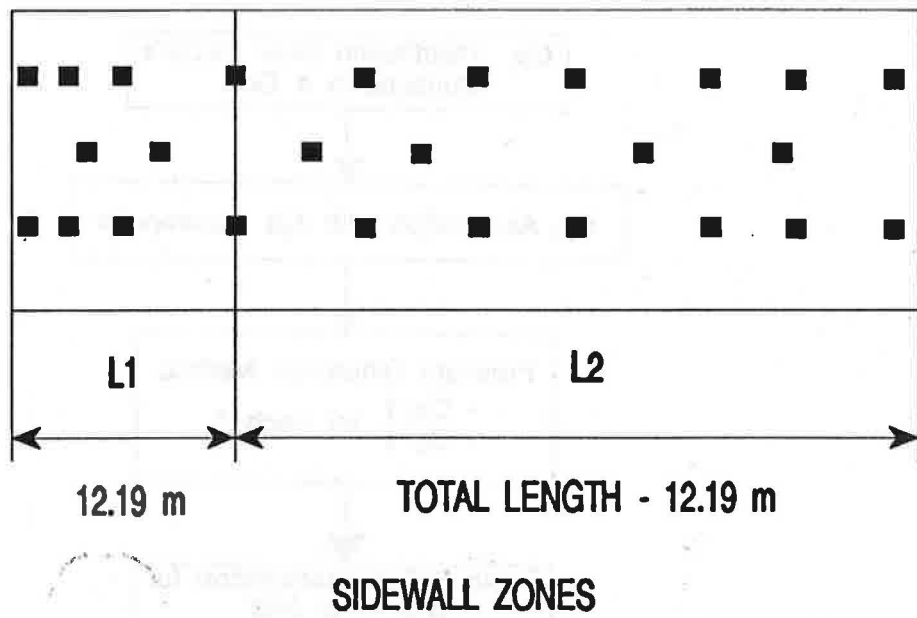


Figure 9. Cp distribution over the sidewall.

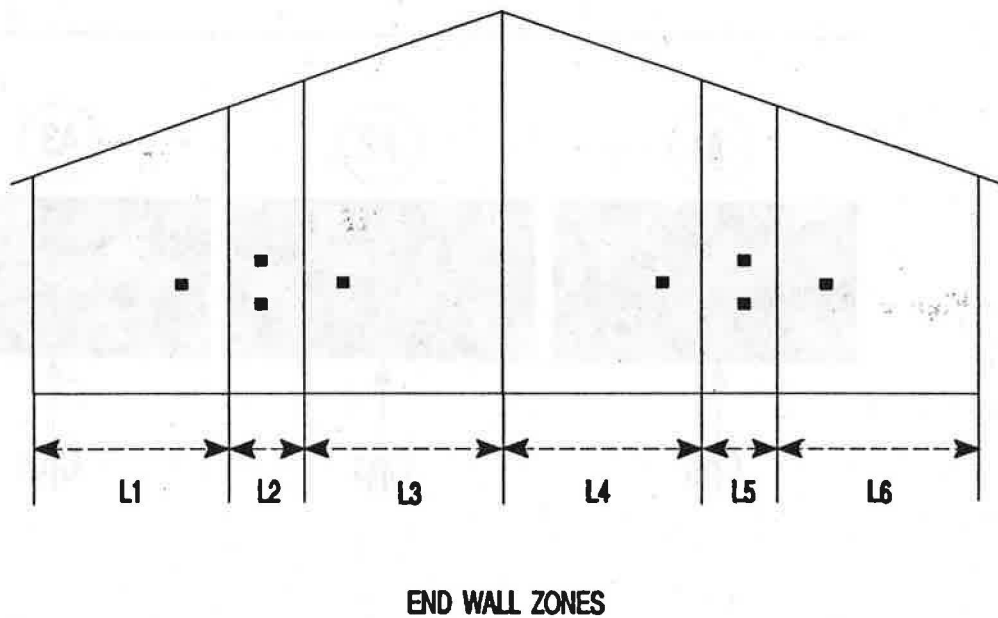


Figure 10. Cp distribution over the end wall.

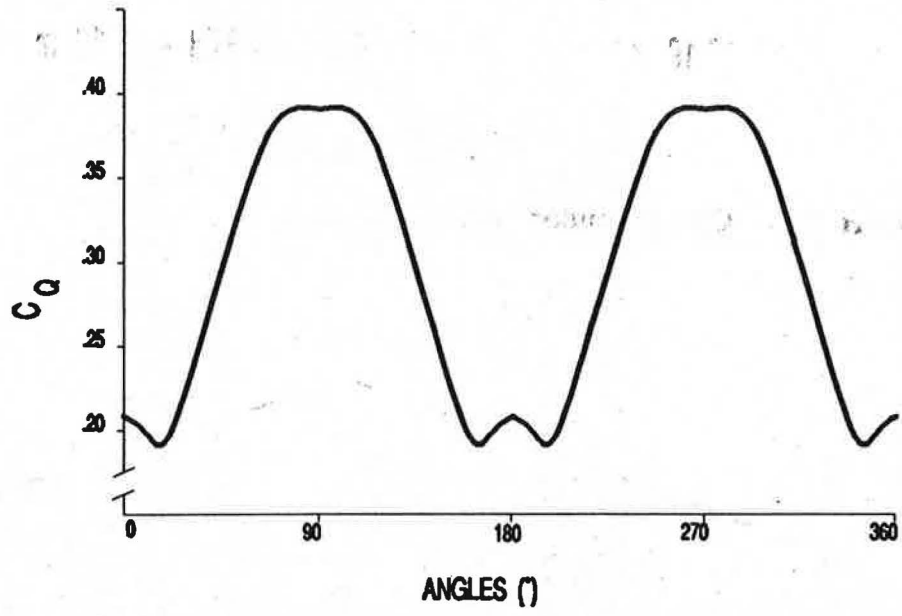


Figure 11. Typical C_Q curve.

