A COMPUTER MODEL
FOR PREDICTING
NATURAL VENTILATION RATES

A THESIS
Presented to
The Faculty of the Division of Graduate Studies
By
David William Nutt

In partial Fulfillment
of the Requirements for the Degree
Master of Architecture

Georgia Institute of Technology
January, 1982

A COMPUTER MODEL
FOR PREDICTING
NATURAL VENTILATION RATES

Approved:

Kalev Ruberg, Chairman

Bill Witte

John Templer

Date approved by Chairman 3·12·82

ACKNOWLEDGEMENT

The successful completion of this thesis depended on the efforts of many individuals. I wish to thank professors Kalev Ruberg and John Templer for their guidance and counseling. I am especially grateful to Bill Witte for his time, interest, and enthusiasm. I also wish to recognize Craig Bennett for instruction in computer programming, Deborah Reid for typing with a smile in sickness and in health, Charlotte Matthews for assisting with research, my fiancee, Anne Barnes for her love, patience, and understanding, my parents for their support, and the Lord for giving me patience and contentment through the past year's work.

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ABSTRACT

The purpose of the thesis is to describe the algorithms and use of a computer model NATVENT. This program determines natural ventilation rates induced in buildings by wind pressure and thermal stack effect. The ventilation rates are computed as a function of the thermal comfort achieved in specific building geometries described by the user. From the output data, the user can determine the feasibility of ventilating buildings by natural means. Equations used to describe natural ventilation phenomenon have been picked from an extensive literature review. Explanations of algorithm structure and supportive theories for each equation are included in the thesis. NATVENT is illustrated by the analysis of natural ventilation potential for an office building in Atlanta, Georgia. Calculations are made hourly based on example days taken from local weather data.

INTRODUCTION

INTRODUCTION

Natural ventilation is a cooling method that may lead to the reduction of air conditioning and energy use in buildings. Decrease in air conditioning energy use and mechanical fresh air ventilation are possible by maximizing wind induced ventilative cooling during hot-humid weather and by crediting the effect of infiltration during cold weather. Since the availability of natural ventilation varies with climate, prediction methods are necessary to determine ventilation potential over an annual cycle. Due to dependence on random weather patterns, a recursive algorithm is required for analysis of annual performance based on yearly climates.

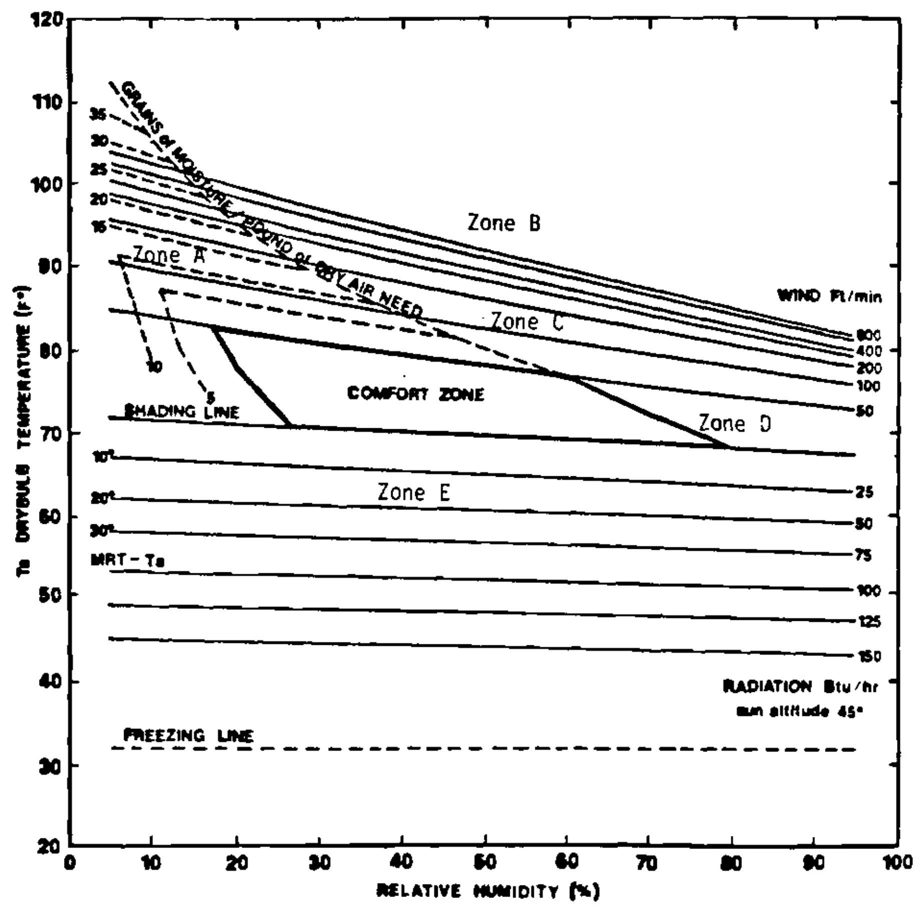
Prediction of natural ventilation is possible with analogue models, graphic methods, or mathematical models. For analysis of annual performance, computer models are necessary for applying the mathematical models to large weather data bases for analysis of long term building performance. The purpose of this thesis is to describe the algorithms and use of a computer model, NATVENT. The equations used in NATVENT are selected from an extensive literature review of natural ventilation prediction techniques.

i.1 Fundamentals of Natural Ventilation

Natural ventilation is induced by the difference between positive and negative air pressures acting across openings or windows in buildings. These pressures are created by differences in air density due to temperature and wind. Infiltration and exfiltration resulting from the thermal stack effect is dependent on pressure differences from air density variations caused by outdoor and indoor air temperatures, the vertical distance between inlets and outlets, and the total area of opening. The amount of ventilation induced by wind is dependent on building openings, internal friction, and the total area of openings on the building face.

Since most buildings use explicit air handling to meet fresh air requirements, stack induced infiltration of cold air is purely wasteful. However, it is not entirely possible to eliminate building leakage. Therefore, it is advantageous to predict the volumetric airflow through cracks in a building so that mechanical intake of fresh air can be reduced. Prediction techniques may also be used to investigate methods of reducing stack effect.

Natural ventilation is only desirable during hot humid conditions when thermal comfort can be restored by air velocities less than 300 ft/min. air velocities greater than 300 ft/min cause physical disturbances and psychological discomfort. Air movement cools the body by increasing the rate of evaporative and convective heat loss. The capability of air for ventilative cooling is limited by high humidities. A pizometric chart, such as the one developed by Dr. E. Arens [61] illustrates the relationship between the climatic elements and comfort. As Figure I.1 shows, air velocity can be used to achieve comfort in a range of temperatures and humidities beyond the delineated comfort zone. Pizometric charts have also been used to plot corresponding points of dry bulb temperature and relative humidity to produce a daily plot that reveals the hourly intervals for each month where climate conditions are



Climate	Requirements to restore thermal comfort
Zone A	Cooling by humidifying and ventilating
Zone B	Cooling by removal of heat and/or humidity
Zone C	Cooling by ventilating
Zone D	Cooling by dehumidifying
Zone E	Cooling by radiation

FIGURE i.1

Arens Bioclimatic Chart

comfortable and indicates measures required for thermal comfort. The varying potential of natural ventilation can be seen in a comparison of bioclimatic mapping of climate data for New York and Miami. Figures I.2 and I.3 [62] indicate that ventilative cooling in New York is trivial while in Miami it can be used approximately 60% of the year to restore thermal comfort. The degree to which ventilative cooling may be induced naturally is dependent on internal and external building geometries, area of openings, and available wind speeds.

i.2 NATVENT: Described and Used

A natural ventilation availability computer model named NATVENT has been developed using accurate stack effect and wind pressure algorithms. NATVENT is a modular program which uses separate subroutines to:

A. Initialize input

B. Change input

C. Adjust comfort parameters

D. Determine if natural ventilation is induced by stack effect or wind pressure.

E. Assign appropriate discharge coefficients for each opening to determine internal friction.

F. Assign the appropriate pressure coefficients for a specified rectangular geometry.

G. Calculate stack induced ventilation.

H. Calculate wind induced ventilation.

I. Reduce ventilation rate based on the incidence angle of wind acting on the openings.

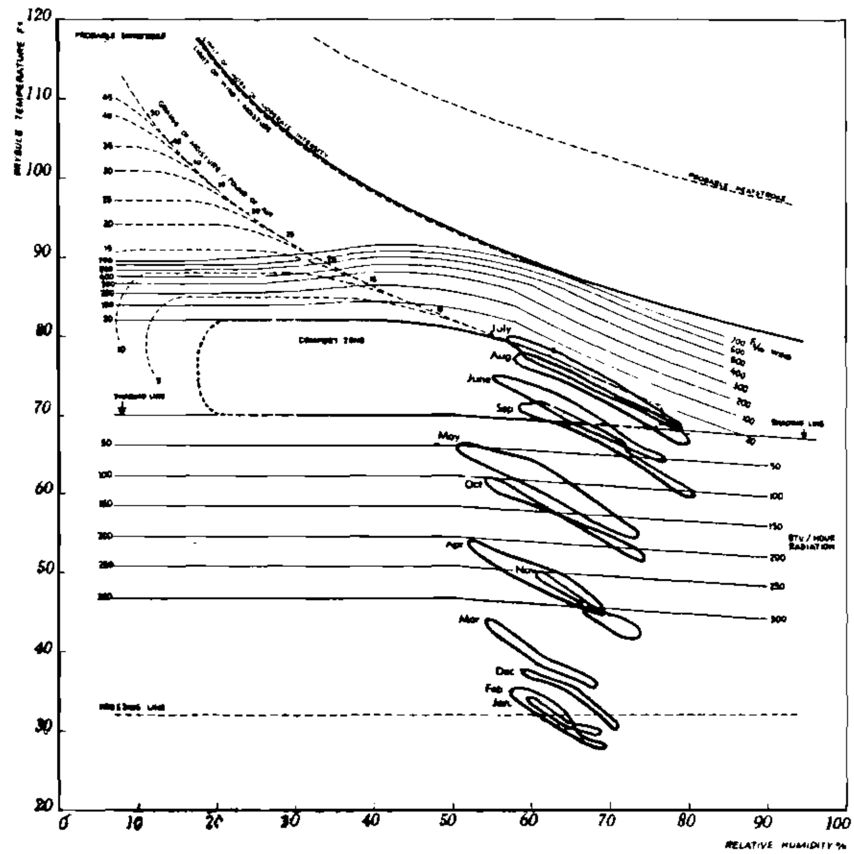


FIGURE i.2

Bioclimatic mapping of climate data for the New York area illustating the need for wind induced ventilative cooling is very small.

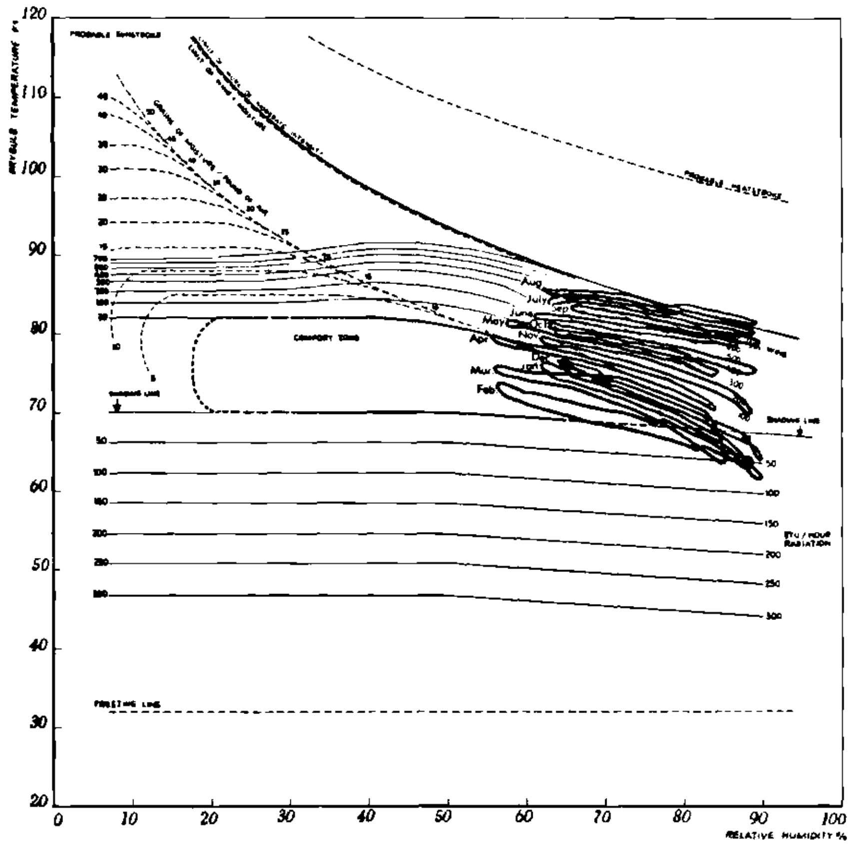


FIGURE i.3

Bioclimatic mapping of climate data for the Miami area indicating great potential of wind induced ventilative cooling.

Calculations are made on an hourly basis using local weather data. With proper inputs described by NATVENT, the user may:

A. Describe external and internal building geometries.

B. Select the mean radiant temperature, clothing insulation level, and define the appropriate activity level.

C. Calculate the size of openings needed to induce ventilation for cooling during hot-humid conditions and meet fresh air requirements during cold and temperate conditions.

D. Test the annual performance of user specified openings by calculating the ventilation rate produced by wind and thermal stack effect.

E. Determine the length of the cooling, intermediate, and heating seasons.

F. Determine the number of hours annually where thermal comfort is restored by wind induced cooling.

G. Change input and re-run the program.

The computer model is designed so that a knowledge of natural ventilation principles is not necessary to use the program. However, the user can gain an understanding of the controlling variables of stack effect and wind induced ventilation by testing various opening configurations, opening sizes, external building geometries, and internal building geometries. The feasibility of ventilating buildings by natural means can be determined by testing these parameters against comfort critieria.

NATVENT is described in detail and its use is illustrated by determining the seasonal natural ventilation potential in an Atlanta high rise office building. The effect of various internal geometries and opening areas on two and four sides of the building are examined. The results of four example runs included illustrate the following:

A. Infiltration of cold air induced by stack effect is minimized by reducing crack areas and preventing air from flowing between floors. The infiltration rates calculated provided from 5% to 12% of the fresh air requirements specified for the office building.

B. Thermal comfort can be restored during hot-humid conditions by wind induced ventilation through an open office plan for approximately 70% of the cooling working hours. A decrease in performance can be observed if:

   1. Small openings are used.
   2. Openings are located on only two sides of the building.
   3. Internal friction is increased resulting from several rooms in series.

C. Ventilation induced by stack effect is trivial for summer cooling in a typical office building.

D. Wind induced ventilation can be used for approximately 85% of the cooling working hours to supply fresh air when outdoor temperatures and humidities define comfortable conditions.

E. Mechanical conditioning is required for approximately 12% of the annual working hours for cooling purposes.

F. Mechanical ventilation is necessary to supply heated fresh air, 48% of the annual working hours.

The computer program may also be used to model the effect of varying radiant temperatures, clothing levels, activity levels, and external building geometries on natural ventilation availability for cooling and fresh air supply. NATVENT requires further work to eliminate the following limitations:

A. Calculation of seasonal performance is not precise due to simplistic assumptions of building heating and cooling needs. Performance figures quoted in this work are based on outside air temperatures and the relationship to comfort conditions rather than actual building cooling or heating seasons.

B. Only two data files (average days and selected days) have been written for Atlanta. A more precise method would access yearly weather data.

CHAPTER I

SELCTION OF AVAILABLE NATURAL VENTILATION PREDICTION TECHNIQUES FOR A COMPUTER MODEL

1.1 Methods of Calculating the Dominating Energy Source of Natural Ventilation

1.2 Methods of Calculating Stack Effect

1.3 Electric Analogue Technique

1.4 A Chart For Predicting Ventilation Caused by Stack Effect

1.5 Charts for Predicting Ventilation Caused by Wind Pressure

1.6 Mathematical Models and Wind Tunnel Prediction Techniques

1.7 Wind Pressure Difference Method

CHAPTER I

SELECTION OF NATURAL VENTILATION PREDICTION TECHNIQUES FOR A COMPUTER MODEL

A computer model NATVENT has been written to determine the potential of cooling with natural ventilation. Many methods are available for natural ventilation analysis. But all are lengthy precedures that require either extensive experimentation, or repetitive mathematical calculation. The latter is well suited to computer modeling.

A computer model that determines the percentage of hours annually where thermal comfort and fresh air requirements are achieved by natural ventilation should include the following (Figure 1.0):

A. User input

B. A data file with hourly readings of dry bulb temperature, relative humidity, wind speeds, and wind direction.

C. An algorithm that determines whether the driving force of natural ventilation is either the stack effect or wind pressure.

D. An algorithm that determines the ventilation resulting from stack effect.

E. An algorithm that determines ventilation resulting from wind pressure.

F. An algorithm that determines the percentage of hours where thermal comfort is achieved.

G. Output

In this Chapter, an extensive literature review of available

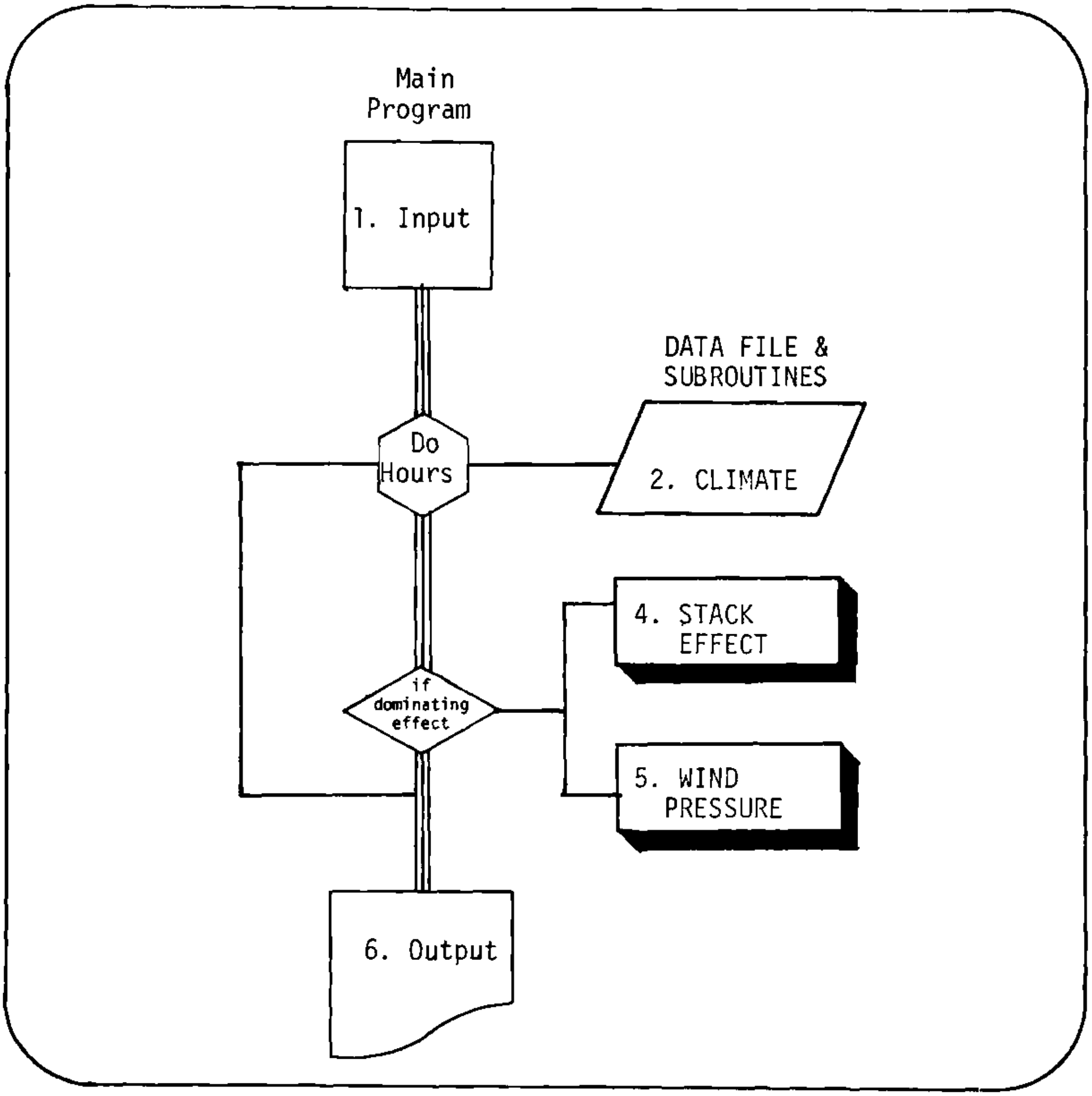


FIGURE 1.0

Flow chart for a natural ventilation availability program.

TABLE 1.0
GLOSSARY OF UNITS

A	=	Area of Opening
A_i	=	Area of Inlet (sq. ft.)
A_o	=	Area of Outlet (sq. ft.)
C_d	=	Discharge Coefficients
C_2	=	Dynamic Loss Coefficient
C_o	=	Coefficient of Opening
C_p	=	Pressure Coefficient
Cp_1	=	Pressure Coefficient (windward side)
C_{pw}	=	Pressure coefficient (windward side)
C_v	=	Wind velocity coefficient
g	=	Gravity (32 ft./sec^2)
h	=	Distance between centerline of inlets and outlets
h_{nz}	=	Distance detween neutral zone and center line of opening (ft.)
Q	=	Volumetric airflow (ft 3/hr)
Δt	=	Temperature diffential between infiltrating and exfiltrating air (°F)
t_i	=	Temperature of infiltrating air (°F)
t_{nz}	=	Temperature difference between opening and neutral zone (°F)
t_o	=	Temperature of exfiltrating air (°F)
T	=	Absolute Temperature (550°R)
V_1	=	Mean air velocity at a point of interest (ft/sec)
V_{10}	=	Mean wind velocity at a reference height of 100 meters
V_{mi}	=	Mean indoor air velocity (ft/sec)
V_{ai}	=	Average indoor air velocity
V_o	=	Average air velocity at each opening (ft/sec)
V_z	=	Reference wind velocity at a height +
X	=	Ratio of window area to wall area
Z_a	=	Local anemometer height (10 meters)
Z_r	=	Reference dynamic pressure height at a height r
α	=	Ground roughness

natural ventilation prediction techniques is presented. These methods may be classified into three groups:

A. Algebraic methods used with wind tunnel testing

B. Mathematical models derived from full-scale measurements and/or wind tunnel testing

C. Charts based on the results of full scale or wind tunnel testing.

Because of the limitations of charts and the expenditure involved in full scale and wind tunnel testing, mathematical models are clearly the most applicable in a computer model. In this Chapter algorithms for the dominating ventilation effect (Section 1.1.3); stack effect induced (Section 1.2.3), and wind induced ventilation (1.7) are selected for computer application.

1.1 Methods of Calculating the Dominating Energy Source of Natural Ventilation

There are two conditions that create air pressure differences used to promote natural ventilation:

A. Pressure differences due to variation in air density with height, created by differences in air temperature, referred to as the "Stack Effect". (Table 1.1.a) [1]

B. Pressure differences due to wind forces on buildings. (Table 1.1b) [1]

If wind velocities are low so that the stack effect ventilation dominates, air will enter through the openings on the lower levels and leave through the openings on the upper levels (Figure 1.1) [2]. As the wind velocity increases, there is a point where internal air flows

Effect	Pressure diff.	Conditions
Stack effect – residential	0.01 in. WG (0.254 mm WG)	Height 15 ft (4.6 m) Temp. diff. 20 °F (11 °C)
Stack effect – fire beds	0.015 in. WG (0.38 mm WG)	Fire bed 1 foot (0.3 m) deep

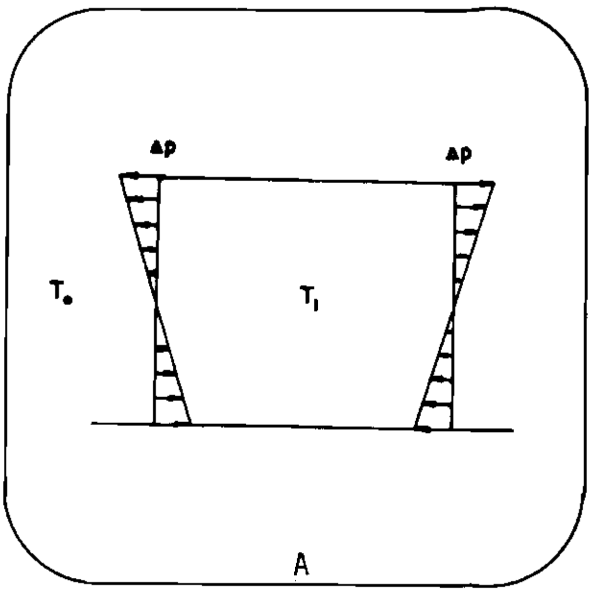
TABLE 1.1a

Common Stack Effect Pressures

Effect	Pressure diff.	Conditions
Wind-exposed area	0.04 in. WG (1.016 mm WG)	Windspeed 8 5 mph (3 8 m/s)
Wind-built up area	0.004 in. WG (0.102 mm WG)	Windspeed 2.8 mph (1.25 m/s)
Stack effect – Heated flues	0.07 in. WG (1.78 mm WG)	Flue height 27 feet (8.2 m) Temp. diff. 100 °F (55.5 °C)

TABLE 1.1b

Common Wind Pressures



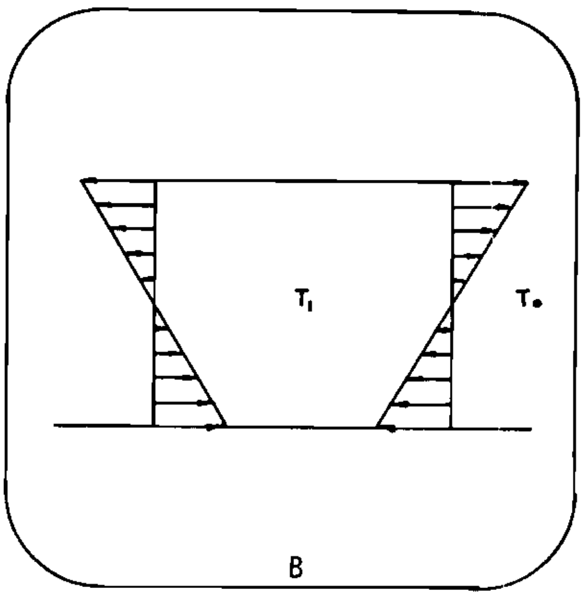


FIGURE 1.1

Stack effect pressure distribution on building surfaces.

move in conjunction with wind (figure 1.2) [2].

Even though the stack effect and wind pressure may act simultaneously on a building, it has been shown by Jackman [3] that the combined action is approximately equivalent to that of the greater of these motive forces acting alone. Therefore, the dominating energy source should be determined so that the correct method of predicting ventilation induced by either the stack effect or wind pressure will be used.

1.1.1 Dominating Effect Equation Presented By Wise. Wise has illustrated diagrammatically and mathematically [4] that the stack effect will dominate when:

$$\frac{(1/2 \cdot \Delta C_p)^{0.5}}{\left[\frac{(\Delta t \cdot g \cdot h)^{0.5}}{(T \cdot V_z^2)}\right]} < 1 \qquad \text{(Equation 1)}$$

WHERE:

ΔCp = Pressure coefficient differential

Δt = Inside and outside temperature differential (°F)

T = 550°R (absolute temperature)

g = Acceleration due to gravity (32 ft/sec^2)

h = Vertical distance between openings (ft)

V_z = Reference wind speed at a height z (ft/s)

The critical variables in the equation are the pressure coefficient diffential (C_p) and reference wind speed (V_z). Wind dominates stack effect when pressure differentials and wind speeds are high.

1.1.2 Dominating Effect Algorithm Presented by Dick. A much

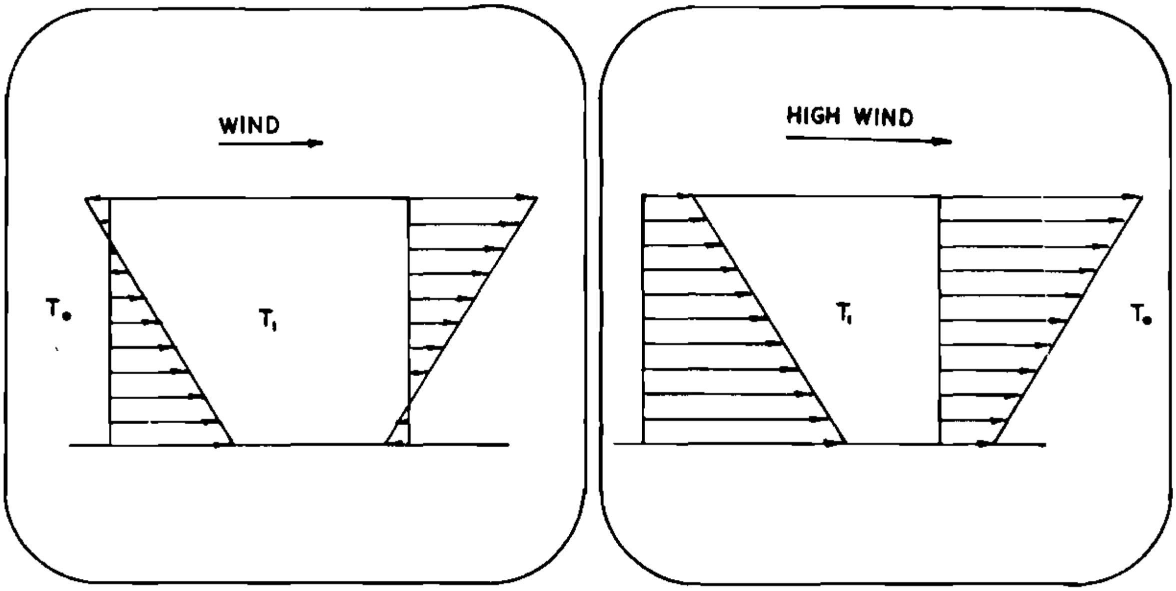


FIGURE 1.2

Wind pressure distribution on building surfaces.

simpler method described by J.B. Dick [5] is to calculate the critical velocity that wind dominates stack effect by the equation:

$$V_z = .35\ [\ h\ (\Delta\ t)]^{0.5} \qquad \text{(Equation 2)}$$

Equation 2 is actually a stack effect equation except that there is not a variable for the area of opening (see 1.2.2). Therefore, the airflow is expressed as velocity rather than mass flow so that it can be compared to acting wind speeds. If wind speeds exceed the velocity of airflow calculated by this equation, ventilation will result from wind pressure.

A series of measurements of an experimental house were used to test Equation 2 [5]. When outdoor air temperatures were less than 10°F below indoor air temperatures, the minimal effective height between openings to induce ventilation by stack effect was found to be ten feet. Under the same conditions, ventilation was induced by wind for velocities greater than 3.5 MPH. Calculations showed fairly good correlation with full scale measurements (Figure 1.3) [5].

1.1.3 A Dominating Effect Algorithm For Computer Application. The purpose of the dominating effect algorithm is to determine whether stack effect or wind pressure prediction techniques should be used. The critical values of wind speed, temperature differential between indoor and outdoor air, and the vertical distance between inlets and outlets determined by Dick's equation and full scale measurements [5] were used to develop the following dominating effect computer algorithm:

A. If temperature differentials are greater than 10°F, stack

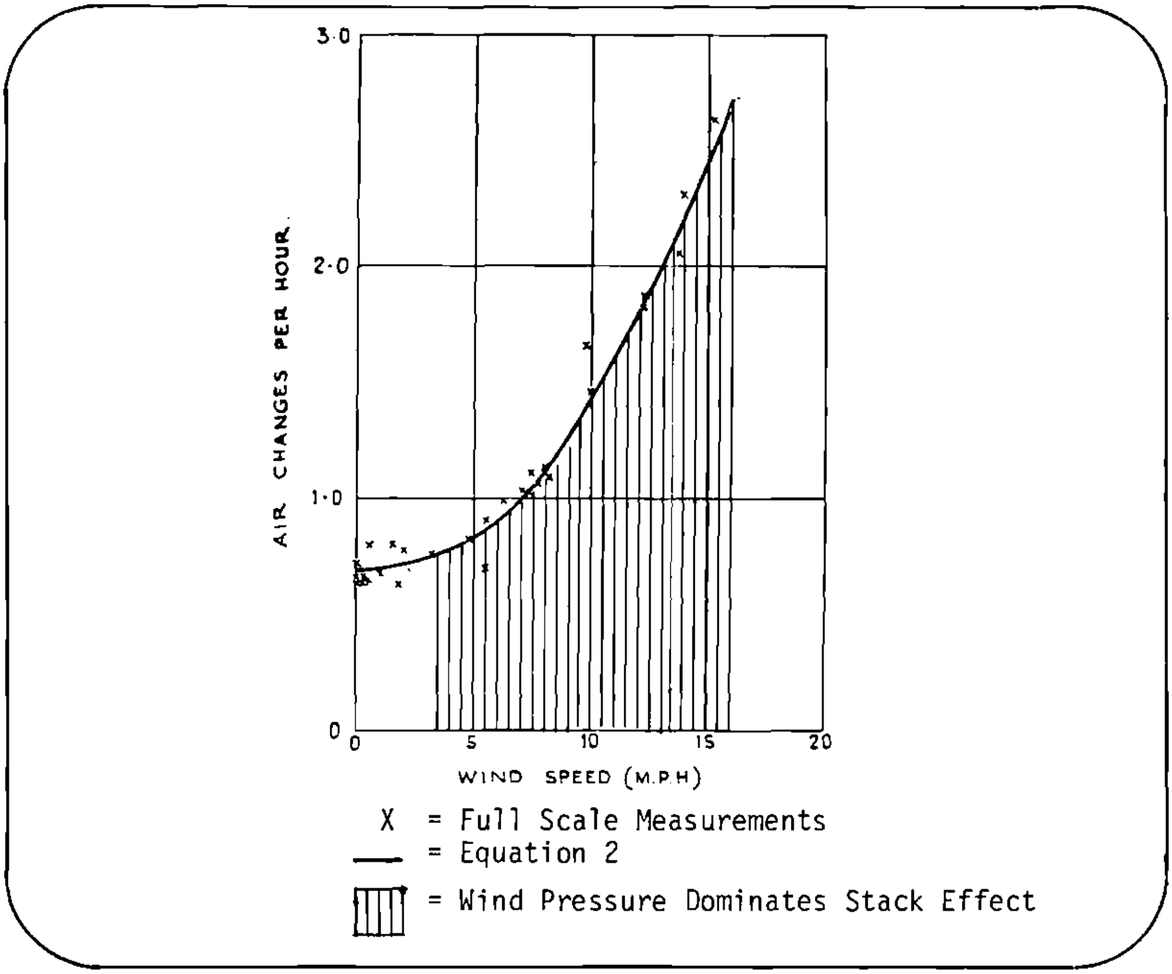


FIGURE 1.3

Ventilation induced by wind and stack effect acting simultaneously.

effect equations are used to calculate one of the following:

1. Area of crack that will induce air flow to meet fresh air requirements (See Appendix B.1).
2. Volume of air that infiltrates through user specified crack areas (See Appendix B.2).

B. If the outdoor temperature is greater than 78°F and wind speeds are less than 3.5 MPH, a stack effect equation is used to calculate:

1. The temperature of exiltrating air (out of a solar chimney) necessary to provide an adequate temperature differential so that sufficient air speeds are induced through the living zone to restore thermal comfort (See Appendix B.3).

C. If temperature differentials are less than 10°F and wind speeds are greater than 3.5 MPH, wind pressure equations are used to calculate one of the following:

1. The area of opening that will induce adequate airflow to restore thermal comfort.
2. The average velocity of air at each user specified area of opening in series.

1.2 Methods of Calculating the Stack Effect

In this section three methods of predicting ventilation rates induced by stack effect are compared. Emswiler's equation is found to be the most accurate of three mathematical models according to full scale measurements by Kreighelt, Kern, and Higgins (Table 1.2) [1].

Ventilation flow rate, million acfm*					
Total	Heat related	Wind related**	Method of determination	Reference	Comments
8.41	...	...	Direct measurement		
8.32	8.32	...	Emswiler	1	Trial-and-error determination of null level. Reported flow rate relates only to roof monitor opening discharge. Assume linear temperature profile within building.
13.30	9.3	7.24	Randall and Conover	2	No consideration given that temperature profile exists; assumes instant mixing of heat at floor level.
7.1	7.1	...	Hemeon	3	Refers to numerous equations for potential use, of which only $V = 20(LH/A)^{1/3}$, i.e., $cfm = 20\ L^{1/3}H^{1/3}A^{2/3}$, differs substantially from those presented by other authors. Therefore, only the results of the use of this equation are presented in this table. Calculation is based on null level calculated by Emswiler, Btu release assumed to occur immediately.
8.91	6.6	7.24	ASHRAE	4	Based on upgrading of Randall's work. Note that heat related flow rate approximates that measured.
9.15	7.03	7.24	*Fan Engineering*	5	Essentially same equation as ASHRAE.
9.3	9.3	...	*Heat and Cooling for Man in Industry*	6	Essentially same as Randall and Conover equation.
9.85	9.85	...	*Steel Mill Ventilation*	7	Method considers null level as nonexistent.
10.23	6.6	3.63	Constance	8	Heat related flow rate based on ASHRAE, and wind related flow rate appears to come from vendor literature.
5.03	5.03	...	Clarke	9	Based on ASHRAE method, except ignores wind effect and does not correct for unequal openings.

* Through roof ventilator only.
** In some cases effect is applied to wall openings, and in other cases effect is applied to roof monitor.

TABLE 1.2

Comparison of methods for predicting stack effect induced ventilation.

However, the equation recommended by ASHRAE is most applicable to a computer model (See Section 1.2.3).

1.2.1 Emswiler's Equation. In 1926, J.E. Emswiler wrote an article concerning the basic principles of ventilation driven by temperature differential induced stack effect [6]. In the article the author introduced the concept of the neutral zone that occurs within the building where neither outside air infiltrates nor inside air exfiltrates (Figure 1.4) [1]. Emswiler explained that infiltration occurs below the neutral zone and exfiltration occurs above it.

The driving force of infiltration or exfiltration at each opening is related to: (Figure 1.5 - 1.6):

A. The vertical distance between that opening and the neutral zone and,

B. The temperature of the air passing through the opening and the temperature of the neutral zone.

The air flow rate through each opening can be determined using the equation:

$$Q = A \sqrt{\frac{hnz * \Delta\ tnz}{C_o * T}} \qquad \text{(Equation 3)}$$

WHERE:

Q = Volumetric air flow through opening A

A = Area of opening. (The air flow through each opening is evaluated separately.)

h_{nz} = Distance vertically between the neutral zone and the opening

t_{nz} = Temperature differential (°F) between the neutral zone and opening A

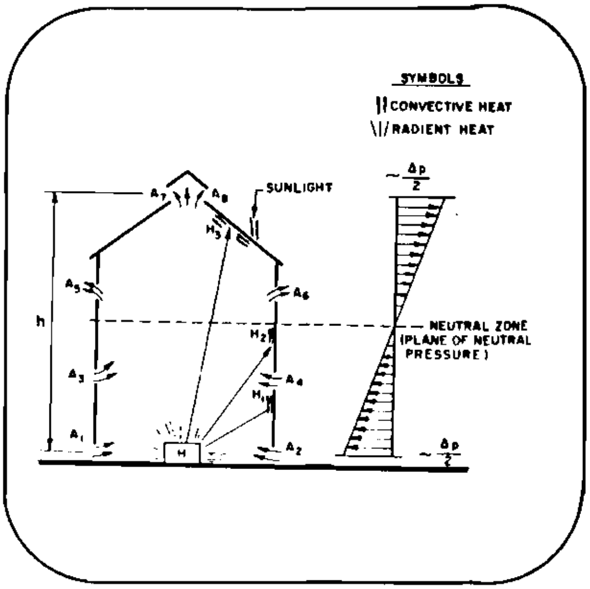


FIGURE 1.4

Points of infiltration and exfiltration.

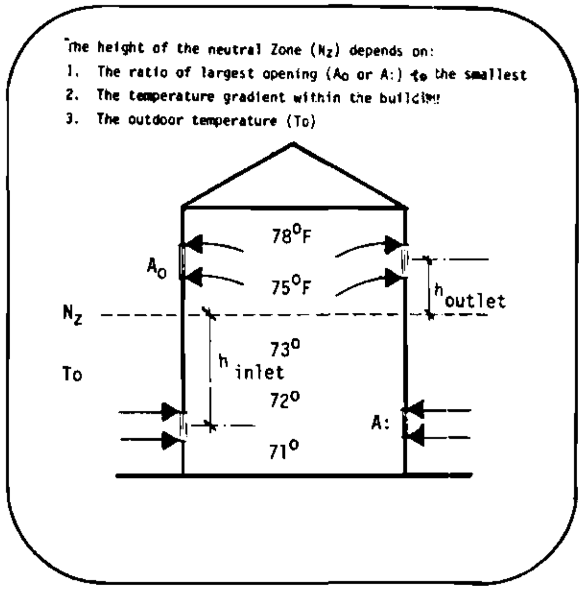


FIGURE 1.5

Variables effecting neutral zone height.

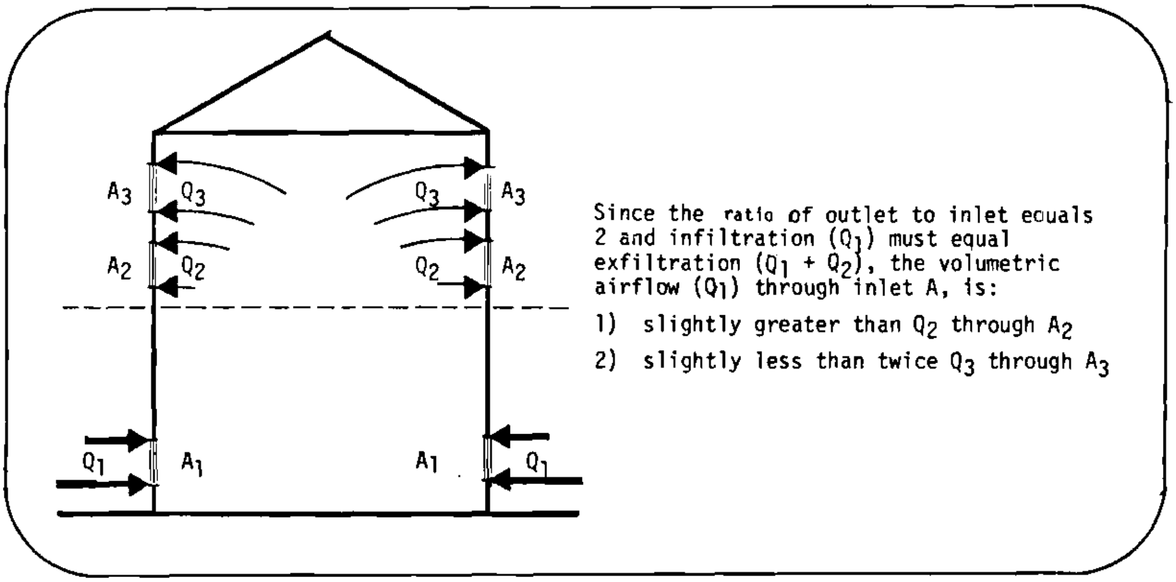


FIGURE 1.6

Infiltration equals exfiltration.

T = Absolute temperature (°R) of air passing through opening A

and $$C_o = \frac{1}{2g \cdot Cd^2 \cdot 60^2}$$ (Coefficient of Opening)

WHERE:

g = Acceleration due to gravity (32.2 ft/s^2)

C_d = Discharge coefficient, 0.60 -0.65.

Using Emswiler's Equations, the air flow rate and the neutral zone elevation is determined by trial and error in iterative calculations. First, the height of the neutral zone is estimated. Next, the air flow through each opening above or below the neutral zone is iteratively calculated using Equation 3. When the air flow through the openings below the neutral zone equals the air flow through the openings above the neutral zone, (Figure 1.5 and Figure 1.6) the correct neutral zone height and air flow rate is determined.

Emswiler's work has been found to be "error free" and quite appropriate for present day application. Full scale measurements conducted by Kreichelt, Kern and Higgins (See Table 1.2) [1] differed by less than 2% from the ventilation rates predicted by Emswiler's Equation.

<u>1.2.2 Equation Used by Randall, Canover, and Aynsley.</u> A simpler method of predicting air flow resulting from stack effect was developed by Randall and Conover [7] and adopted by Aynsley [8]. These authors developed an equation for the simplest situation; a

building that has only one inlet and one outlet of equal size. Assuming that the temperature gradient within the building is linear (Figure 1.7 curve A) [1], the neutral zone will occur midway between the openings. Using an opening coefficient of .65 and an absolute temperature of 550°R, the volumetric air flow (Q) through either the inlet or outlet (A) can be calculated from the equation:

$$Q = 9.4A \sqrt{h * \Delta t} \qquad \text{(Equation 4)}$$

WHERE:

9.4 = (0.65) (60 min/hr) 1/2 (2g/550°R)

A = Outlet or inlet area; whichever is larger

g = Gravity (32 ft/sec^2)

The 1/2 incorporated into the factor 9.4 represents half of the distance between the openings where the neutral zone occurs. Since the 1/2 would not be appropriate for unequal areas of inlets and outlets, a curve was calculated to correct for differences in the neutral zone height (Figure 1.8) [1]. The need for this curve can be obviated by replacing the 1/2 by:

$$A_i^2/(A_i^2 + A_o^2)$$

WHERE:

A_o = Total area of outlet

A_i = Total area of inlet

Calculations with Randall and Conover's simplified equation result in air flow rates 45% greater than full scale measurements by Kreichelt, Kern, and Higgins. Randall, Conover and Anysley did not consider that the equation $9.4 * A \sqrt{H * \Delta t}$ implied that the building's

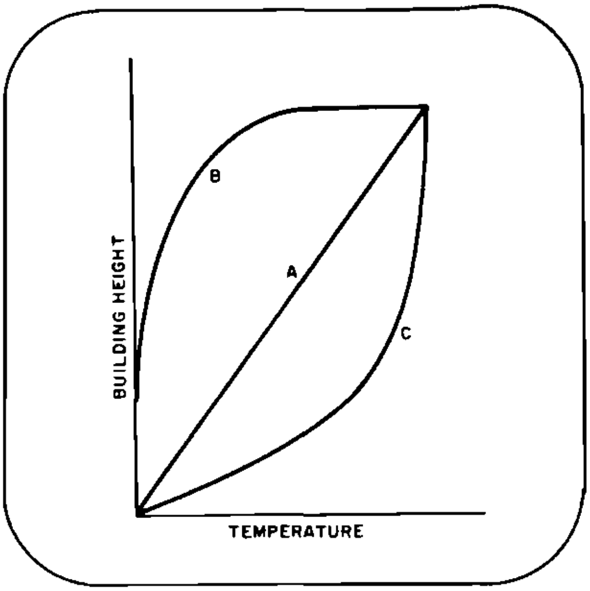


FIGURE 1.7

Typical indoor temperature profiles.

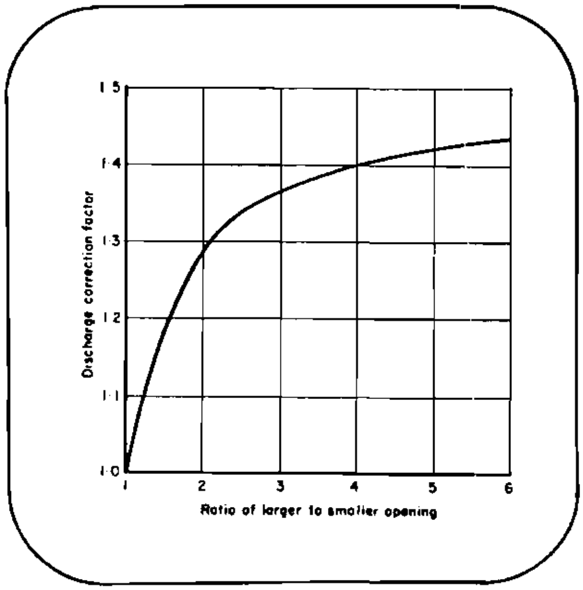


FIGURE 1.8

Corection factors for relative areas of inlets and outlets.

entire heat load is mixed into the infiltrating air instantaneously (Figure 1.9). This one oversight accounts for the large error that was found in the full scale measurements.

1.2.3 Equation Used by ASHRAE. ASHRAE publishes a handbook [9] that recommends the use of Randall and Conover's equation except that the temperature differential has been corrected. The authors of ASHRAE'S Handbook of Fundamentals explain that the appropriate temperature differential between the neutral zone and the openings for a linear temperature gradient is half the difference between the exfiltrating air (t_o) and the infiltrating air (t_i):

$$\text{Flowrate} = 9.4\ A \sqrt{h * \Delta t_{AVE}} \qquad \text{(Equation 5)}$$

WHERE: $\Delta t_{AVE} = \frac{t_i - t_o}{2}$

Kreichelt, Kern, and Higgins have shown that the calculated flow rate of Ashrae's version of the equation by Randall and Conover is 1% less accurate than Emswiler's Equation (See Table 1.2) [1]. However, the method presented by Ashrae was selected for computer application because it requires less user input and less computer time for calculation.

1.3 Electric Analogue Technique

In 1963 H.Ph.L. den Ouden of the T.N.O. Institute in Holland demonstrated an analogy between natural air flow through openings and the passage of electrical current through a number of resistances [10]. By using 216 combinations of electrical lamps and shunt resistances representing the pressure differentials of wind across a

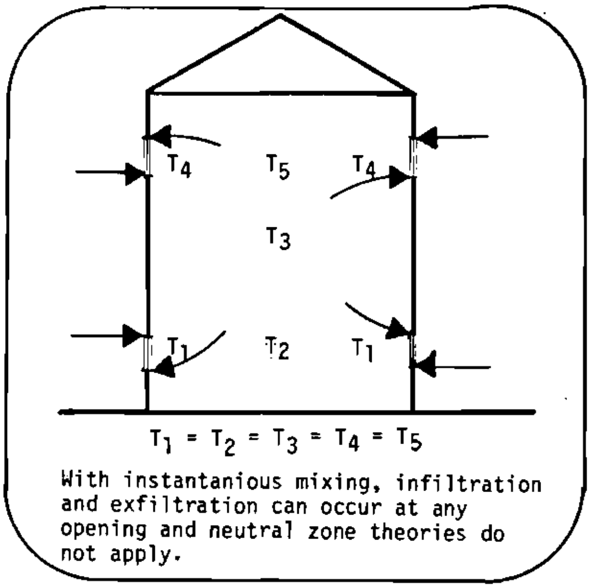


FIGURE 1.9a

Instantaneous mixing.

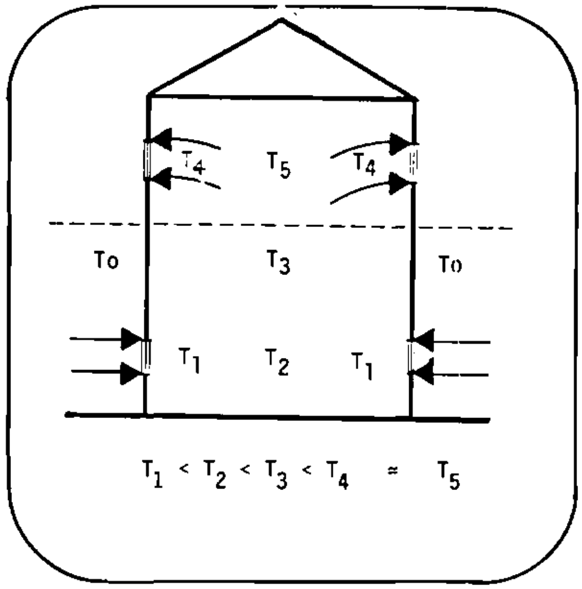


FIGURE 1.9b

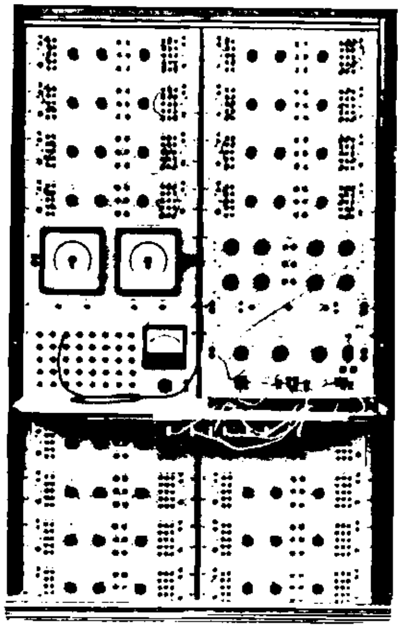
Typical temperature profile.

building's surface, current could be used to simulate the natural air flows generated by wind pressure and the stack effect (Figure 1.10) [11].

An interesting result using this analogue was reported by P.J. Jackman and Den Ouden at a symposium in London in 1968. They found that in a building where the floors were isolated from one another by closing off the stair and elevator cores, the stack effect was of no practical importanace in calculating the total infiltration rate. This is particularly significant for typical commercial office buildings. Effect was also found to be insignificant when high wind speeds were acting on the building's surface. With wind speeds greater than 10 M.P.H. and a temperature differential of 40 degrees F, the infiltration resulting from the stack effect was only 2% of the total air flow of a twenty story building [11].

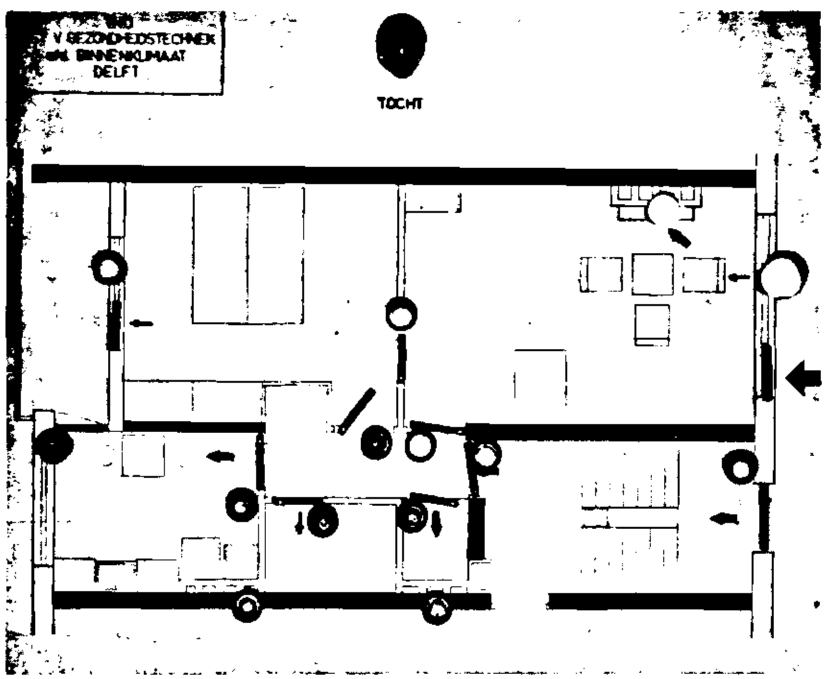
1.4 A Chart for Predicting Ventilation Caused by the Stack Effect

The electric analogue technique was tested by P.J. Jackman, in 1968 with a digital computer program originally designed for the determination of flows and pressures in pipe networks [4]. The program consisted of several interconnected nodes that were idertified individually (Figure 1.11) [12] to correspond to the resisters in the electric analogue method. Since the two methods showed good correlation (Figure 1.12) [12], Jackman used them to produce charts for quick approximations of natural ventilation rates (Figure 1.13, and Figure 1.14) [12]. The variables of the charts include the buildings height, the velocity gradient of wind, the boundary conditions of the terrain (urban site or exposed site), the wind speed



ELECTRIC RESISTANCE analog for simulating building air flow under wind pressure, developed by H. Ph. L. den Ouden at the Research Institute of Public Health Engineering TNO, Delft, Holland.

Photos courtesy of Research Institute of Public Health Engineering TNO, ***Holland.***



ARRANGEMENT of lights in den Ouden's analog, showing the resistance points of the structure.

FIGURE 1.10

Electric analogue modeling.

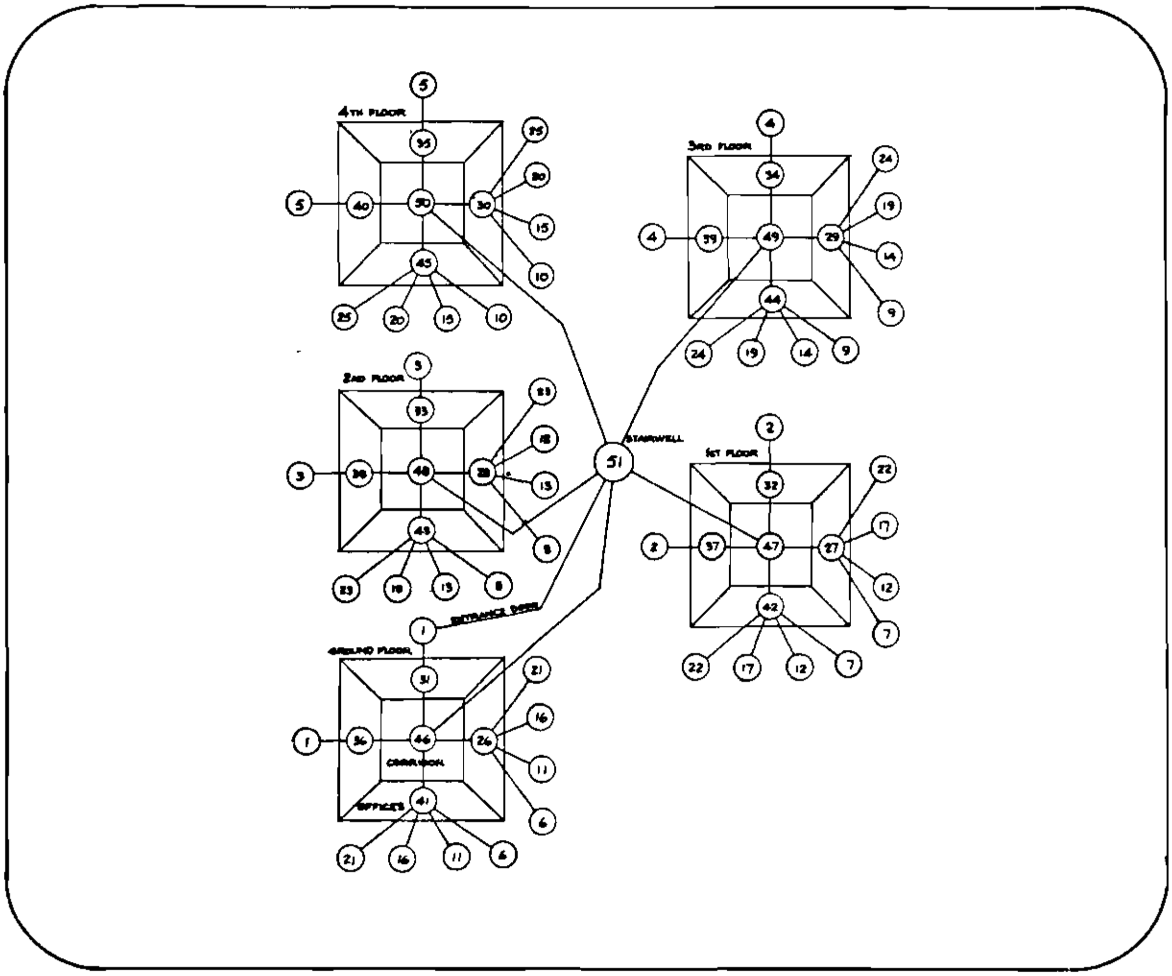


FIGURE 1.11

Example of identification of air flow paths for use in a digital computer program.

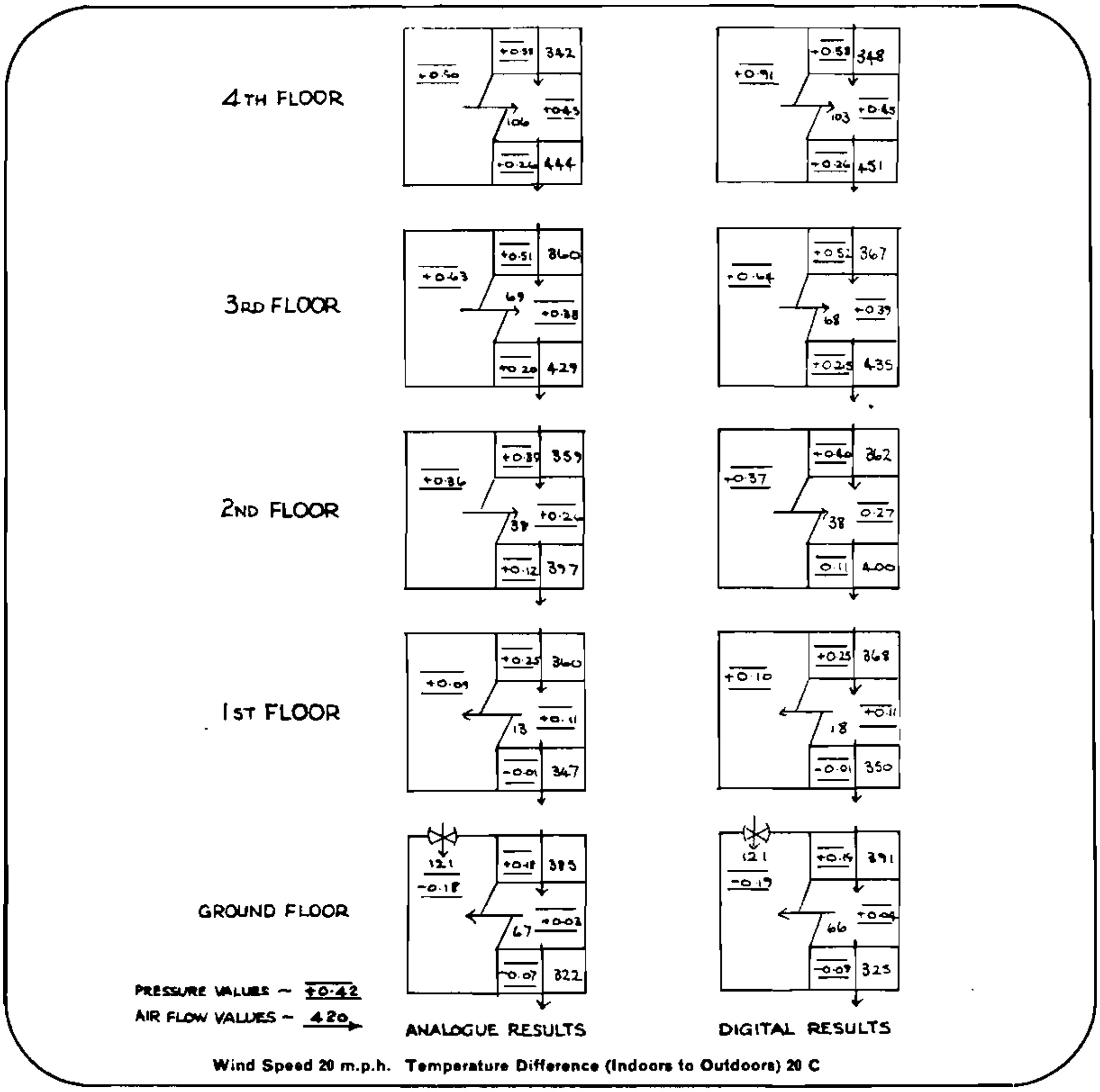
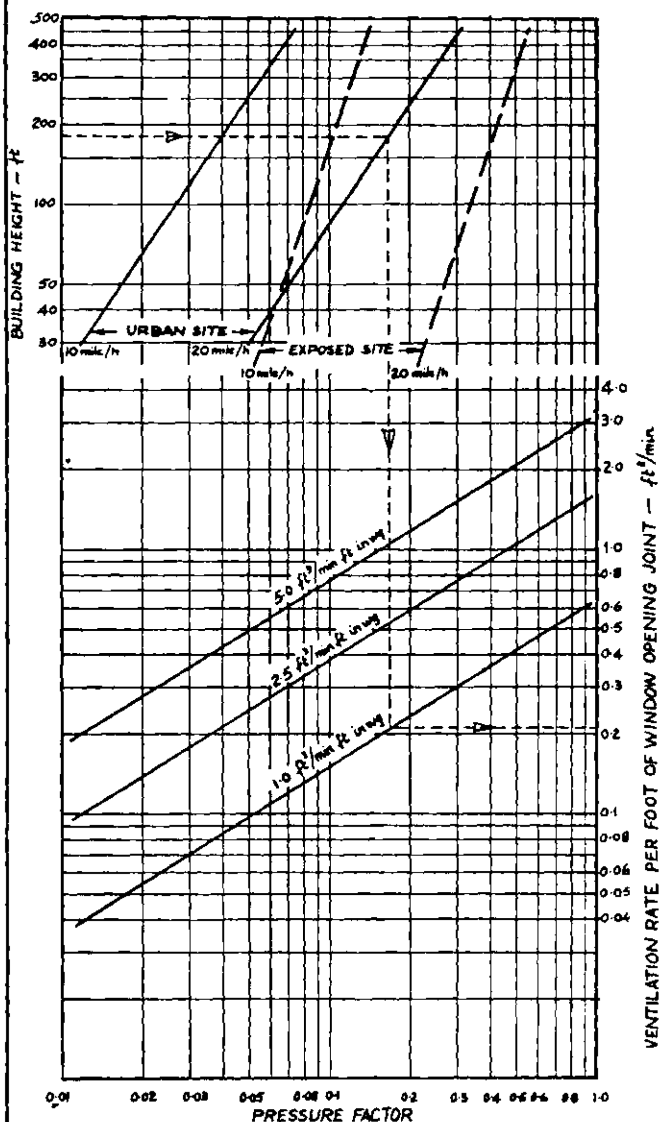


FIGURE 1.12

Comparison of analogue and digital results.



Problem

To find the rate of natural ventilation in a rectangular plan building of 150 × 60 × 180ft high located near a town centre for a winter design wind speed of 20 mile/h. The building has metal horizontally pivoted windows on all four sides with an average length of opening joint (weather-stripped) per unit area of building face of 0·5ft/ft². The internal layout of the building is generally of 'open plan' design.

From the 'Natural Ventilation Chart', the pressure factor is determined for the height of 180ft (see dotted line on Chart). The vertical line is then traced until it crosses the line for the appropriate window leakage, in this case, 1·0ft³/min ft in wg (Table 1.3). A horizontal line projected from the point of intersection to the ventilation rate scale, gives a ventilation rate per foot of window opening joint of 0·21ft³/min. No correction is applied for an open plan office (Table 1.3). The total window joint length is 0·5 × A, where A is the sum of the area of all four sides of the building. The area factor is equal to the diagonal cross-sectional area (Fig.1.15) divided by A,

and is given by $\frac{\sqrt{150^2 + 60^2} \times 180}{A}$

The total ventilation rate

$$= 0{\cdot}21 \times 0{\cdot}5 \times A \frac{\sqrt{150^2 + 60^2} \times 180}{A}$$

$$= 0{\cdot}21 \times 0{\cdot}5 \times 162 \times 180$$

$$= 3060\text{ft}^3/\text{min}$$

This rate of ventilation is equivalent to an air change rate of approximately 0·5 times/hour (in windward office area assuming infiltration on one side of the building only) compared to 1·3 air changes/hour given by the *IHVE Guide*.

The total ventilation rate so determined will be valid for buildings in which the window characteristics are similar on all of the glazed faces of the building and where the openable windows are reasonably equally distributed over the building faces. It has also been assumed that the building is uniform in shape and is substantially square or rectangular in plan with similar types of internal layout on each floor.

In instances where the building features do not conform to these assumptions it may well be possible to estimate the ventilation rates for particular zones or groups of similar floors and make a summation to determine the total ventilation rate. In such circumstances the effectiveness of the estimation method will depend on the judgement of the designer involved, but for particularly complex or unique buildings, specific analysis of the ventilation process will need to be undertaken for which purpose the computer programme developed for this study may be advantageously used.

FIGURE 1.13

Natural ventilation chart.

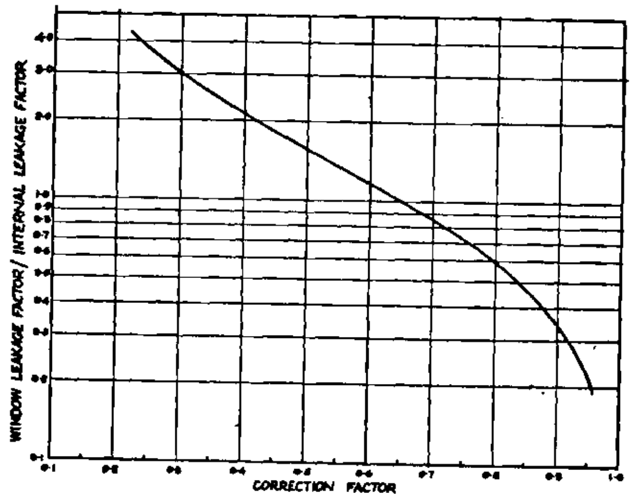


FIGURE 1.14

Ventilation Corection Curve.

Window Type	Internal Structure	Correction factor
All types	Open plan (no full partitions)	1·0
Short length of well fitting window opening joint	Single corridor with many side doors	1·0
Short length of well fitting window opening joint	Liberal internal partitioning with few interconnecting doors	1·0
Long length of well fitting window opening joint or short length of poor fitting joint	Single corridor	1·0
Long length of well fitting window opening joint or short length of poor fitting joint	Liberal partitioning	0·8
Long length of poor fitting joint	Single corridor	0·8
Long length of poor fitting joint	Liberal partitioning	0·65
Very long length of poor fitting joint	Single corridor	0·65
Very long length of poor fitting joint	Liberal partitioning	0·4

TABLE 1.3

Correction factors applied to the Natural ventilation chart for internal structure and window type.

(10 or 20 M.P.H.), and the air pressure (1.0, 2.5, 5.0 cubic feet/min.ft.in,wg). Since there is not an allowance for indoor and outdoor temperature differentials in the chart, it isn't clear if the ventilation rate is a result of stack effect or wind pressure. However, the units found in the chart's ventilation rate (cubic feet/min per foot of window joint) are typical for stack effect equations.

In earlier tests of the electric analogue and the digital technique, Jackman determined that the airflow into a building was found to be approximately equal to the flow caused by the greater of the two infiltration processes (wind pressure or the stack effect). Therefore two separate charts should be used to predict ventilation rates resulting from either of these two separate sources of natural ventilation. Yet Jackman contradicts himself by combining the variables of wind pressure with the variables of the stack effect in this chart. The natural ventilation chart could be corrected by replacing the velocity gradients, boundary conditions, and wind speed variables with curves representing the inside and outside air temperature differentials to obtain stack effect induced ventilation. However, another chart would be required for ventilation rates produced by wind pressure at the buildings openings.

1.5 Charts for Predducting Ventilation Caused by Wind Pressure

It has been shown by Morris [13] and confirmed by Soliman and Lee [14] that wind induced ventilation is dependant on two groups of factors: form related factors and flow related factors. These factors affect the pressure distribution around the building and thus the wind induced ventilation. In 1955, Morris described a number of flow regimes that occured during the separation and reattachment of turbulent air flow around a number of forms. In 1977, Lee and Soliman denoted these regimes as:

A. Isolated roughness flow regime,

B. Wake interference flow regime (moderately turbulent); and

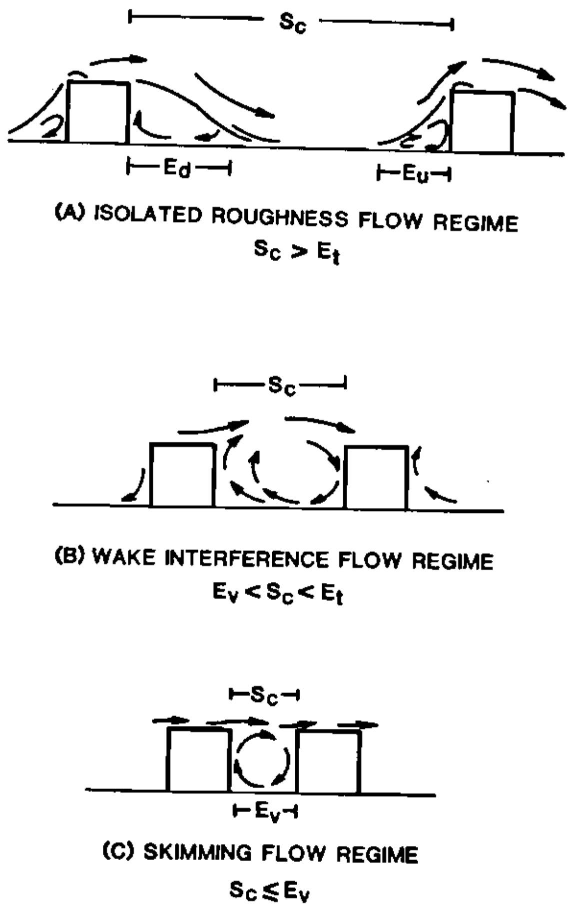
C. Skimming flow regime (highly turbulent).

In the isolated roughness flow regime, Figure 1.15a [15], the clear space (S_c) between built forms is large enough for reattachment of the air wake downstream from one element (E_d) to occur before separation begins upstream from the next element (E_u). Therefore, the isolated roughness flow regime results when the distance between elements is sufficient for each element to act in isolation.

The wake interference regime, Figure 1.15b, results if the clear space is not large enough for the elements to act in isolation. However, the clear space is too large to create a stable vortex.

In the skimming flow regime, Figure 1.15c, the clear space (Ev) between the forms is small enough to create a stable vortex. Air flow appears to skim on the crests of the vortex and the elements.

The distances between elements for the occurance of these three regimes has been described by B.E. Lee, M. Hussain, and B. Soliman [15]. Several arrangements of cuboid models were tested in a wind tunnel to determine the clear space required for each regime and the resulting pressure differentials across the cuboid surfaces (Figure 1.16). After several tests a set of relationships between the wind induced pressure forces on a building and its immediate surroundings were established. As a result, a graphic technique for predicting



S_c= clear space between forms

E_d= length downstream for reattachment of air wake

E_u= length upstream of air wake separation

E_v= maximum distance for a stable vortex to occur

E_t= $E_d + E_v$

FIGURE 1.15

Governing conditions for three flow regimes.

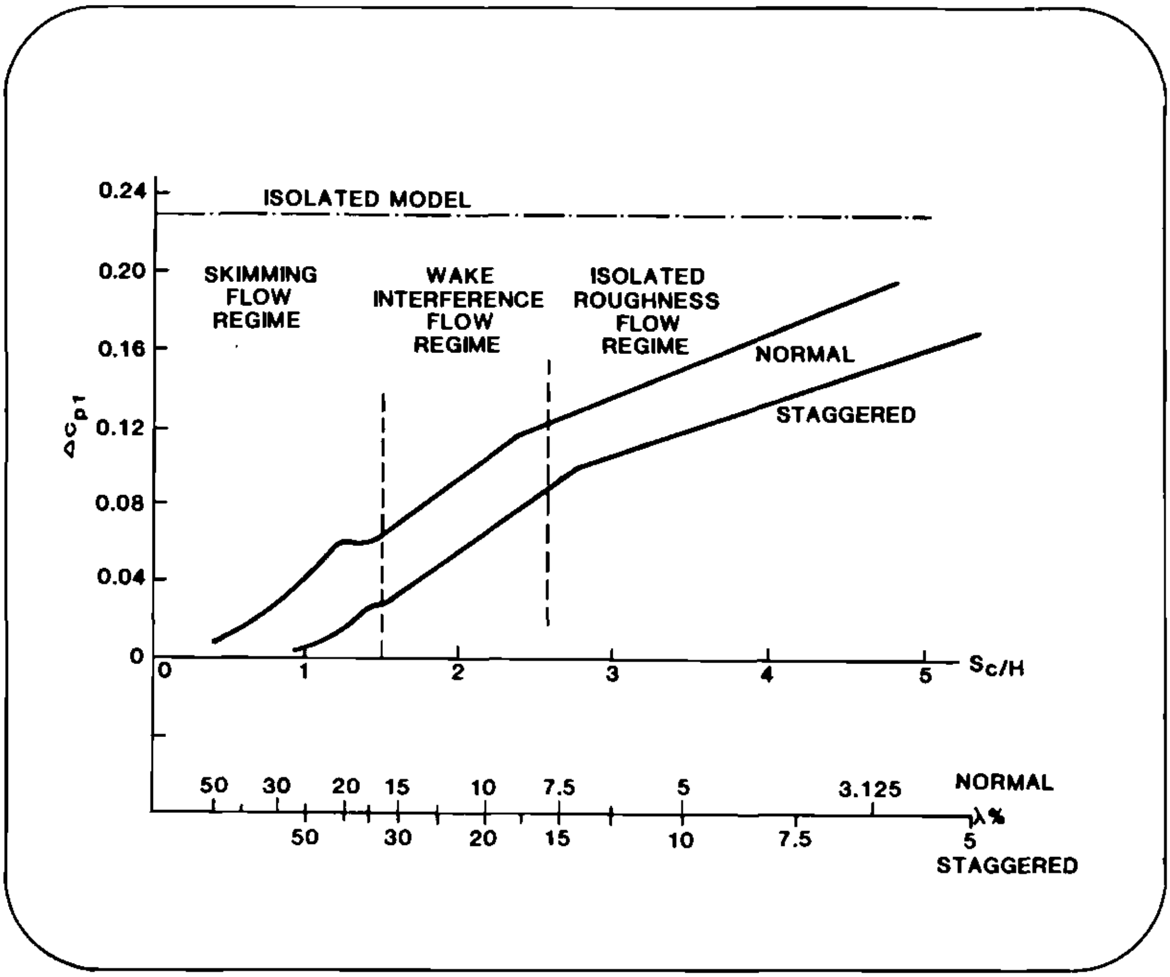


FIGURE 1.16

Variation of Pressure Difference Coefficient with array spacing and plan area density of cuboid models.

pressure differentials was devised (Figure 1.17). The technique includes corrections for the clear space (S_c/h) in front of the object (Figure 1.17a), the clear space on the sides of the object (Figure 1.17b), turbulence (Figure 1.17c), and wind direction (Figure 1.17).

The greatest advantage with this graphic technique is that model making and wind tunnel testing can be eliminated. One could simply match the context of a site with the results of the wind tunnel testing conducted by Lee Hussain and Soliman of a normal, Gridiron arrangement, a staggered, checkerboard arrangement, or a random, scattered arrangement. Unfortunately three graphs are not available for predicting the surface pressures resulting from these different arrangements. Figure 1.17c should be expanded to take into account the turbulence that results from the three arrangements. The greatest weakness is that if the building geometries within the urban context (Figure 1.18) do not match the cuboid arrangements, further inaccuracies will result.

1.6 Mathematical Models and Wind Tunnel Prediction Techniques for Wind Induced Ventilation

In Sections 1.6 and 1.7, three methods of predicting wind induced ventilation are described. Each method has definite advantages and disadvantages but the wind pressure difference method presented in Section 1.7 is the most applicable to a computer model (See Section 1.8).

1.6.1 Misconceptions and Theoretical Corrections.

The wind tunnel has been a primary source for establishing the prediction methods of natural ventilation. Unfortunately several mathematical

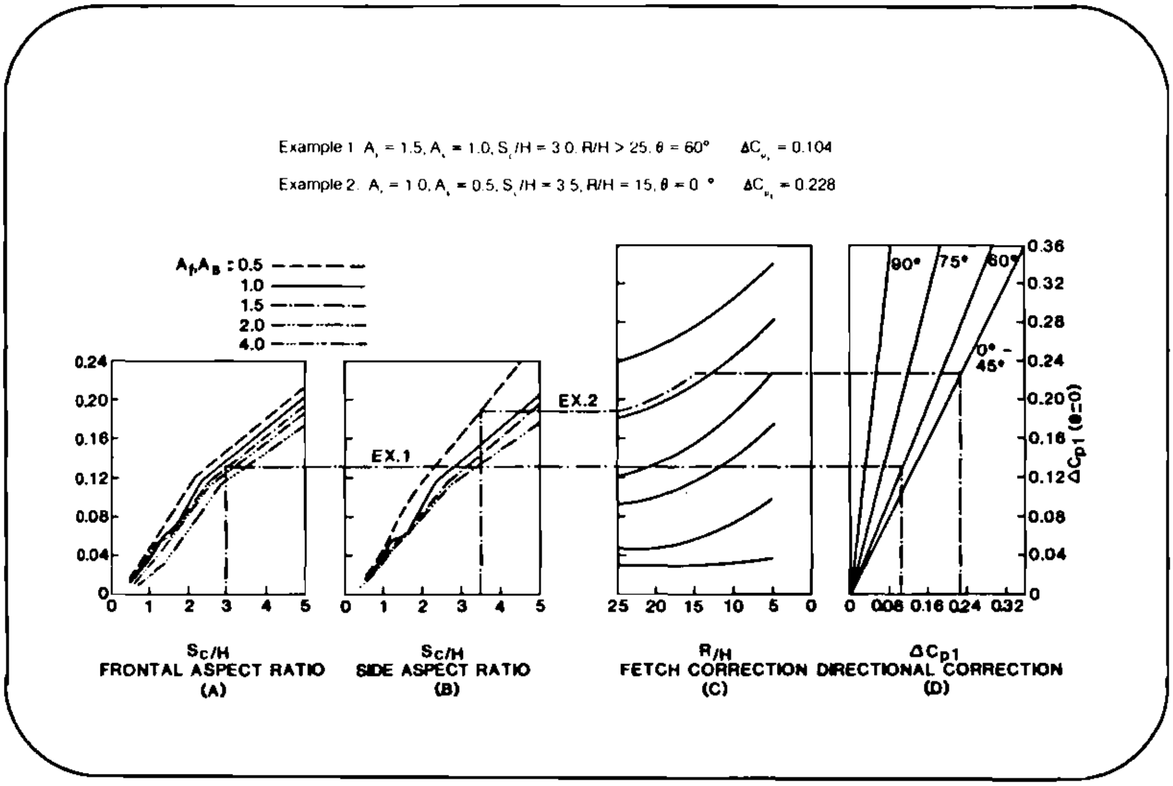


FIGURE 1.17

Graphical prediction techniques for Pressure Difference Coefficients.

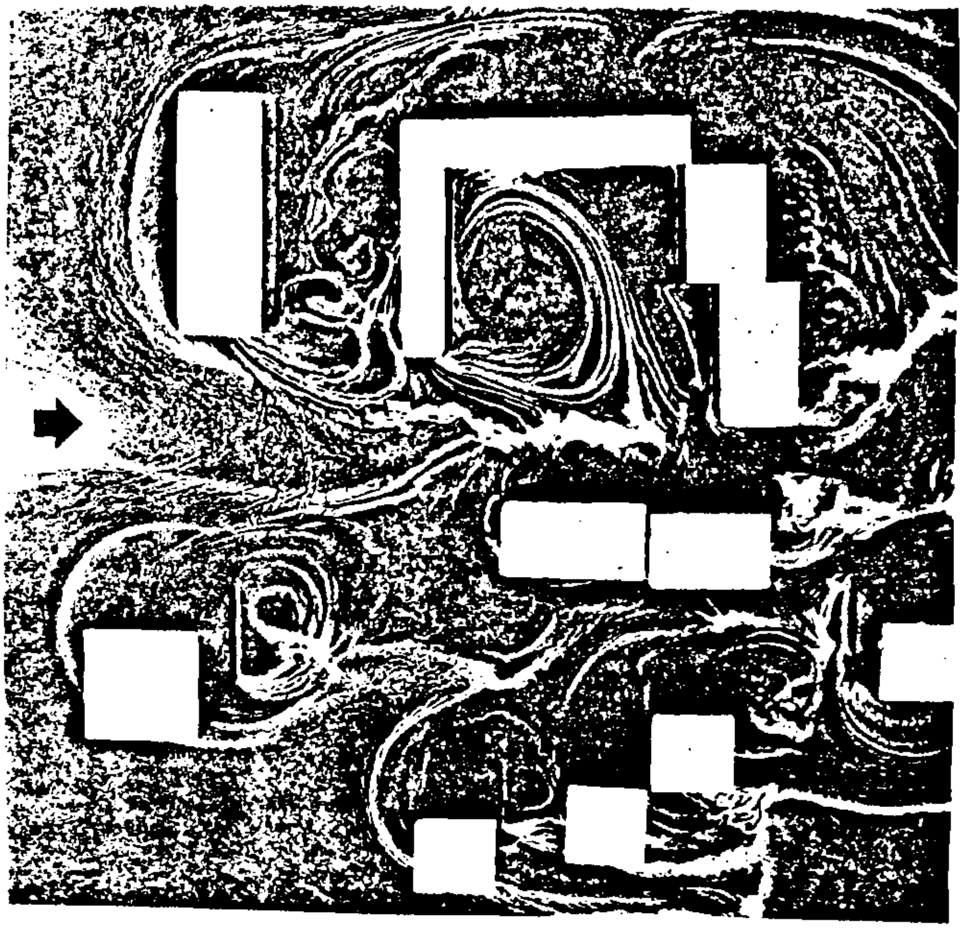
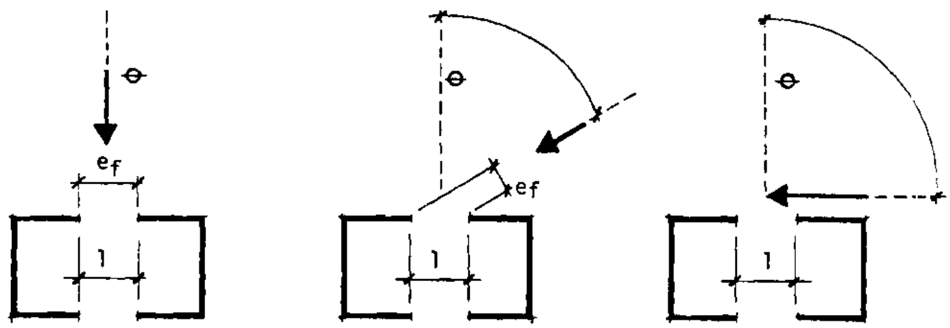


FIGURE 1.18

Wind tunnel testing of the urban context.

models and theories developed strictly from wind tunnel experiments have proven to be inaccurate. For instance, predictions from some mathematical equations [8] yield zero for wind incidence angles tangental to openings (Figure 1.19). In full scale modeling [44], it has been found that actual ventilation rates resulting from turbulance for tangential wind incidence angles are only half the ventilation rate of wind incidence angles normal to the inlets (Figure 1.20). The greatest problem with wind tunnel measurements is that the scaling of heat and velocity can not be matched. Problems with wind tunnel testing have been illustrated in a historical to current review of model wind effect studies by D. Durry and N. Isyumov [43].

Even though inaccurate theories developed from wind tunnel tests, it was often the wind tunnel that disproved or confirmed misinterpretations from previous wind tunnel results. For many years it was believed that the largest openings should face the wind to "scoop" the air into the room. Givoni [16] and Chand [17,18] used the wind tunnel to prove that small inlets and large discharge areas provide best results. Maximum air changes result if outlets and inlets are of equal size and as large as possible. Later Benjamin H. Evans [19] recommended using larger outlets than inlets to maximize air velocities for summer cooling because "maximizing air changes is trivial in regard to summer cooling". One serious oversight in Evans' statement is that air changes are important for mass cooling when the outside air is cooler than the inside air, which is often the case during summer nights. (Figure 1.21). Another problem with Evans' recommendation is that while air velocities are maximized near the inlets, velocities are very low in other parts of the room (Figure



$e_f = (\cos 0^o)(l)$
$= l$

$e_f = (\cos 60^o)(l)$
$= l$

$e_f = (\cos 90^o)(l)$
$= l$

Where:

l = length of opening
e_f = effective length of opening
θ = wind incidence angle

FIGURE 1.19

Effect of wind incidence angles on ventilation rates. Conventional mathematical theory.

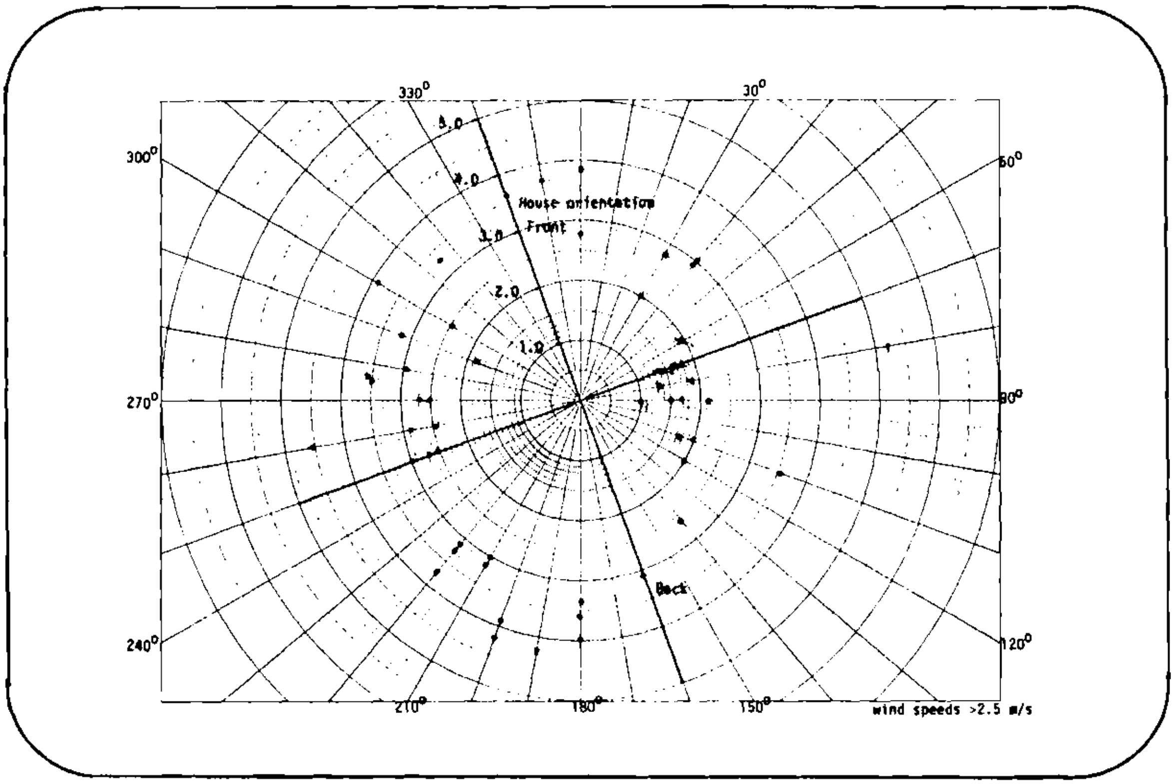


FIGURE 1.20

Actual effect of wind incidence angles on ventilation rates.

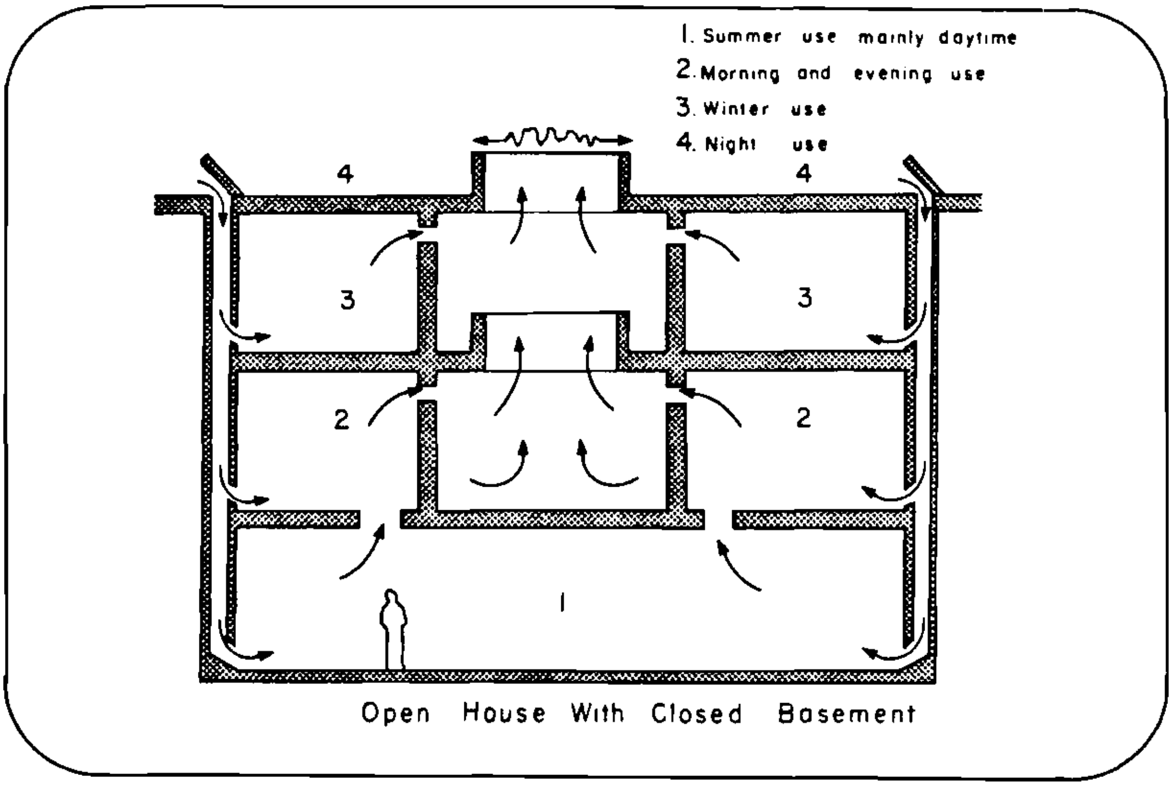


FIGURE 1.21

Maximizing air changes for night-mass cooling is equally important to maximizing air velocities for evaporative cooling in arid climates.

1.22). With changing wind directions it would be impractical for an occupant to continually change positions within the room or manually operate window devices to control natural drafts. Therefore, outlet and inlets of equal size are necessary to maximize velocity rates in the whole room area.

1.6.2 Average Velocity Method. The recommendation that window openings should be located in opposite walls to maximize cross ventilation in the whole room area is untrue. Assumptions such as these have been made from incomplete wind tunnel tests or mathematical models that failed to consider air velocities outside the main airstream. Wind tunnel studies of the entire space have demonstrated that better ventilation conditions occur when the air stream has to change direction, i.e., superior ventilation occurs from openings in adjacent walls rather than opposite walls (Table 1.4) [20].

It has been determined from recent wind tunnel tests that the most important variable of average velocity is the size of the smaller opening rather than the ratio of the inlet and outlet sizes (Figure 1.23) [20]. Increasing the inlet or outlet alone only slightly affects the internal air velocities. If a room has larger outlets than inlets, the speed of the main air stream is increased and slightly higher average velocities are obtained. The greatest increase on the average internal velocities occurs when the inlets and outlets are increased simultaneously. However, internal air speeds are not proportional to the window size. As the area of opening increases the first differential velocity decreases (Table 1.5) [20] (Figure 1.24) [1.17].

Much work has been conducted by Givoni [21] in the area of wind

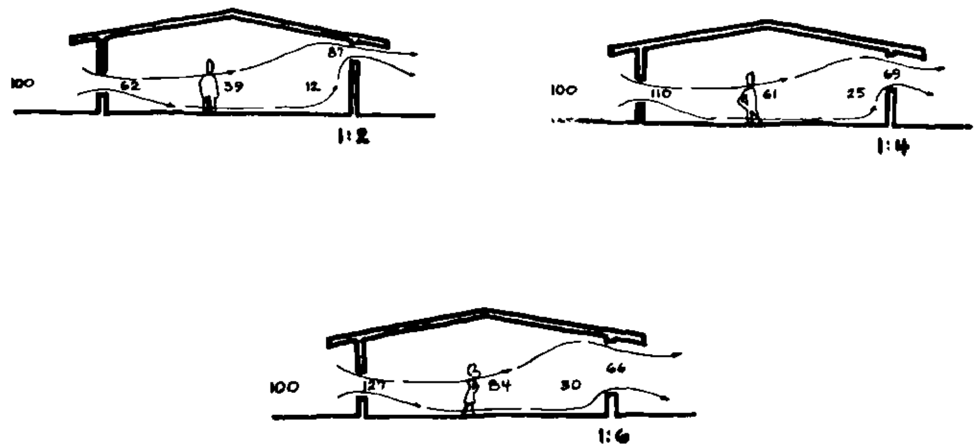


FIGURE 1.22

Increased outlet size in relation to inlet size results in increased air speeds but velocities in other parts of the room remain very low.

Inlet width	Outlet width	Windows in opposite walls		Windows in adjacent walls	
		Wind perpend.	Wind oblique	Wind perpend.	Wind oblique
1/3	1/3	35	42	45	37
1/3	2/3	39	40	39	40
2/3	1/3	34	43	51	36
2/3	2/3	37	51	—	—
1/3	3/3	44	44	51	45
3/3	1/3	32	41	50	37
2/3	3/3	35	59	—	—
3/3	2/3	36	62	—	—
3/3	3/3	47	65	—	—

TABLE 1.4

Effect of window location and wind direction on average air velocities (per cent of external velocity).

Distribution of internal air speeds (% of external speed) in models with different ratios of inlet to outlet size.

FIGURE 1.23

Distribution of internal air speeds (% of external speed) in models with different ratios of inlet to outlet size.

Wind direction	Outlet size	Inlet size 1/3		2/3		3/3	
		Av.	Max.	Av.	Max.	Av.	Max.
Perpendicular	1/3	36	65	34	74	32	49
	2/3	39	131	37	79	36	72
	3/3	44	137	35	72	47	86
Oblique	1/3	42	83	43	96	42	62
	2/3	40	92	57	133	62	131
	3/3	44	152	59	137	65	115

TABLE 1.5

Effect of inlet and outlet width on average and maximum velocities (percent of external wind speed).

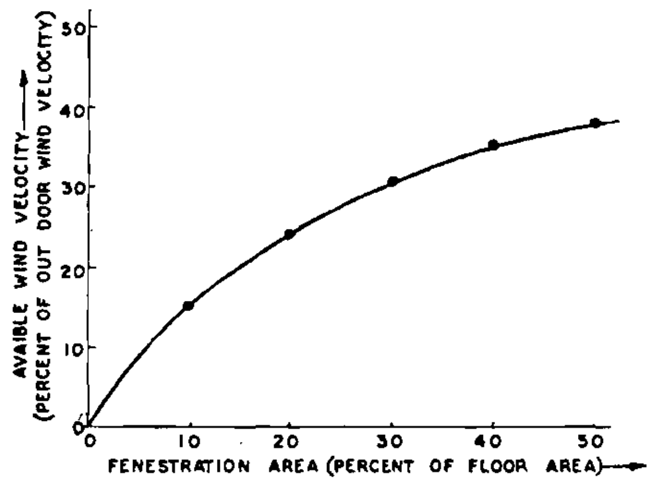


FIGURE 1.24

The first differential of velocity decreases as opening area increases.

tunnel modeling of internal air flow. The following relationship was found between the indoor average air velocity, outdoor air velocity and the area of openings. From an analysis of Givoni's work [22]:

$$V_{ai} = 0.45 \left(1 - e^{-3.84 X} \right) V_z \qquad \text{(Equation 6)}$$

WHERE:

V_{ai} = Average indoor air velocity

X = Ratio of window area to wall area

V_z = Outdoor wind velocity

With this equation, average indoor velocities can be predicted independently of a wind tunnel. Unfortunately, this mathematical relationship is only applicable to a square room with equal areas of inlets and outlets in opposite walls.

1.6.3 Mean Wind Speed Coefficient Method. A common method for assessing ventilation rates of buildings in hot humid climates involves the use of mean wind speed coefficients. Previous studies using the mean wind speed coefficient method include: School Classroom Studies conducted by Van Straaten [23], Caudill, Reed, and Holleman [24,25,26,27], industrial building studies conducted by Weston [28, 29], housing studies conducted by Givoni [16,20] and Chand [31], and highly porous building studies conducted by R.M. Aynsley (Figure 1.25, 1.26) [8]. Windspeed coefficients (C_v) are the ratio of the mean air speed at a point of interest (V_1) to the mean wind speed (V_z) at a specified reference height upstream from the building in the undisturbed wind flow so that:

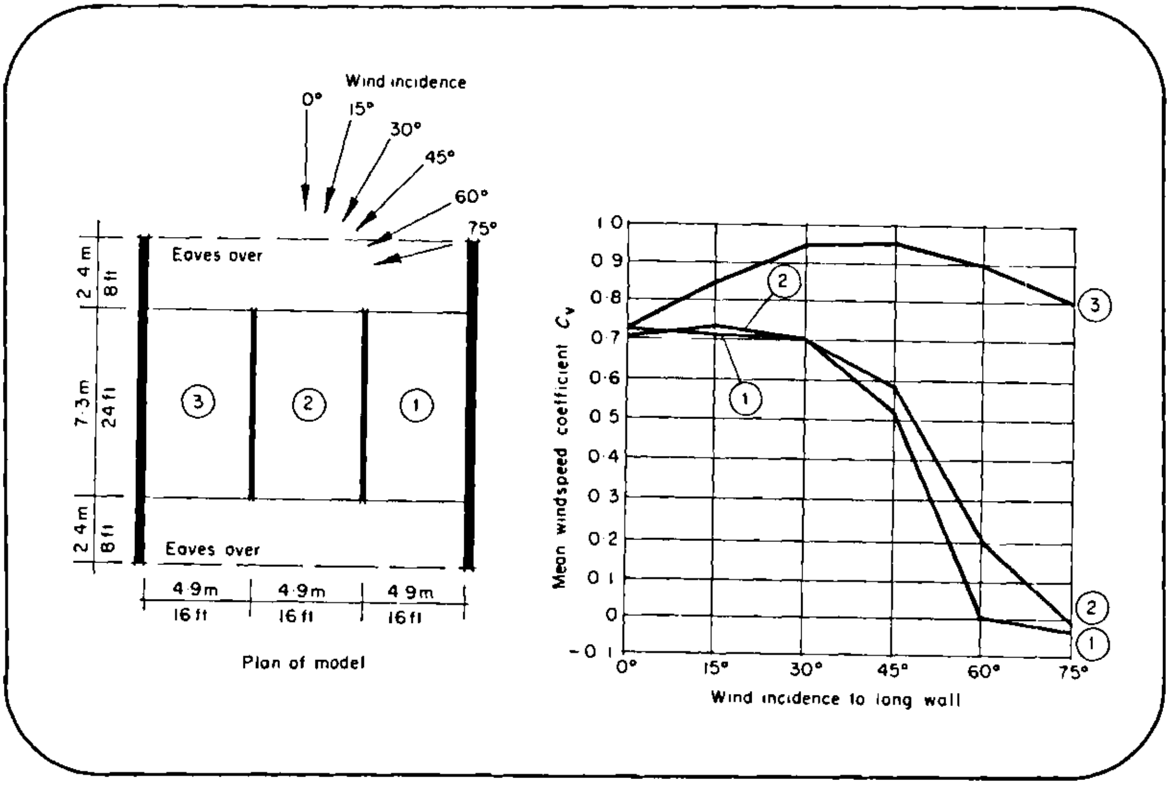


FIGURE 1.25

Mean wind speed coefficients at varying incidence through a low set house with extended eaves and end walls and two internal partitions. NOTE: Reference wind speed for wind speed coefficients was the mean wind speed at a height of 10m in a mean wind speed profile with a gradient height of 400m and an exponent 0.28.

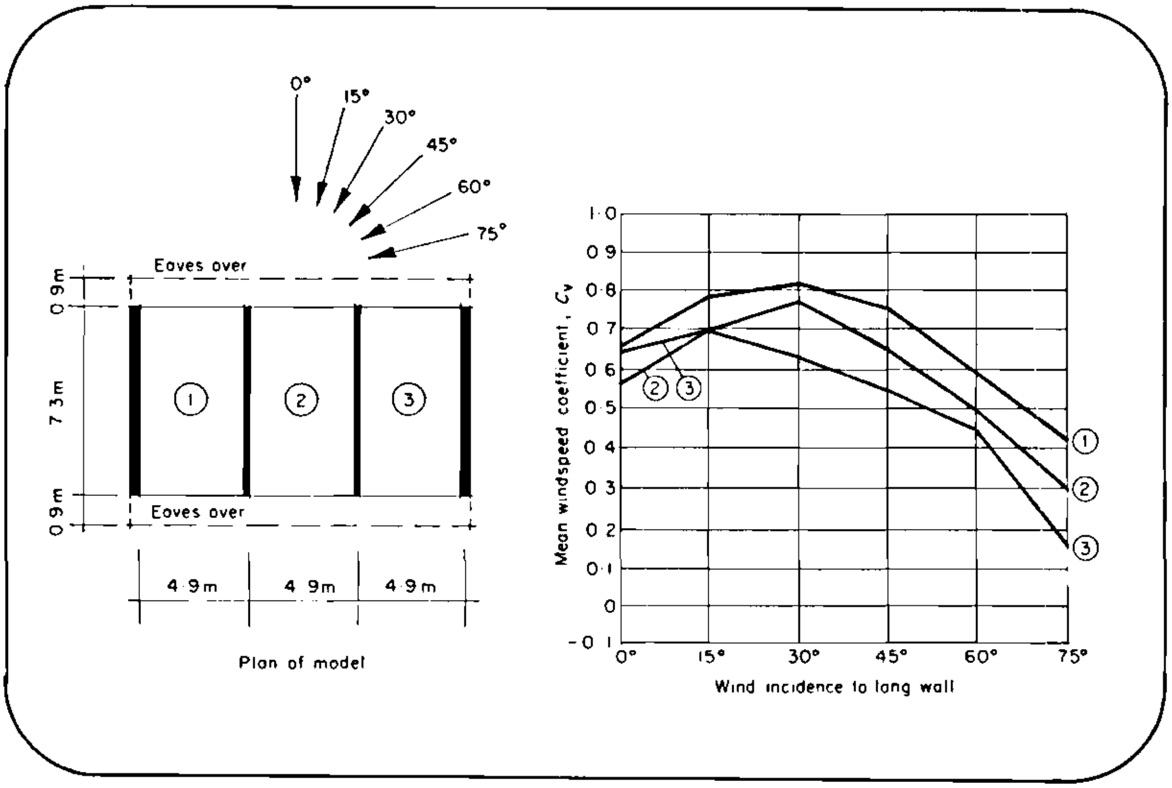


FIGURE 1.26

Mean wind speed coefficients at varying incidence through a low set house with small eaves and two internal partitions. NOTE: Reference wind speed for wind speed coefficients was the mean wind speed at a height of 10m in a mean wind speed profile with a gradient height of 400m and an exponent 0.28.

$$C_v = \frac{V_1}{V_r} \quad \text{(Equation 7)}$$

Air speeds in different building models can be compared by adopting a common reference wind speed in similarly modeled winds. Reference heights should be related to meteorological station records so that wind speeds and wind directions near the site can be taken for each month, day, and hour of the year. Using the appropriate velocity coefficient from a wind tunnel study, the mean indoor air speed (V_{mi}) can be predicted as follows:

$$V_{mi} = C_v V_{10} \quad \text{(Equation 8)}$$

WHERE: V_{10} = The mean wind speed at a reference height of 10 meters.

The mean wind speed coefficient method is ideally suited for predicting ventilation rates of buildings with complex geometries (1.27) [8]. For such buildings, extremely accurate modeling of complex openings and other architectural features is necessary (Figure 1.28) [8]. Even the use of insect screening can reduce airflow through openings. However, the full scale effects of screens with curved or rounded sections is nearly impossible to reproduce in wind tunnel modeling. Even if insect screen could be simulated accurately at small scale, flow past rounded elements in insect screening, for example, could be significantly different due to differences in Reynolds numbers of air flowing through full scale and model scale screen. For this reason openings in small models should be kept clear and a wind speed reduction factor should be applied to allow for the

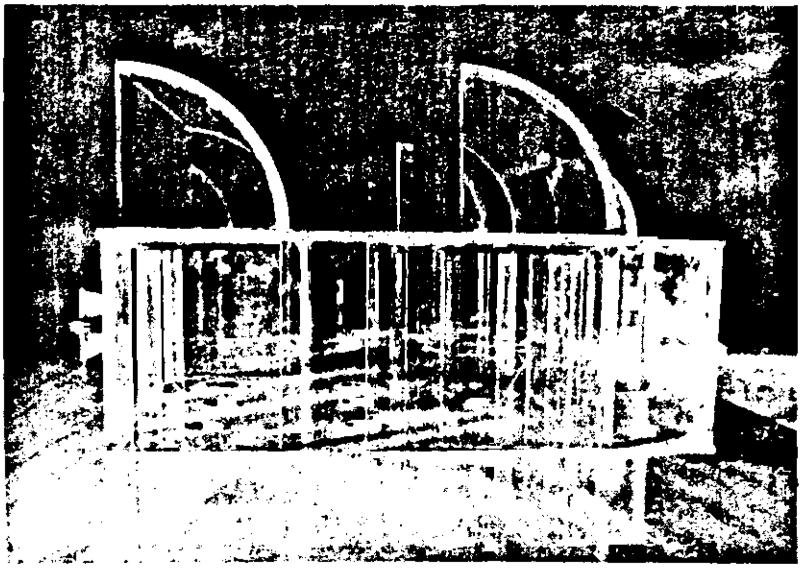


FIGURE 1.27

Wind tunnel model of an unusual building used to determine velocity coefficients for estimating natural ventilation.

effect of inserting components such as insect screens (Table 1.6) [8].

The mean wind speed coefficient method is ideally suited for predicting ventilation rates of buildings with complex geometries. Since wind speed coefficients are obtained directly by measuring reference velocities and internal velocities, estimates of air velocities in the main airstreams as well as in the sheltered eddy zones are easily determined. However if the height for external reference wind speeds do not correspond with the height for local wind speed records, estimating full scale velocities will be difficult. (See Appendix C.4.3 for Instrumentation available for flow measurements.)

1.7 Wind Pressure Difference Method

With the wind pressure difference method, it is possible to assess the mean airspeeds through openings without wind tunnel tests provided that pressure coefficients are available for the given building geometry. Sources of pressure coefficients include: studies of simple block forms without any architectural features conducted by Chien [32], Wise (Table 1.7) [4] Jackman (Figure 1.29, Table 1.8, Figure 1.20)[8] Simiu and Scanlan [33], studies of models with projecting eaves conducted by Jensen and Franck [34], studies of a wide range of building forms provided in wind loading codes, [35,36] and studies of high and low set houses conducted by R.M. Aynsley (Figure 1.31, 1.32) [8].

Since the anemometer height for most wind speed records is ten meters, the height for the reference dynamic pressure of most available pressure coefficients is typically chosen to match.

Screen material	Wind speed through clear opening. m/s	% Wind speed reduction with screen %
Bronze wire screen 5.5. wires/cm porosity 80 %	2 4 6	26 17 11
Plastic coated fibreglass 7 threads/cm porosity 60 %	2 4 6	41 34 19

TABLE 1.6

Reduction of airflow through insect screens.

Building height ratio	Building plan ratio	Side elevation	Plan	Wind angle α	C_{pe} for surface A	B	C	D	Local C_{pe}
$\frac{h}{w} < \frac{1}{2}$	$1 < \frac{\ell}{w} < \frac{3}{2}$			0°	+0.7	−0.2	−0.5	−0.5	−0.8
				90°	−0.5	−0.5	+0.7	−0.2	
	$\frac{3}{2} < \frac{\ell}{w} < 4$			0°	+0.7	−0.25	−0.6	−0.6	−1.0
				90°	−0.5	−0.5	+0.7	−0.1	
$\frac{1}{2} < \frac{h}{w} < \frac{3}{2}$	$1 < \frac{\ell}{w} < \frac{3}{2}$			0°	+0.7	−0.25	−0.6	−0.6	−1.1
				90°	−0.6	−0.6	+0.7	−0.25	
	$\frac{3}{2} < \frac{\ell}{w} < 4$			0°	+0.7	−0.3	−0.7	−0.7	−1.1
				90°	−0.5	−0.5	+0.7	−0.1	
$\frac{3}{2} < \frac{h}{w} < 6$	$1 < \frac{\ell}{w} < \frac{3}{2}$			0°	+0.8	−0.25	−0.8	−0.8	−1.2
				90°	−0.8	−0.8	+0.8	−0.25	
	$\frac{3}{2} < \frac{\ell}{w} < 4$			0°	+0.7	−0.4	−0.7	−0.7	−1.2
				90°	−0.5	−0.5	+0.8	−0.1	

ℓ - length of major face of building. w - width of building (length of minor face)

TABLE 1.7

Pressure coefficients C_d for vertical walls of rectangular clad buildings.

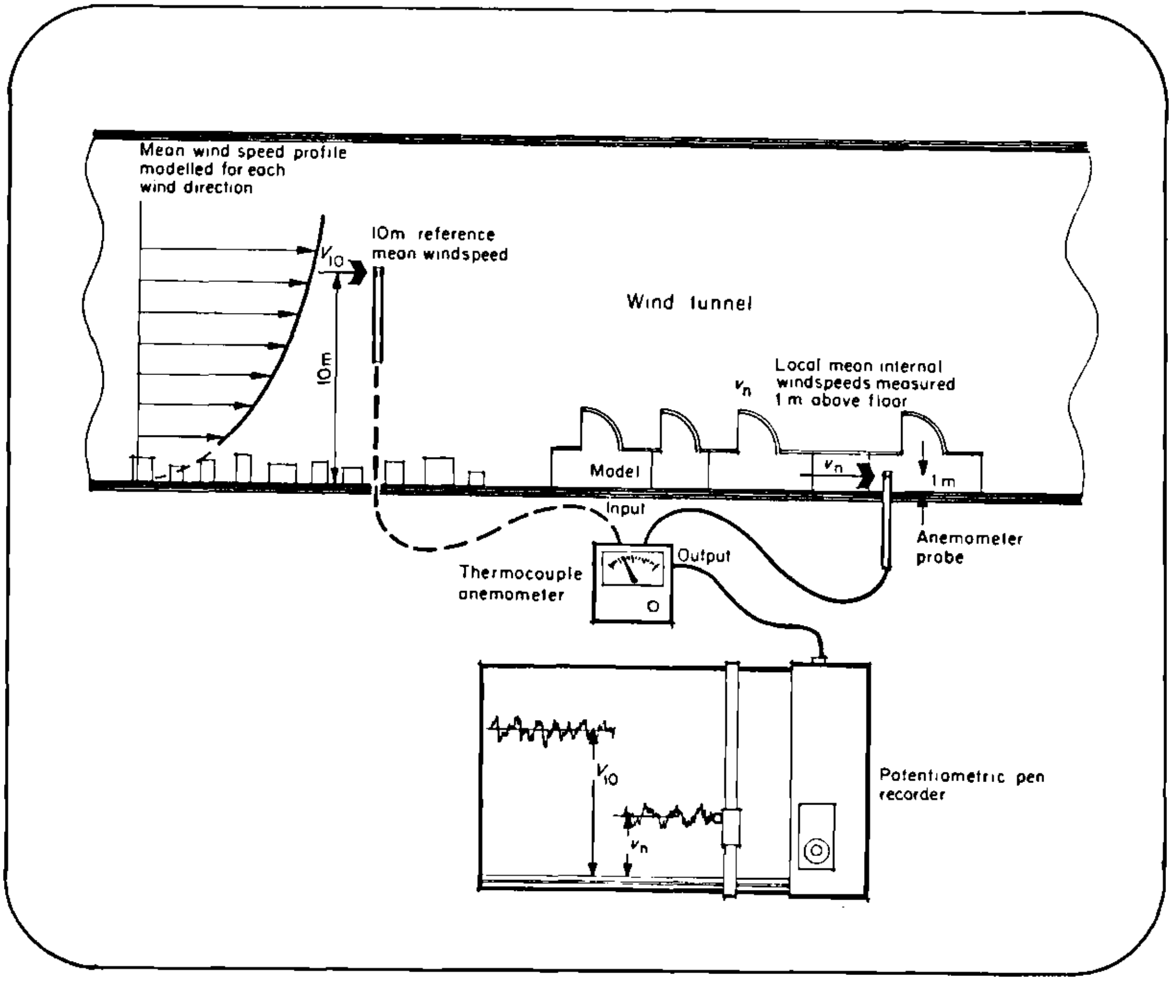


FIGURE 1.28

Wind tunnel technique for determining mean wind speed coefficients. Mean wind speed coefficient $C_v = V_n$. Local mean wind speeds V_n are estimated from 10m wind records $V_n = C_v * V_{10}$.

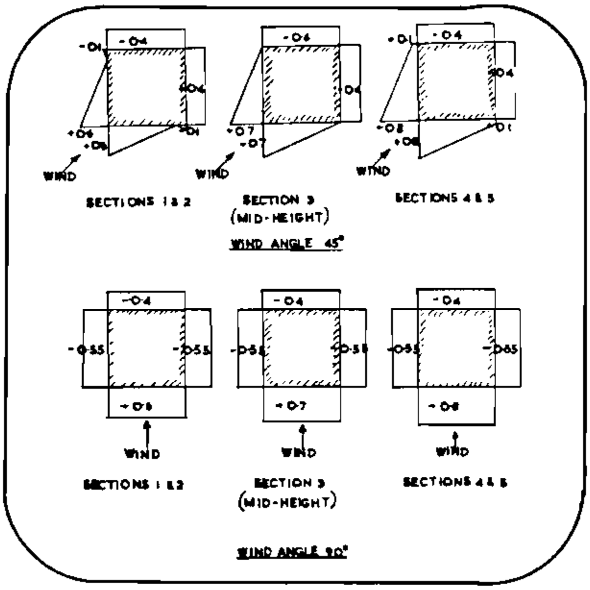


FIGURE 1.29

Pressure coefficients at Varying Wind Incidence Angles for a Square Building.

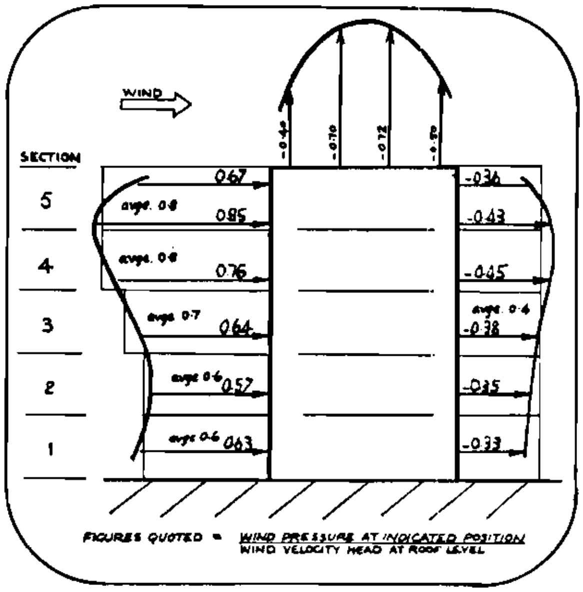


FIGURE 1.30

Pressure Coefficients at Five Locations on a Rectangular Building.

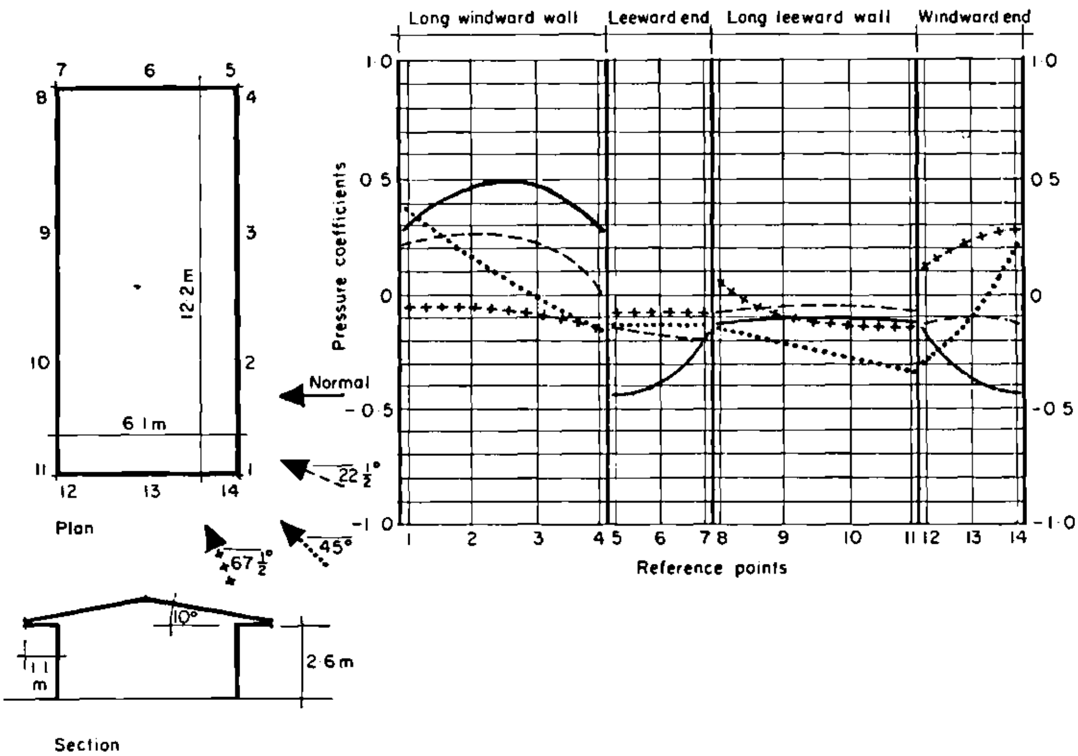


FIGURE 1.31

Pressure distribution at midheight of walls on a low set house with eaves. NOTE: Pressure coefficeints above are based on a reference dynamic pressure 10m above ground. Mean wind speed profile gradient height 400m and exponent 0.28.

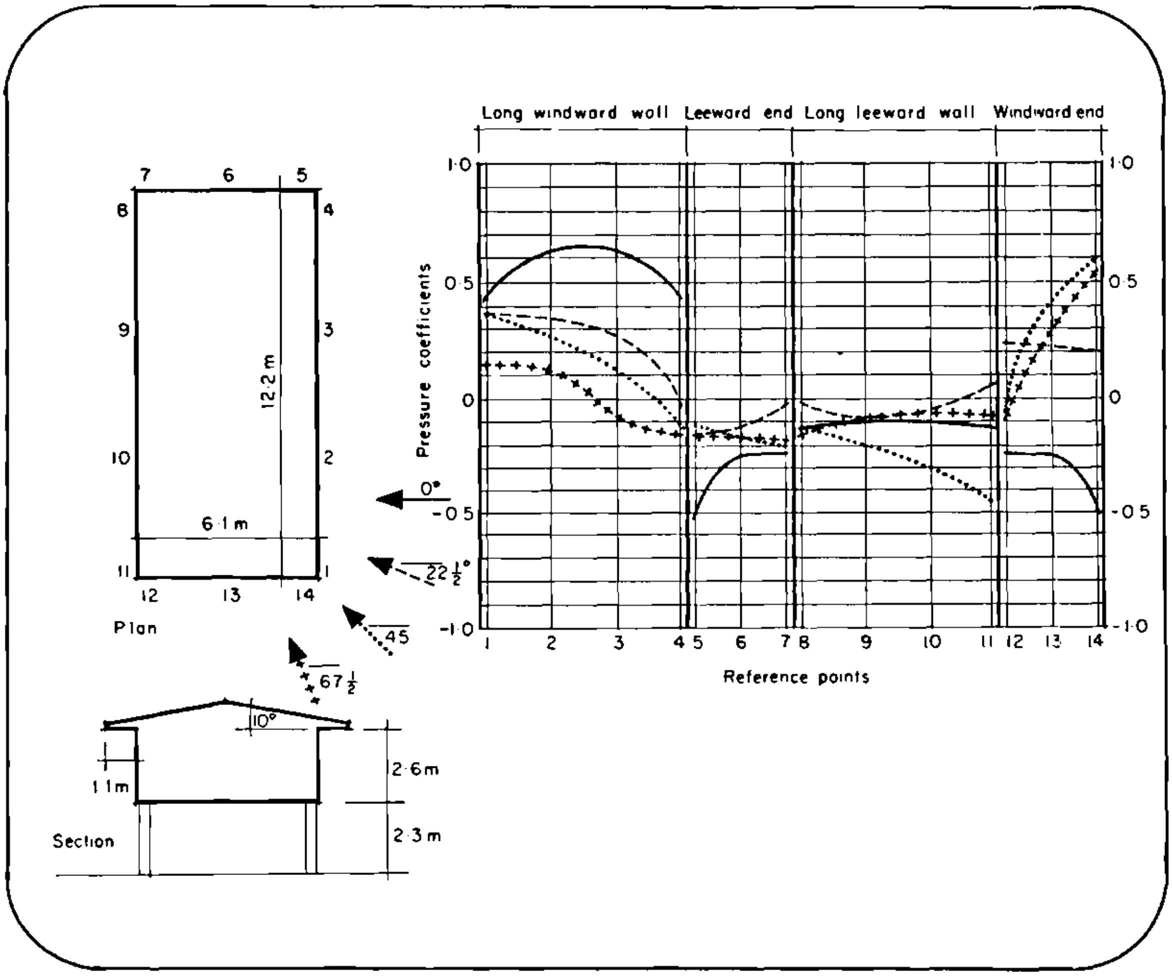


FIGURE 1.32

Pressure distribution at midheight of walls on a high set house with eaves. NOTE: Pressure coefficients above are based on a reference dynamic pressure 10m above ground. Mean wind speed profile gradient height 400m and exponent 0.28.

Average Air Pressure		
Section	Windward Side	Leeward Side
1	+0·6 $\frac{1}{2}\rho V^2$	−0·4 $\frac{1}{2}\rho V^2$
2	+0·6 $\frac{1}{2}\rho V^2$	−0·4 $\frac{1}{2}\rho V^2$
3	+0·7 $\frac{1}{2}\rho V^2$	−0·4 $\frac{1}{2}\rho V^2$
4	+0·8 $\frac{1}{2}\rho V^2$	−0·4 $\frac{1}{2}\rho V^2$
5	+0·8 $\frac{1}{2}\rho V^2$	−0·4 $\frac{1}{2}\rho V^2$

TABLE 1.8

Average pressure coefficients at five locations on a rectangular building

Wind pressures on rectangular plan building				
Meteorological Wind speed mile/h	Building Height feet	Horizontal Section No.	Pressure (in wg)	
			Wind-ward side	Leeward side
10	50	1 & 2	+0·0083	−0·0055
		3	+0·0097	−0·0055
		4 & 5	+0·0110	−0·0055
	100	1 & 2	+0·0138	−0·0087
		3	+0·0152	−0·0087
		4 & 5	+0·0173	−0·0087
	200	1 & 2	+0·0208	−0·0139
		3	+0·0244	−0·0139
		4 & 5	+0·0279	−0·0139
20	50	1 & 2	+0·0330	−0·0220
		3	+0·0386	−0·0220
		4 & 5	+0·0440	−0·0220
	100	1 & 2	+0·052	−0·035
		3	+0·061	−0·035
		4 & 5	+0·069	−0·035
	200	1 & 2	+0·083	−0·056
		3	+0·098	−0·056
		4 & 5	+0·112	−0·056

TABLE 1.9

Average pressure coefficients at five locations on rectangular buildings with various heights

Description of opening	Typical range of discharge coefficients for normal incidence	Jet characteristics
Small openings in thin walls less than 10% of wall area near the centre of the wall	0·50–0·65	Small inertia due to small mass of air in jet
Openings 10–20% near the centre of a wall with aspect ratio similar to the cross-section of the downwind space	0·65–0·70	Significant inertia due to increased mass of air in jet
Openings 10–20% of a wall with one edge common with the downwind space such as a doorway	0·70–0·80	Wall effect reduces energy losses on one side of jet
Openings similar in size to the cross-section of the downstream space	0·80–0·90	Wall effect around the perimeter of the jet significantly reduces turbulent energy losses

TABLE 1.10 A

Discharge coefficients for outlet openings.

A_0/A_i	C_d
Approaching 0·0	0·63
0·2	0·64
0·4	0·67
0·6	0·71
0·8	0·81
1·0	1·00

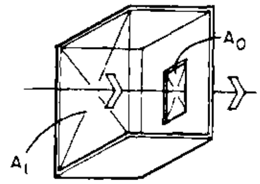


TABLE 1.10 B

Typical discharge coefficients for single inlet or intermediate openings in buildings.

However, for high rise structures it may be necessary to choose other reference heights (Table 1.9)[3]. If there are differences between the reference dynamic pressure height (Zr) and the local anemometer height (Za). (Figure 1.33) [8], it is possible to modify the pressure coefficients by the following equation:

$$C_{p2} = C_{p1} \left[\left(\frac{Zr}{Za} \right)^{\alpha} \right]^2 \qquad \text{(Equation 9)}$$

WHERE:

α = Ground roughness

C_{p1} = Initial pressure coefficient

C_{p2} = Modified pressure coefficient

In most natural ventilation studies, the discharge coefficient (C_d) is used rather than the dynamic loss coefficient (C_1) these coefficients have the following relation:

$$C_d = \frac{1}{(C_1)^{1/2}} \qquad \text{(Equation 10)}$$

Sources for discharge coefficients include: typical building openings as determined by Van Straaten [37] and ASHRAE authors [38], square edge cracks as determined in full scale studies conducted by Dick [39], large classroom windows approximately 10% of the wall area as determined by Wannenburg and Van Straaten [40], larger rectangular openings in series up to 20% of the wall area as determined by Snuckers [41], and rectangular openings from 0-100% of the wall area as determined by Aynsley (table 1.10 a,b) [8].

Using discharge coefficients, the following equations can be used to calculate the air velocity rate (Vo) through a single opening

$$V_o = C_d \, [(C_{pw} - C_{pl}) \, V_z^2]^{1/2} \qquad \text{(Equation 11)}$$

or in terms of the volumetric flow rate (Q)

$$Q = C_o A \, [(C_{pw} - C_{pl}) \, Vr^2]^{1/2} \qquad \text{(Equation 12)}$$

and the air velocity (V_o) through openings in series

$$V_o = \frac{(C_{pw} - C_{pl}) \, V_z^2}{\frac{1}{C_{d1}^2 A_1^2} + \frac{1}{C_{d2}^2 A_z^2} + \ldots + \frac{1}{C_{dn}^2 A_n^2}} \qquad \text{(Equation 13)}$$

WHERE:

A = Area of opening (ft^2)

C_{pw} = Pressure coefficient (windward side)

C_{pl} = Pressure coefficient (leeward side)

C_d = Discharge coefficients

Vz = The reference wind speed (ft/sec)

The principal advantage of the pressure and discharge coefficient approach is that with growing sources of wind pressure distribution data, estimates of natural ventilation can be made without wind tunnel studies. Unfortunately, the majority of wind distribution data is associated with wind loading research using solid model forms in wind tunnel testing. It has been shown by R.E. Bilsborrow and F.R. Fricke that if pressure distribution on solid models were used, inaccuracies of up to thirty percent could occur from lateral flow over openings that were ten percent of the wall area

(Figure 1.34, 1.35, 1.36) [42]. If the building's openings exceed 20%, it becomes increasingly difficult to determine the effective pressure difference responsible for airflow through these openings from the pressure distribution data on solid models. Another disadvantage with the pressure differences method is that estimates of mean internal wind speeds are limited to the jet near the inlets. Since these jets occupy only a small proportion of the room, this limitation can be a significant problem [8]. (See Appendix C.4.4 for instrumentation available for pressure measurements.)

Only two of the wind related equations discussed in the previous sections do not require wind tunnel testing to predict ventilation rates; these include the average velocity method and the pressure difference method. The accuracy of these two equations is dependant on the precision of previous wind tunnel studies from which these methods were derived, and the availability of representative pressure coefficients for specific building geometries and opening configurations.

The average velocity method is a mathematical relationship developed from wind tunnel studies of a square room with equal areas of inlets and outlets in opposite walls. Since no additional wind tunnel data is needed for this method, it is ideal for a computer model. Unfortunately, the average velocity method is limited to:

A. One specific room geometry, ratio of opening sizes, and opening placement.

B. Providing only the average air velocity with no indication of maximum and minimum velocities at specific points in the room.

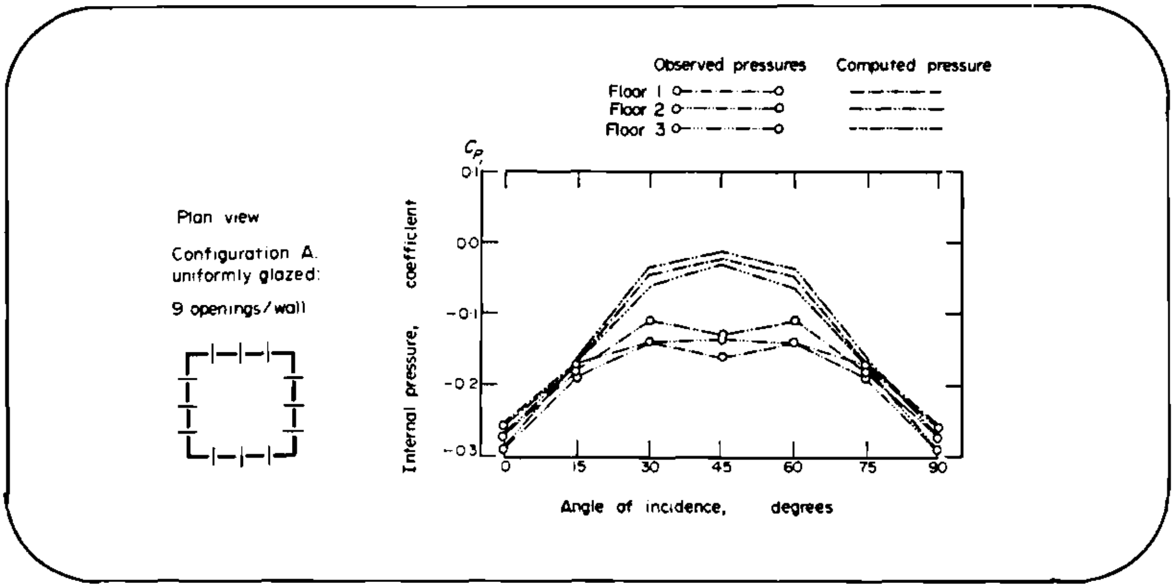


FIGURE 1.34

Observed and computed internal pressures, opening configuration A, boundary layer I, variation with angle of incidence.

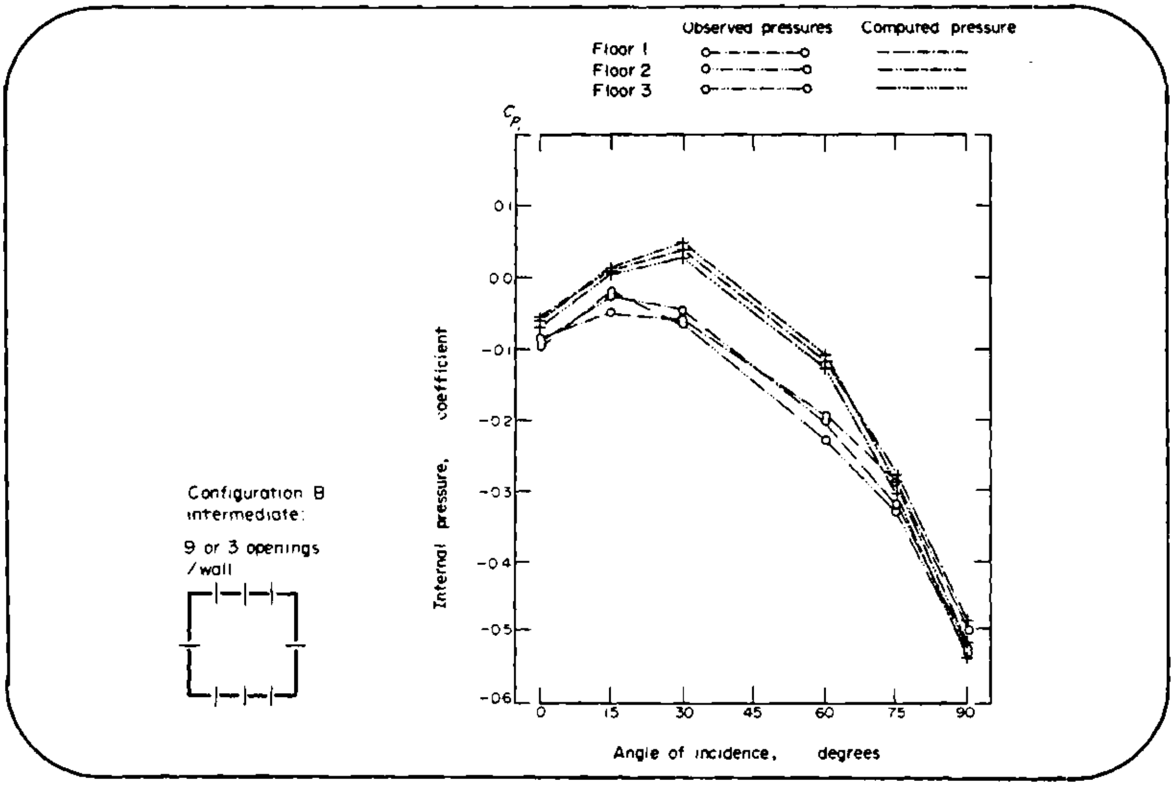


FIGURE 1.35

Observed and computed internal pressures, opening configuration B, boundary layer I, variation with angle of incidence.

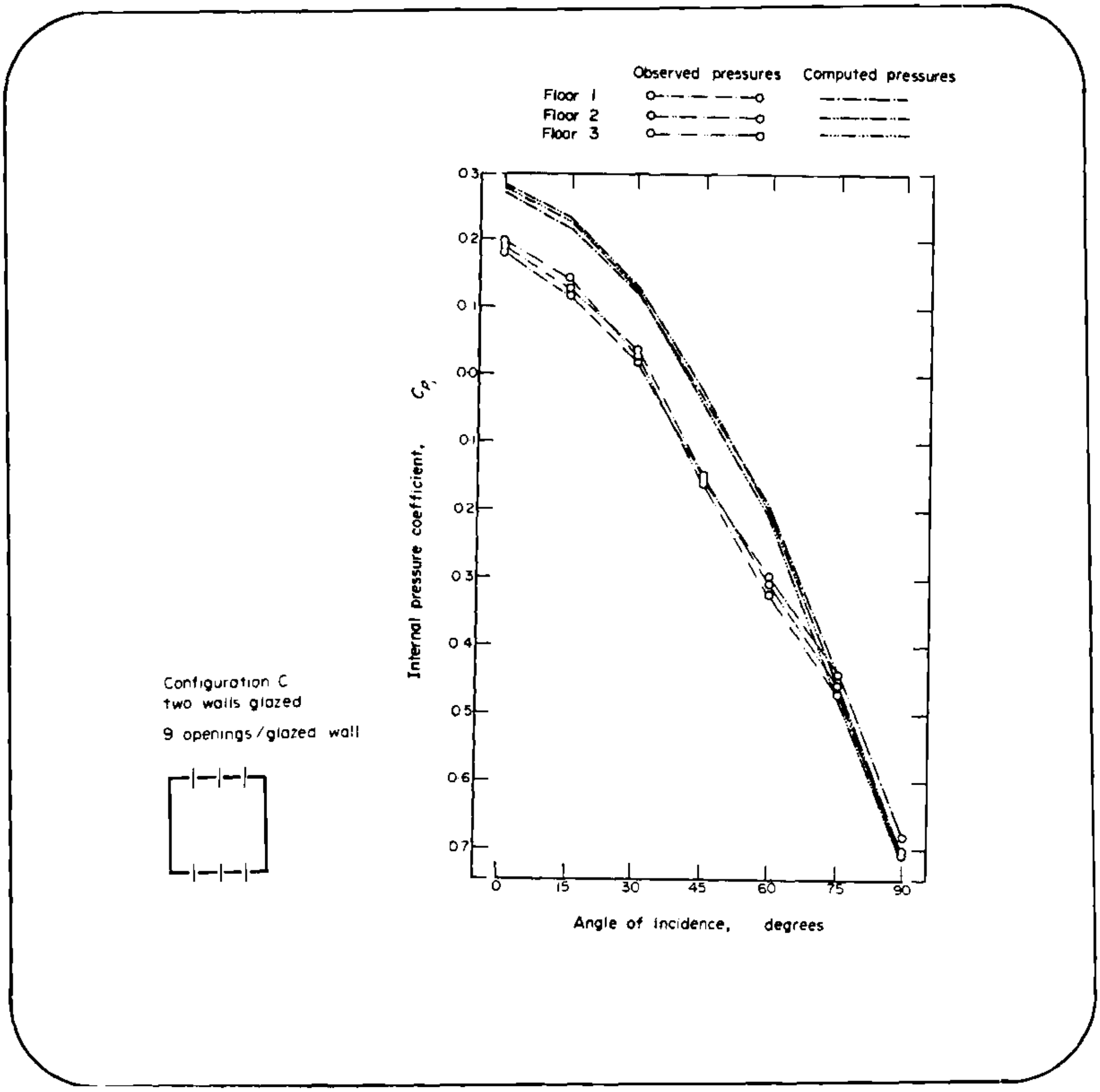


FIGURE 1.36

Observed and computed internal pressures, opening configuration C, boundary layer I, variation with angle of incidence.

The accuracy of the pressure difference method is dependent on how well geometries and openings of the building being analyzed match the model from which the pressure coefficients were determined in previous wind tunnel tests. For example, inacuracies will begin to develop when coefficients derived from solid models are used for openings greater than 20%.[1] Another concern of using the pressure difference method is that the velocities outside the main airstream cannot be determined. However, by assuming that the main air stream flows through the living zone to maximize the cooling effect, velocities at other points in the room are of no practical importance.

The pressure difference method is most applicable to the computer model because of its flexibility. Natural ventilation assessments of any geometry and opening configuration can be made without the aid of a wind tunnel provided that wind pressure coefficients from previous wind tunnel studies are available.

[1] In disscussions with Kalev Ruberg, Professor of Architecture, Georgia Institute of Technology, Recommendations have been made to prevent large error by setting an upper limit of 30% of the wall area for opening sizes that can be tested when pressure coefficients of solid model forms are used.

CHAPTER II

NATVENT: PROGRAM DESCRIPTION

2.1 Use of NATVENT

2.2 Input Runstreams

2.3 Input Runstream Paths

2.4 Output

CHAPTER II

PROGRAM DESCRIPTION

The extent to which natural ventilation can be used to meet fresh air requirements and thermal comfort criteria is affected by:

A. Architectural details:

1. External geometries,
2. Internal geometries,
3. Type of openings on the building facades; and
4. Ratio of outlet size to inlet size

B. Comfort parameters:

1. Radiant temperatures, or room temperatures:
2. Occupant activity levels
3. Occupant clothing levels
4. Fresh air requirement

C. Climate conditions

1. Ambient dry bulb temperature
2. Relative humidity
3. Wind speeds
4. Wind direction

NATVENT, the natural ventilation availability program calculates the effect of architectural design details and climate variables on actual climate conditions. Calculations are made on an hourly basis using local weather data. A flowchart of the program is illustrated in Figure 2.1. It shows the principal program components, including the

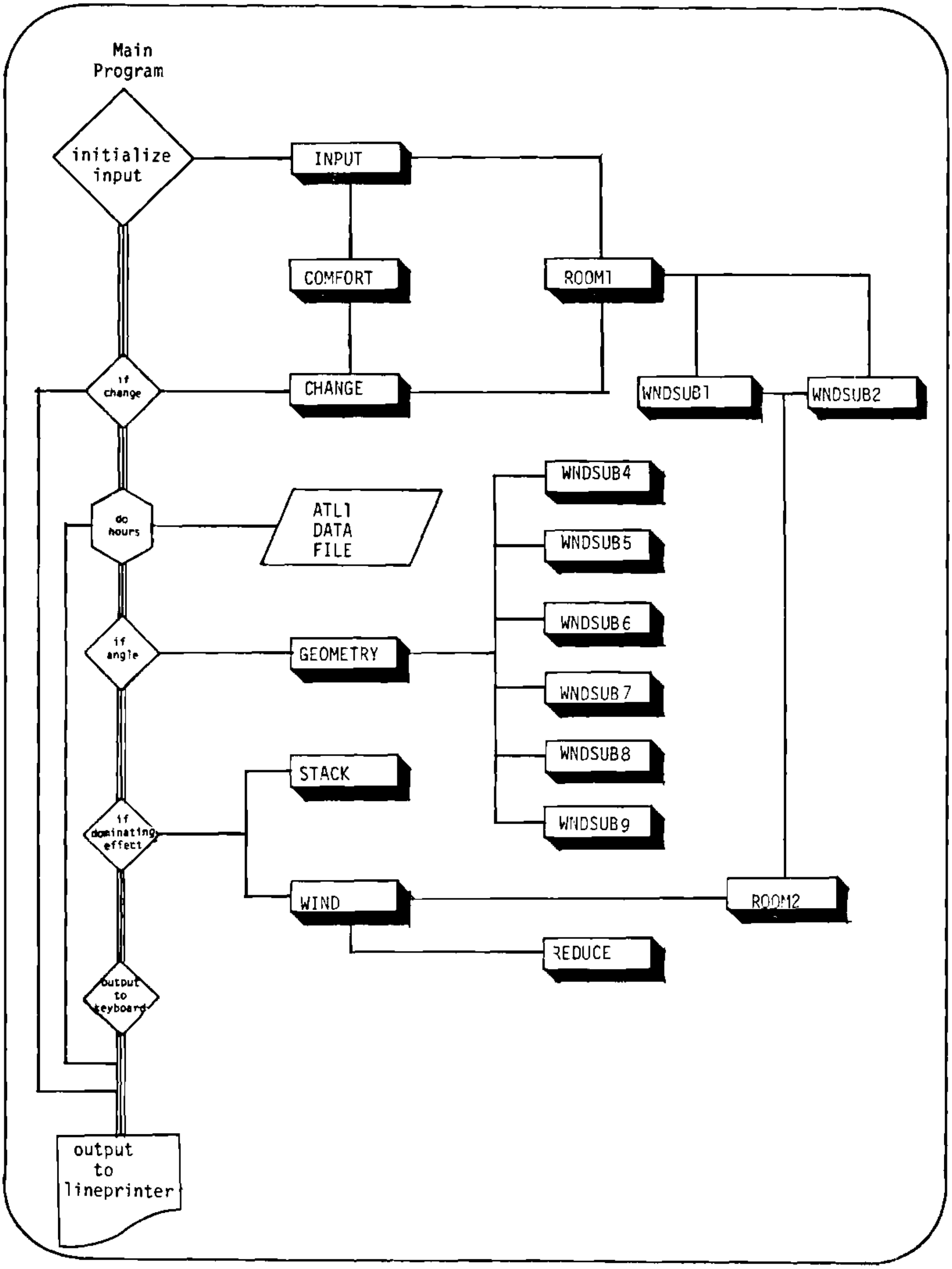


FIGURE 2.1
Flow chart of natural ventilation availability program, NATVENT. Sequence subroutines are accessed.

main program and various subroutines. Input and output formating are handled in the main program and subroutine INPUT. The program has limited interactive input prompting. Prompts are dependant on the path the user takes through the program. The main program calls subroutine INPUT to initiate the prompts and call various subroutines in response to the users description of architectural details, comfort parameters, and format of output. These subroutines are listed below in their sequence of execution:

INPUT:

Interactively prompts the user for the type of output and architectural detail descriptors.

COMFORT:

Modifies the indoor temperature based on radiant temperature, occupant activity, and occupant clothing levels.

ROOM1:

Interactively prompts the user for the area for each opening and the sectional area of each room.

WNDSUB1:

Contains discharge coefficients for various types of inlets (accessed by ROOM1).

WNDSUB2:

Contains discharge coefficients for various outlets (accessed by ROOM1).

CHANGE:

Uses a menu to allow user to change input (accessed from the main program.

ATL1

A data file containing local climiate data (accessed from the main program).

GEOMETRY:

Calls the appropriate subroutine containing the wind pressure coefficients for a given geometry.

WNDSUB4:

Contains wind pressure coefficients for a building with a height less than 1/2 the width and a length less than 3/2 the width.

WNDSUB5:

Contains wind pressure coefficients for a building with a length less than 1/2 the width and a length less than four times the width.

WNDSUB6:

Contains wind pressure coefficients for a building with a height less than 3/2 the width and a length less than 3/2 the width.

WNDSUB7:

Contains wind pressure coefficients for a building with a height less than 3/2 the width and a length less than four times the width.

WNDSUB8:

Contains wind pressure coefficients for a building with a height less than six times the width and a length less than 3/2 the width.

WNDSUB9:

Contains wind pressure coefficients for a building with a height less than six times the width and a length less than four times the width.

A dominating effect algorithm located in the main program selects one of the following subroutines to calculate natural ventilation rates for fresh air requirements and thermal comfort:

STACK Calculates:

1. The area of opening.
2. The volume of air exfiltrating and infiltrating the building to achieve fresh air requirements.
3. The temperature of solar heated exhaust air in a solar chimney for example, needed for a sufficient temperature differential to provide adequate air velocities for summer cooling.

WIND Calculates:

1. The area of openings needed for thermal comfort based on the building geometry and climate conditions.
2. The velocity produced by wind on the selected facade opening configurations. The average velocity at each opening is compared to velocity needed to achieve thermal comfort.

ROOM2:

Calculates the area of each opening and the sectional area of each room (accessed from wind) as illustrated.

WNDSUB1:

Contains discharge coefficients for various sizes of inlets (accessed from ROOM2).

WNDSUB2:

Contains discharge coefficients for various sizes of outlets (accessed from Room 2).

REDUCE:

Reduces ventilation rates for each degree from normal wind incidence to the opening.

2.1 Use of NATVENT

This program uses a data file that contains annual hourly weather data (see Appendix D). Program NATVENT is capable of determining the number of hours during the cooling season that thermal comfort is restored by wind induced cooling, the number of hours during the intermediate season that fresh air is supplied by wind, and the volumetric airflow induced by stack effect during the heating season. The program can be used to analyze any building geometry with openings on two or four sides, any size and number of rooms in series, any size and number of inlets and outlets in series, any size outlet above the neutral zone, and any size inlet below the neutral zone.

A complete list of variable names and definitions appear at the beginning of the main program so that the user may more easily identify these for any desired changes in the program. NATVENT is well documented to provide the user with an option of making changes to the program. General descriptions for each subroutine and specific comments describing or each algorithm are included.

2.2 Input Runstreams

Interactive prompts lead the user through the program. The following input is required for all run streams:

A. Selection of analysis

   1. Area of opening calculated for each hour

   2. Air velocity resulting from selected opening areas.

B. Building's external geometry

   1. Height

   2. Length

3. Width

C. Building's internal geometry

1. Number of rooms in series

D. Fresh air requirements

1. Building's required ventilation rate

2. Room with the maximum fresh air requirements.

NOTE: See Appendix A.2 for a listing of fresh air requirements for several building types.

E. Opening configurations

1. Distance vertically between openings

2. Number of building sides with openings

2.3 Input Runstream Paths

The path of each runstream is dependant on the user's input. Examples of two of the many possible paths and the unique input for each of these runstreams are described below and illustrated in Figures 2.5 and 2.6.

The following input is required to solve for the area of outlets and inlets needed on four sides of a building to achieve thermal comfort and fresh air requirements for fluctuating weather conditions. If the building has radiant heat gains from factory machinery, the required data unique to the runstream includes input for comfort parameters.

A. Sectional area of the room perpendicular to:

1. The buildings long face

2. The buildings short face

NOTE: The sectional area for each series of rooms is assumed to be equal so that every opening in the wall partitions can be increased by a percentage of this area for each iterative calculation.

B. Comfort Parameters

1. Radiant surface temperatures

a. Summer temperatures

b. Winter temperatures

2. Activity

3. Clothing

C. Opening Configurations

1. Ratio of the largest to smallest area of opening above or below the neutral zone.

a. Winter (windows closed)

b. Summer (windows open)

D. Menu

1. Run program

2. Send output to lineprinter

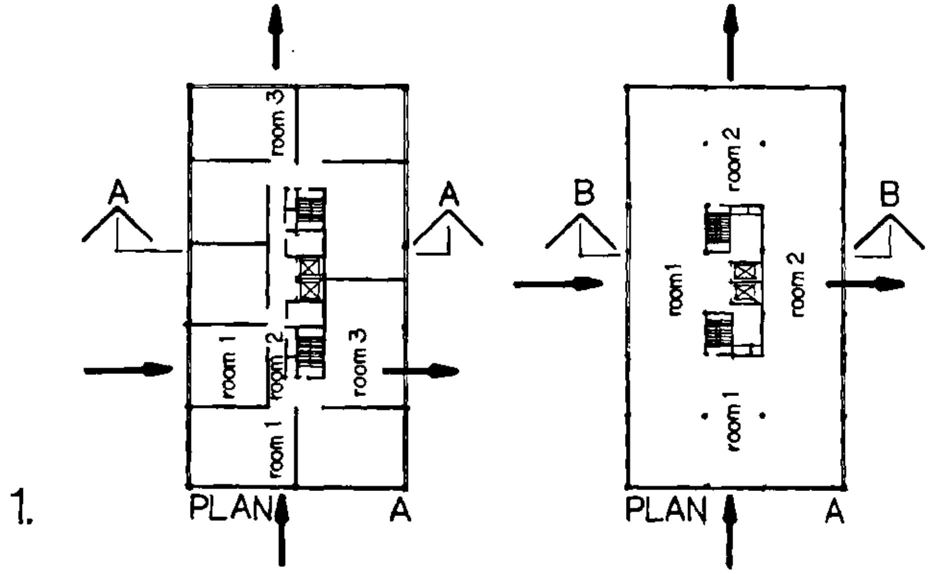
The following is required for comparing the number of hours annually when fresh air requirements and thermal comfort is achieved by natural air flows through three rooms in series of a low rise and a high rise office building with openings 40% of the wall area located on two sides of the structure (Figure 2.2).

The required data unique to this problem solution includes:

A. Comfort Parameters

1. Radiant surfaces

NOTE: If radiant surfaces equal 78°F, it is not necessary to adjust the comfort parameters. Because the computer model's internal comfort parameters are:



1. The open office plan increases natural ventilation potential due to less internal friction resulting from less rooms in series.

2. The high rise office building has greater wind velocities available to induce natural ventilation. However, infiltration of cold air due to stack effect during the heating season is a greater problem for high rise structure.

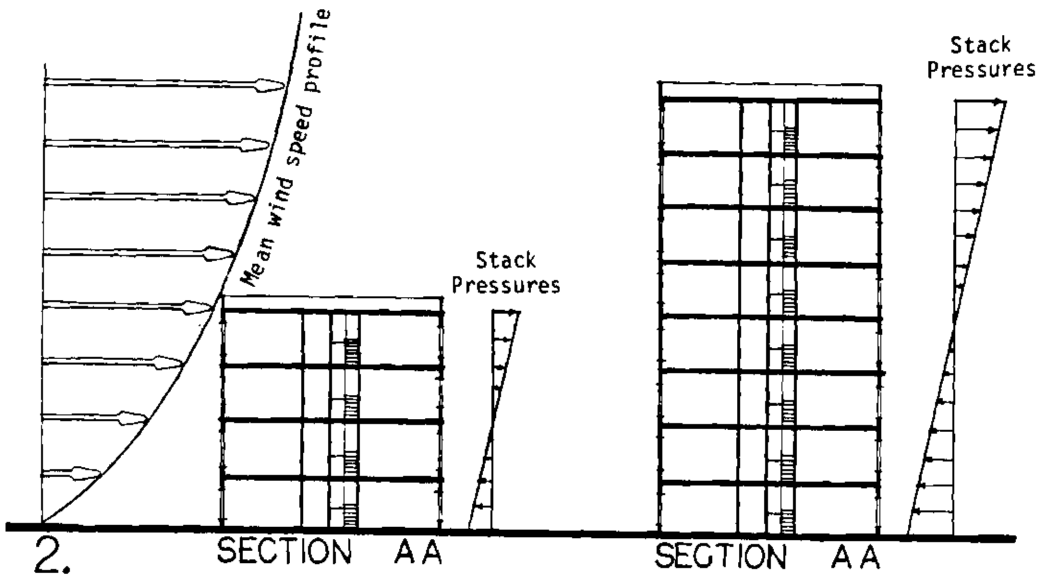


FIGURE 2.2

Comparison of natural forces acting on a low and a high-rise structure.

a. A mean radiant temperature of 78°F

b. A clothing level of 1.0 CLO (Business suit)

c. An activity level of 480 - 560 BTU/Hr (Office work).

d. A dry bulb temperature of 78°F

e. A relative humidity of 60% comfort charts show that with these variables 80% of the adult population is most comfortable [45].

B. Opening Configurations

1. Area of crack (windows closed)

a. Above the neutral zone

b. Below the neutral zone

NOTE: Typical areas of crack per linear foot of the window periphery is listed in Table A-2 (See Appendix A-3)

2. Area of opening (windows open)

a. Above the neutral zone

b. Below the neutral zone

3. Total area of opening of building's

a. Two long faces

4. Area of opening for the:

a. First internal partion (OUTLET-2)

b. Second internal partion (OUTLET-3)

C. Internal Geometries

1. Series of rooms perpendicular to long face

a. Sectional area for Room 1

b. Sectional area for Room 2

c. Sectional area for Room 3

D. Menu

1. Run program (for the low-rise building see Appendix A.2).

2. Change input (for high-rise building)

   a. Building's external

      i. Height

      ii. Exit change menu

3. Re-run program (for the high-rise building)

4. Send all output to the lineprinter.

Measures have been taken to prevent abortive runs from erroneous input. All of the program's menus (numbered interactive input selection systems) utilize a safety algorithm that prevents a termination of the program from the computer reaching an "END OF FILE". Normally, an "END OF FILE" would be reached when the interactive input is other than that specified by the menu. Instead, the safety algorithm will print "YOU SCREWED UP! TRY AGAIN." and re-lists the choices that the user may select from the menu (Figure 2.3). The program also contains a subroutine that enables the user to change any or all of the input before the program is run (Figure 2.4).

2.4 Output

The following examples of output are possible with program NATVENT:

I. A Listing of the input

   A. The calculated maximum areas of window and door cracks that will minimize infiltration yet meet fresh air requirements for each three hour interval of the fluctuating winter weather.

   B. The calculated minimum area of window and door opening that

```
WOULD YOU LIKE THE COMPUTER TO...
      1) SOLVE FOR THE OPENING SIZES THAT WILL MAXIMIZE THE
         HOURS THAT THERMAL COMFORT IS ACHIEVED
OR
      2) TEST THE OPENING SIZES THAT YOU INPUT FOR
         THE NUMBER OF HOURS PER YEAR THERMAL
         COMFORT IS ACHIEVED.
(TYPE 1 OR 2)
? 1200
YOU SCREWED UP! TRY AGAIN.
WOULD YOU LIKE THE COMPUTER TO...
      1) SOLVE FOR THE OPENING SIZES THAT WILL MAXIMIZE THE
         HOURS THAT THERMAL COMFORT IS ACHIEVED
OR
      2) TEST THE OPENING SIZES THAT YOU INPUT FOR
         THE NUMBER OF HOURS PER YEAR THERMAL
         COMFORT IS ACHIEVED.
(TYPE 1 OR 2)
? 2
```

FIGURE 2.3

Safety algorithm for erroneous input.

```
WOULD YOU LIKE TO...
      1) CHANGE THE BUILDING HEIGHT
      2) CHANGE THE BUILDING LENGTH
      3) CHANGE THE BUILDING WIDTH
      4) CHANGE THE VERTICAL DISTANCE BETWEEN OPENINGS
      5) CHANGE THE THE ORIENTATION OF THE BUILDING'S LONG FACE
      6) CHANGE THE BUILDING'S VENTILATION RATE
      7) CHANGE THE REQUIRED VENTILATION RATE FOR 1 ROOM
      8) CHANGE THE COMFORT PARAMETERS
      9) CHANGE THE MAXIMUM AREA OF OPENINGS
      10) CHANGE THE OF SIDES OF THE BUILDING WITH OPENINGS
      11) CHANGE THE NUMBER OF ROOMS PARALLEL TO THE LONG FACE
      12) CHANGE THE NUMBER OF ROOMS PARALLEL TO THE SHORT FACE
      13) SOLVE FOR OPENINGS
            CHANGE THE ROOM'S SECTIONAL AREA(S)
            CHANGE THE RATIO OF THE LARGEST TO SMALLEST OPENING
      14) TEST THE PERFORMANCE OF THE OPENINGS SELECTED
            CHANGE AREA OF OPENING ABOVE AND BELOW THE NEUTRAL ZONE
            CHANGE THE SERIES OF OPENING AND ROOM SECTIONAL AREAS
15) EXIT THIS CHANGE ROUTINE
```

FIGURE 2.4

A menu for input changes.

will induce adequate air movement through a user specified building geometry to restore thermal comfort for each three hour interval of the fluctuating summer weather.

II. A Listing of the output

A. The calculated volumetric flowrate infiltrating and exfiltrating based on the area of window and door cracks for each three hour interval of winter weather data.

B. The calculated air velocity that will induce thermal comfort based on the user's specification of building geometries and area of openings for each three hour interval of summer weather data.

From the first output example, the user is able to make intelligent selections of opening sizes that will minimize winter infiltration and maximize summer ventilation. The second example of output indicates the performance of selected opening sizes performs with fluctuating climatic conditions. Performance in both examples of output is described by the descriptions found under the headings" Type of Vent" and "Is Comfort Achieved?" Explanations of the possible combinations of the descriptions "STACK, WIND, MINOR, NONE, YES, and NO" are described in Table 2.1.

Type of Vent	Is Comfort Achieved	Explanation
STACK		Infiltration of cold air induced by stack effect.
STACK	YES	Adequate air flow is induced by stack effect to restore thermal comfort.
WIND	YES	Adequate air flow is induced by wind pressure to restore thermal comfort.
MINOR	NO	Wind pressure acting on configuration of openings is not sufficient to restore thermal comfort. Thermal comfort. Thermal comfort can be restored by supplementation of fans.
NONE	NO	Removal of heat and/or humidity is required because of one or both of the following: 1. Temperature of air transfers heat to the body despite the air velocity. 2. Combination of dry bulb temperature and relative humidity necessitates an air velocity over 300 feet per min.

TABLE 2.1

Description of output.

```
*********************************************************************************
                A NATURAL VENTILATION MODEL
                      BY DAVE NUTT 1981
*********************************************************************************
WOULD YOU LIKE THE COMPUTER TO...
     1) SOLVE FOR THE OPENING SIZES THAT WILL MAXIMIZE THE
        ANUAL HOURS OF NATURAL VENTILATION USE
OR
     2) TEST THE PERFORMANCE OF THE OPENING
        SIZES SELECTED.
(TYPE 1 OR 2)
2
 ENTER THE BUILDING HEIGHTH (ROUND TO
  NEAREST TENTH OF A FOOT).
? 200.
 ENTER THE BUILDING LENGTH (ROUND TO
  NEAREST TENTH OF A FOOT).
? 150.
 ENTER THE BUILDING WIDTH (ROUND TO
  NEAREST TENTH OF A FOOT).
? 100.
 ENTER THE NUMBER OF FLOORS
? 20
 ENTER THE DISTANCE VERTICALLY BETWEEN THE CENTERS
 OF THE INLETS(GROUND FLOOR) AND THE OUTLETS(TOP FLOOR).
 NOTE: IF AIR MOVEMENT BETWEEN FLOORS IS PREVENTED BY
 CORRIDOR DOORS, STAIR DOORS, ETC, THE DISTANCE VERTICALLY
 BETWEEN POINTS OF IN-FILLTRATION AND EX-FILLTRATION
 WILL BE HALF THE WINDOW HEIGHT ON THAT FLOOR.
? 10.
 ENTER THE ORIENTATION ANGLE OF THE BUILDING'S LONG     FACE CLOCKWISE
  FROM DUE NORTH(0. TO 360.DEGREES).
? 250.
 ENTER THE BUILDING'S REQUIRED VENTILATION RATE (CFM).  SEE THE ASHRAE
  COOLING AND HEATING LOAD CALCULATION MANUAL
  (PAGES 5.12 TO 5.15).
? 3750.
 ENTER THE VENTILATION RATE OF THE ROOM IN SERIES
  WHICH HAS THE HIGHEST VALUE.(SEE ASHRAE MANUAL)
? 625.
 THIS PROGRAM ASSUMES THAT:
      A) THE MEAN RADIANT TEMPERATURE EQUALS 78 DEG. F.
      B) THE HEAT REJECTED FROM THE BODY IS
         520 BTU/HR (OFFICE WORK)
      C) THE CLOTHING INSULATION IS
         1.0 CLO (BUISNESS SUIT)

 DO YOU WISH TO ADJUST ANY OF THESE COMFORT PARAMETERS
 TO CHANGE THE IDEAL INDOOR TEMPERATURE FROM 78 DEG. F.?
     1) YES
     2) NO
 (TYPE 1 OR 2)
? 2
 THE AREA PER FLOOR OF THE BUILDING'S SKIN IS 5000.

 THIS PROGRAM IS LIMITED TO THE CALCULATION
 OF VENTILATION RATES FOR MAXIMUM OPENINGS 30 PERCENT OF
 THE BUILDING'S SURFACE AREA.FOR YOUR BUILDING
 THE MAX. AREA OF OPENING IS   1500.00 SQ.FT. PER FLOOR.

 HOW MANY SIDES OF THE BUILDING HAVE OPENINGS?
     1) TWO SIDES
     2) FOUR SIDES
 (TYPE 1 OR 2)
```

FIGURE 2.5

Input runstream for testing the performance of the opening sizes selected.

```
? 1
 IF WIND PASSES THROUGH THE BUILDING PERPENDICULAR TO THE
  LONG FACE, WHAT IS THE NUMBER OF ROOMS IN SERIES?
? 2
 ENTER THE TOTAL AREA OF INLETS (WINDOWS CLOSED) FOR
  THE LOWER PORTION OF THE BUILDING.
? .1875
 ENTER THE TOTAL AREA OF OUTLETS (WINDOWS CLOSED) FOR
  THE UPPER PORTION OF THE BUILDING.
? .1875
 ENTER THE TOTAL AREA OF INLETS (WINDOWS OPEN)
   FOR THE LOWER PORTION OF THE BUILDING.
? 750.
 ENTER THE TOTAL AREA OF OUTLETS (WINDOWS OPEN)
   FOR THE UPPER PORTION OF THE BUILDING.
? 750.
 ENTER THE TOTAL AREA OF OPENING ON THE
  TWO LONG FACES OF THE BUILDING.
? 16000
 THE OPENING AREA PER FLOOR FOR ONE LONG SIDE IS 400  SQ.FT.
     SERIES OF ROOMS PERPENDICULAR TO THE LONG FACE
 ENTER THE SECTIONAL AREA FOR ROOM-1
? 1200
 ENTER THE AREA FOR OUTLET-1
? 126
 ENTER THE SECTIONAL AREA FOR ROOM-2
? 1200
 *************************************************
                WOULD YOU LIKE TO...

      1)   CHANGE INPUT
      2)   RUN PROGRAM
      3)   STOP PROGRAM AND SEND OUTPUT TO LINEPRINTER

 *************************************************
      (TYPE 1,2,OR 3)
? 2
```

FIGURE 2.5 (cont.)

```
*********************************************
                WOULD YOU LIKE TO...

     1)   CHANGE INPUT
     2)   RUN PROGRAM
     3)   STOP PROGRAM AND SEND OUTPUT TO LINEPRINTER

*********************************************
     (TYPE 1,2,OR 3)
? 2
THE COMPUTER WILL SOLVE FOR OPENING SIZES.


***********************************************
      INPUT FOR BUILDING'S EXTERNAL GEOMETRY
***********************************************
THE BUILDING HEIGHT IS 200. FT.
THE BUILDING LENGTH IS 150. FT.
THE BUILDING WIDTH IS 100. FT.
THE AREA PER FLOOR OF THE BUILDING'S SKIN IS 5000. SQ.FT.
THE ORIENTATION OF THE BUILDING'S LONG FACE IS 250. DEG.
***********************************************
      INPUT FOR BUILDING'S INTERNAL GEOMETRY
***********************************************
THERE ARE 2 ROOMS PERPENDICULAR TO THE LONG FACE OF THE BUILDING.
THERE ARE 3 ROOMS PERPENDICULAR TO THE SHORT FACE OF THE BUILDING.
THE SECTIONAL AREA OF THE ROOM(S) PERPENDICULAR
 TO THE LONG FACE IS 1200. SQ.FT.
THE SECTIONAL AREA OF THE ROOM(S) PERPENDICULAR
 TO THE SHORT FACE IS 800. SQ.FT.
***********************************************
           INPUT FOR FRESH AIR REQUIREMENTS
***********************************************
THE BUILDINGS REQUIRED VENTILATION RATE IS 3750. CFM.
AIRFLOW THROUGH THE ROOM WITH THE MAXIMUM FRESH AIR      REQUIREMENTS
 IS 10.41666666667 FPM.
***********************************************
                  INPUT FOR OPENINGS
***********************************************
OPENINGS ARE ON 4. SIDES OF THE BUILDING.
THE MAXIMUM AREA FOR THE INLET IS 1500. SQ.FT.
THE VERTICAL DISTANCE BETWEEN OPENINGS IS 10. FT.
THE RATIO OF OPENINGS IN THE WINTER IS 1.
THE RATIO OF OPENINGS IN THE SUMMER IS 1.
```

FIGURE 2.6

Output of User's Input

CHAPTER III

EXAMPLE OF ALGORITHM USE

CHAPTER III

EXAMPLE OF ALGORITHM USE

3.1 Natural Ventilation for an Atlanta Office Building

The potential of natural ventilation for an average twenty story high rise office building in Atlanta, Georgia was analysed using program NATVENT. A hypothetical floor plan of a 100 by 150 foot building used by Spielvogel (Figure 3.1) was adopted for the nautral ventilation study. Several arrangements of opening areas on two and four sides of the building were tested by NATVENT. The area of crack for each 5 x 10 foot window was 1.8 square inches (.06 square inches per linear foot of crack. See Appendix A.3, Table A.2). The total area of crack entered into the interactive runstream corresponded to the total area of windows selected. Since air movement between floors is prevented by fire doors in the building's core, the vertical distance between points of infiltration and exfiltration through window cracks for each floor was assumed to be 10 feet (i.e., the height of the windows). Fresh air requirements for each floor of the office building was determined as follows:

1. Floor Plan Area = 100 x 150 = 15,000 square feet.
2. 1000 square feet per occupant yields 15 occupants,
3. 25 CFM (For smokers) x 15 yields 375 CFM per foor (See Appendix A.3, table A.1).

The pressure coefficients used in the algorithm were representative of the wind pressure distribution that develops from

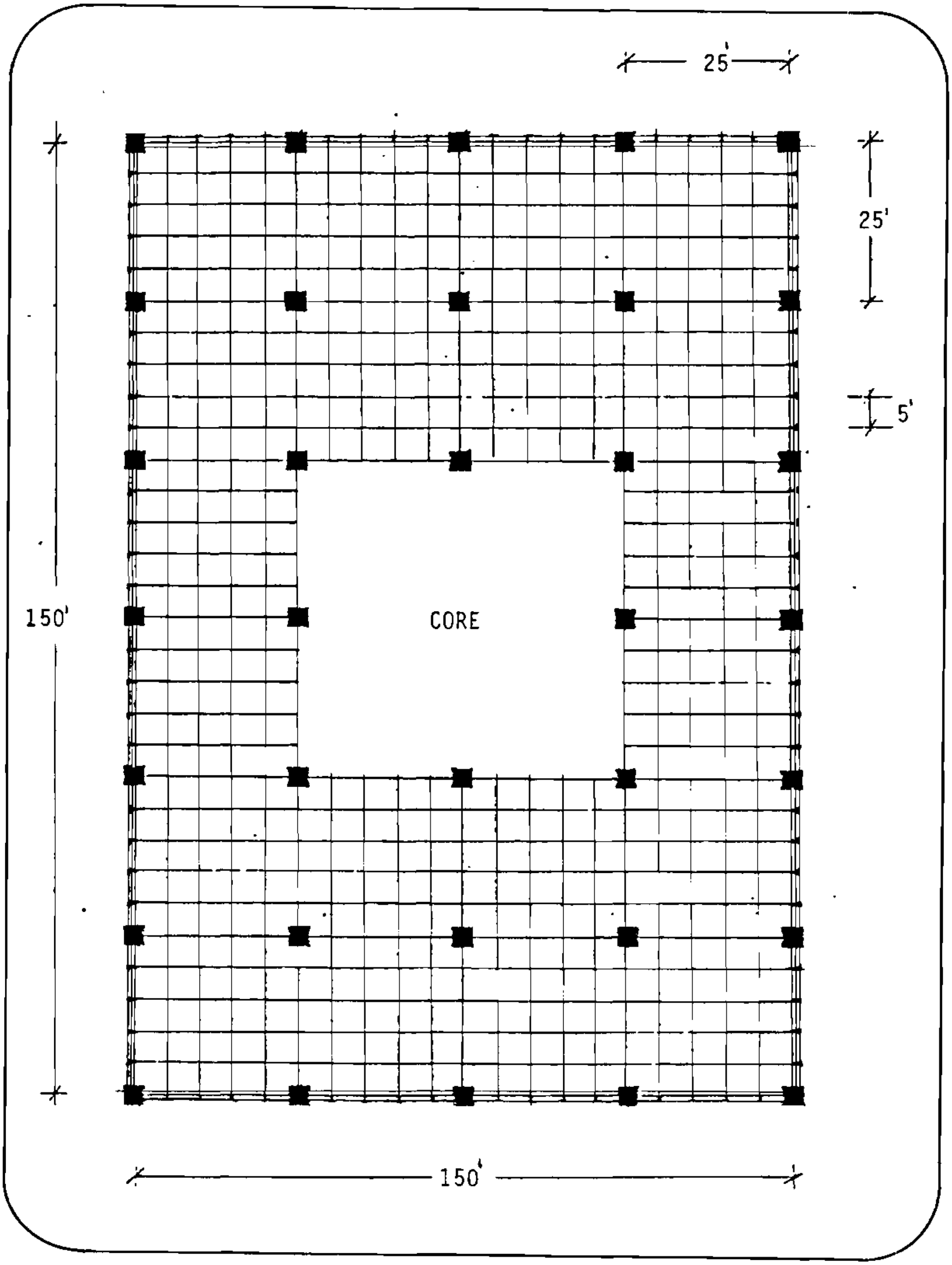


FIGURE 3.1

Floor plan of hypothetical building used by Spielvogel.

turbulent air flow in the central business district (see Appendix A.6, Figure A.16). Calculations of the ventilation rates for the working hours of 9:00 am to 6:00 pm were made using hourly weather data of representative days for each month. (See Appendix D). An example of output for the resulting ventilation rates from openings distributed over 30% of the buildings's two long faces is listed in Figure 3.2.

3.2 Analysis of Example

A typical office building was analyzed for natural ventilation potential in Atlanta, Georgia. NATVENT was used to examine how ventilation rates were affected during the heating, intermediate, and cooling season by:

A. Operable openings on 15% and 30% of the external wall;

B. Openings located on two and four sides of the building; and

C. Internal friction resulting from two and three rooms in series.

The boundary conditions establishing the seasons are not based on the building's thermal performance, but rather reflect ambient air temperatures and their effect on thermal comfort.

The length of the following three seasons can be observed from the output in Figure 3.2 for the climate in Atlanta, Georgia:

	Season	Month	Outdoor Temperature	% of Annual Working Hours
1.	Heating	Oct-Apr	$T < 68°F$	48%
2.	Intermediate	Apr-May, Sept-Oct	$68 \leq T \leq 78°F$	19%
3.	Cooling	May-Sept	$T > 78°F$	33%

During the heating season, the concern for natural ventilation is to

DATE JAN 21

HOUR	WIND SPEED (MPH)	VENT SPEED (FPM)	WIND INCIDENCE ANGLE	VOLUMETRIC AIR FLOW (CFM)	TEMP AIR ENTER	TEMP AIR EXIT	TYPE OF VENT	IS COMFORT ACHIEVED?
900	3.5		40.0	25.9437	35.0	78.0	STACK	
1000	2.3		50.0	24.3887	40.0	78.0	STACK	
1100	2.9		60.0	21.6700	48.0	78.0	STACK	
1200	4.0		80.0	19.7819	53.0	78.0	STACK	
1300	3.5		60.0	18.5570	56.0	78.0	STACK	
1400	2.9		60.0	17.6934	58.0	78.0	STACK	
1500	2.9		20.0	16.7855	60.0	78.0	STACK	
1600	4.0		50.0	16.3126	61.0	78.0	STACK	
1700	4.0		10.0	16.3126	61.0	78.0	STACK	
1800	4.0		10.0	18.1304	57.0	78.0	STACK	

DATE FEB 21

HOUR	WIND SPEED (MPH)	VENT SPEED (FPM)	WIND INCIDENCE ANGLE	VOLUMETRIC AIR FLOW (CFM)	TEMP AIR ENTER	TEMP AIR EXIT	TYPE OF VENT	IS COMFORT ACHIEVED?
900	3.5		50.0	27.6946	29.0	78.0	STACK	
1000	5.8		50.0	27.1235	31.0	78.0	STACK	
1100	5.2		50.0	25.6402	36.0	78.0	STACK	
1200	5.8		50.0	25.0223	38.0	78.0	STACK	
1300	5.2		50.0	24.3887	40.0	78.0	STACK	
1400	6.3		30.0	24.3887	40.0	78.0	STACK	
1500	6.9		30.0	24.3887	40.0	78.0	STACK	
1600	5.2		40.0	24.7076	39.0	78.0	STACK	
1700	6.3		40.0	25.0223	38.0	78.0	STACK	
1800	3.5		50.0	25.3332	37.0	78.0	STACK	

DATE MAR 21

HOUR	WIND SPEED (MPH)	VENT SPEED (FPM)	WIND INCIDENCE ANGLE	VOLUMETRIC AIR FLOW (CFM)	TEMP AIR ENTER	TEMP AIR EXIT	TYPE OF VENT	IS COMFORT ACHIEVED?
900	9.2		30.0	22.7276	45.0	78.0	STACK	
1000	9.8		30.0	23.4062	43.0	78.0	STACK	
1100	6.3		50.0	23.0694	44.0	78.0	STACK	
1200	8.6		50.0	22.7276	45.0	78.0	STACK	
1300	8.0		50.0	23.0694	44.0	78.0	STACK	
1400	9.2		30.0	23.4062	43.0	78.0	STACK	
1500	9.2		40.0	23.7383	42.0	78.0	STACK	
1600	9.2		40.0	24.0657	41.0	78.0	STACK	
1700	8.6		40.0	24.0657	41.0	78.0	STACK	
1800	9.2		40.0	24.3887	40.0	78.0	STACK	

FIGURE 3.2

Example of output. Ventilation rates of an average office building in Atlanta.

DATE APR 21

HOUR	WIND SPEED (MPH)	VENT SPEED (FPM)	WIND INCIDENCE ANGLE	VOLUMETRIC AIR FLOW (CFM)	TEMP AIR ENTER	TEMP AIR EXIT	TYPE OF VENT	IS COMFORT ACHIEVED?
900	4.6	211.9	20.0		70.0	78.0	WIND	YES
1000	5.2	251.4	30.0		74.0	78.0	WIND	YES
1100	6.3	375.5	30.0		75.0	78.0	WIND	YES
1200	4.6	375.5	40.0		78.0	78.0	WIND	YES
1300	5.2	375.5	10.0		78.0	78.0	WIND	YES
1400	3.0	375.5	20.0		77.0	78.0	WIND	YES
1500	24.2		30.0		76.0	78.0	WIND	YES
1600	25.9		30.0		77.0	78.0	WIND	YES
1700	25.9		30.0		75.0	78.0	WIND	YES
1800	27.0		0.0					

DATE MAY 21

HOUR	WIND SPEED (MPH)	VENT SPEED (FPM)	WIND INCIDENCE ANGLE	VOLUMETRIC AIR FLOW (CFM)	TEMP AIR ENTER	TEMP AIR EXIT	TYPE OF VENT	IS COMFORT ACHIEVED?
900	4.6	198.6	30.0		75.0	78.0	WIND	YES
1000	5.2	251.4	30.0		77.0	78.0	WIND	YES
1100	4.6	251.4	30.0		80.0	78.0	WIND	YES
1200	3.5	251.4	10.0		82.0	78.0	WIND	YES
1300	4.0	251.4	30.0		83.0	78.0	WIND	YES
1400	4.0	251.4	30.0		84.0	78.0	WIND	YES
1500	2.9	251.4	10.0		85.0	78.0	WIND	YES
1600	2.9	251.4	30.0		85.0	78.0	WIND	YES
1700	1.7	251.4	10.0		84.0	98.7	STACK	YES
1800	4.0	251.4	10.0		84.0	78.0	WIND	YES

DATE JUNE 21

HOUR	WIND SPEED (MPH)	VENT SPEED (FPM)	WIND INCIDENCE ANGLE	VOLUMETRIC AIR FLOW (CFM)	TEMP AIR ENTER	TEMP AIR EXIT	TYPE OF VENT	IS COMFORT ACHIEVED?
900	3.5	251.4	70.0		86.0	78.0	STACK	YES
1000	2.9	251.4	70.0		89.0	78.0	MINOR	NO
1100	2.9	0.0	80.0		91.0	78.0	NONE	NO
1200	3.5	0.0	90.0		93.0	78.0	NONE	NO
1300	4.6	0.0	60.0		92.0	78.0	NONE	NO
1400	4.6	0.0	70.0		95.0	78.0	NONE	NO
1500	2.9	0.0	0.0		94.0	78.0	NONE	NO
1600	2.9	0.0	0.0		95.0	78.0	NONE	NO
1700	2.9	0.0	70.0		95.0	78.0	NONE	NO
1800	6.9	0.0	10.0		85.0	78.0	WIND	YES

FIGURE 3.2 (cont.)

DATE JULY 21

HOUR	WIND SPEED (MPH)	VENT SPEED (FPM)	WIND INCIDENCE ANGLE	VOLUMETRIC AIR FLOW (CFM)	TEMP AIR ENTER	TEMP AIR EXIT	TYPE OF VENT	IS COMFORT ACHIEVED?
900	3.5	99.7	50.0		76.0	78.0	WIND	YES
1000	4.0	99.7	10.0		78.0	78.0	WIND	YES
1100	2.9	99.7	70.0		78.0	78.0	WIND	YES
1200	2.3	99.7	70.0		78.0	78.0	WIND	YES
1300	2.9	99.7	50.0		80.0	78.0	MINOR	NO
1400	3.5	99.7	80.0		80.0	78.0	MINOR	NO
1500	4.6	99.7	70.0		82.0	78.0	MINOR	NO
1600	3.5	99.7	70.0		83.0	78.0	MINOR	NO
1700	3.5	99.7	50.0		83.0	78.0	MINOR	NO
1800	3.5	99.7	50.0		83.0	78.0	MINOR	NO

DATE AUG 21

HOUR	WIND SPEED (MPH)	VENT SPEED (FPM)	WIND INCIDENCE ANGLE	VOLUMETRIC AIR FLOW (CFM)	TEMP AIR ENTER	TEMP AIR EXIT	TYPE OF VENT	IS COMFORT ACHIEVED?
900	1.2	11.1	50.0		72.0	78.0	WIND	YES
1000	1.7	24.5	60.0		77.0	78.0	WIND	YES
1100	2.3	24.5	50.0		81.0	78.0	WIND	YES
1200	4.0	24.5	50.0		83.0	78.0	WIND	YES
1300	4.0	24.5	30.0		83.0	78.0	WIND	YES
1400	5.2	24.5	40.0		84.0	78.0	WIND	YES
1500	4.0	24.5	80.0		85.0	78.0	WIND	YES
1600	4.6	24.5	30.0		82.0	78.0	WIND	YES
1700	5.2	24.5	0.0		84.0	78.0	WIND	YES
1800	4.0	24.5	40.0		83.0	78.0	WIND	YES

DATE SEPT 21

HOUR	WIND SPEED (MPH)	VENT SPEED (FPM)	WIND INCIDENCE ANGLE	VOLUMETRIC AIR FLOW (CFM)	TEMP AIR ENTER	TEMP AIR EXIT	TYPE OF VENT	IS COMFORT ACHIEVED?
900	4.6		10.0	13.7053	66.0	78.0	STACK	
1000	4.0	152.1	30.0		68.0	78.0	WIND	YES
1100	4.6	198.6	30.0		70.0	78.0	WIND	YES
1200	4.0	187.6	10.0		74.0	78.0	WIND	YES
1300	4.0	162.2	20.0		76.0	78.0	WIND	YES
1400	3.5	137.8	10.0		77.0	78.0	WIND	YES
1500	3.5	186.2	0.0		77.0	78.0	WIND	YES
1600	3.5	137.8	10.0		76.0	78.0	WIND	YES
1700	2.9	77.6	30.0		77.0	78.0	WIND	YES
1800	2.9	77.6	30.0		75.0	78.0	WIND	YES

FIGURE 3.2 (cont.)

DATE OCT 21

HOUR	WIND SPEED (MPH)	VENT SPEED (FPM)	WIND INCIDENCE ANGLE	VOLUMETRIC AIR FLOW (CFM)	TEMP AIR ENTER	TEMP AIR EXIT	TYPE OF VENT	IS COMFORT ACHIEVED?
900	2.3		40.0	22.0282	47.0	78.0	STACK	
1000	3.5		20.0	18.9741	55.0	78.0	STACK	
1100	5.8		10.0	16.7855	60.0	78.0	STACK	
1200	4.0		40.0	15.8255	62.0	78.0	STACK	
1300	4.6		70.0	14.8034	64.0	78.0	STACK	
1400	2.9		50.0	13.1218	67.0	78.0	STACK	
1500	4.6		~~50.0~~	~~13.1218~~	~~67.0~~	~~78.0~~	~~STACK~~	
1600	5.8	382.8	10.0		68.0	78.0	WIND	YES
1700	5.2		10.0	13.1218	67.0	78.0	STACK	
1800	3.5		10.0	15.3230	63.0	78.0	STACK	

DATE NOV 21

HOUR	WIND SPEED (MPH)	VENT SPEED (FPM)	WIND INCIDENCE ANGLE	VOLUMETRIC AIR FLOW (CFM)	TEMP AIR ENTER	TEMP AIR EXIT	TYPE OF VENT	IS COMFORT ACHIEVED?
900	4.6		30.0	25.0223	38.0	78.0	STACK	
1000	7.5		60.0	23.7383	42.0	78.0	STACK	
1100	7.5		50.0	23.0694	44.0	78.0	STACK	
1200	5.8		60.0	22.7276	45.0	78.0	STACK	
1300	6.3		40.0	22.0282	47.0	78.0	STACK	
1400	6.3		30.0	22.0282	47.0	78.0	STACK	
1500	6.9		50.0	22.3806	46.0	78.0	STACK	
1600	5.8		50.0	23.0694	44.0	78.0	STACK	
1700	5.8		50.0	23.7383	42.0	78.0	STACK	
1800	6.9		50.0	25.0223	38.0	78.0	STACK	

DATE DEC 21

HOUR	WIND SPEED (MPH)	VENT SPEED (FPM)	WIND INCIDENCE ANGLE	VOLUMETRIC AIR FLOW (CFM)	TEMP AIR ENTER	TEMP AIR EXIT	TYPE OF VENT	IS COMFORT ACHIEVED?
900	2.9		10.0	24.7076	39.0	78.0	STACK	
1000	2.9		10.0	24.3887	40.0	78.0	STACK	
1100	1.7		10.0	24.0657	41.0	78.0	STACK	
1200	2.9		10.0	24.0657	41.0	78.0	STACK	
1300	4.6		10.0	24.3887	40.0	78.0	STACK	
1400	4.6		10.0	24.3887	40.0	78.0	STACK	
1500	4.0		0.0	24.3887	40.0	78.0	STACK	
1600	4.0		20.0	24.7076	39.0	78.0	STACK	
1700	4.6		10.0	24.7076	39.0	78.0	STACK	
1800	2.9		10.0	25.0223	38.0	78.0	STACK	

FIGURE 3.2 (cont.)

minimize the volumetric infiltration of cold air. During the intermediate and cooling seasons air velocity rather than air volume is critical for providing fresh air and restoring thermal comfort. NATVENT output lists ventilation as the rate of volumetric exchange of infiltrating and exfiltrating air during the heating season and as air velocity rates for the intermediate and cooling seasons. The output presented in Figure 3.2 is quantified and listed as "Computation A" in Table 3.1. Three other computations are included in the table for comparison of ventilation rates resulting from different opening areas distributed over two and four sides of the building.

The ventilation rates calculated for the heating season were 5.8% and 11.6% of the fresh air requirements infiltrating through .375 and .75 square feet of crack respectively. Various building geometries did not affect infiltration rates because it was assumed that air flow was prevented between floors. However, if airflow was permitted between floors, building height would induce stack pressures and result in increased infiltration. In addition to height, the building's horizontal temperature profile may affect lateral airflow. If the temperature of the rooms adjacent to the window cracks equal the temperature of the innermost rooms, the building's internal geometry does not affect infiltration.

During the intermediate season when outdoor temperatures range between 68°F and 78°F, Table 3.1 indicates that 100% of the fresh air requirements are provided by wind induced ventilation for all examples. Since airflow induced by wind is effected by the area of openings and internal geometries, the buildings with the fewest rooms in series and the largest area of openings induce ventilation rates higher than those

		A	B	C	D
INPUT					
1.	Window Openings				
	A. Area for each floor (SQ.FT.)	800	1600	1600	1600
	B. % of buildings facade	16%	30%	30%	30%
2.	Area of crack (windows closed) for each floor (SQ.FT)	.375	.75	.75	.75
3.	Number of sides of the building with openings	2	2	2	2
4.	Series of rooms perpendicular to the building's long face				
	A. Number of rooms in series	2	2	2	2
	B. Sectional area of room-1 (SQ.FT.)	1200	1200	1200	1200
	C. Outlet area in 1st partition (SQ.FT.)	126	126	126	126
	D. Sectional area of room-2 (SQ.FT.)	1200	1200	1200	1200
5.	Series of rooms perpendicular to the buildings short face				
	A. Number of rooms in series			2	3
	B. Sectional Area of room-1			800	800
	C. Outlet area in 1st partition			84	84
	D. Sectional area of room-2			560	560
	E. Outlet area in 2nd partition				84
	F. Sectional Area of room-3				800
RESULTS		% of annual working hours			
1.	Heating season (Oct-Apr)	48%			
	A. Length of season				
	B. Percent of fresh air through the cracks of specified openings	Best 5.8%	11.6%	11.6%	11.6%
2.	Intermediate season (Apr, May, Sept, Oct)	% of annual working hours			
	A. Wind induced ventilation for fresh air requirements	19%			
3.	Cooling season (May-Sept)	% of annual working hours			
	A. length of season	33%			
	B. percentage of seasonal working hours thermal comfort is restored by wind induced cooling	68%	69.5%	Best 74%	62%
	C. Percentage of seasonal working hours that thermal comfort is restored by natural ventilation plus fans	20.5%	19%	14.5%	26.5%
	D. Percentage of seasonal working hours mechanical systems are needed	11.5%	11.5%	11.5%	11.5%

TABLE 3.1
Tabulation of output from example problem.

required for fresh air provisions. (Table 3.2 Examples B-C). For these cases air flow should be reduced by decreasing area of window openings to prevent chilling of the occupants below comfort level.

During the cooling season, thermal comfort is restored by air velocities resulting from wind velocities greater than 3.5 mph. At lower wind speeds NATVENT calculated the required temperature differential for inducing air movement due to stack effect. The temperature of exhaust air needed to promote ventilation ranged from 20°F to 60°F higher than the outdoor temperature. Implementation of a thermal chimney to create these temperatures is not reasonable due to increased thermal gain from the chimney and the high potential of reverse flow down the chimney due to wind pressure.

During the cooling season, thermal comfort is restored by natural ventilation for 68% of the working hours. The airflow is achieved through two rooms in series in a 100 x 150 x 200 foot building with openings located on two opposite sides with a total opening area of 16% of the interior walls (Table 3.1 Example A) if opening areas are increased to 30% of the wall area, thermal comfort is restored by wind induced airflow during 69.5% of the seasonal working hours (Table 3.1, Run B). The small seasonal increase of 1.5% is attributed to the unchanged variables for the wind incidence angles at the openings and the internal friction of each room in series. If the same area of windows is distributed over all four sides of the building (Table 3.1, Example C), thermal comfort can be achieved by wind induced airflow for 74% of the cooling season due to smaller wind incidence angles. By increasing internal friction with the addition of another room in series (Table 3.1, Run-D), the hours of wind induced ventilation for comfort are reduced to 62% of the seasonal working hours. Mechanical removal of heat and/or humidity is required for 8.5% of the cooling season. Thermal comfort can be achieved during the remaining hours by wind induced ventilation supplemented by fans (see Figure A.15).

It is important to note that the above ventilation rates can be achieved only if windows are properly operated by occupants. If, for example, windows on opposing building sides are left closed, the desired ventilation will not occur.

CHAPTER IV

CONCLUSION

4.1 Recommendations for Naturally Ventilated Buildings

4.2 Limitations of NATVENT

4.3 Future Work

CHAPTER IV

CONCLUSION

An extensive literature review and description of available natural ventilation prediction techniques has been presented. Methods of predicting natural ventilation include charts, wind tunnel techniques, and mathematical models. Mathematical methods were selected for application to a computer model based on their accuracy of predicting ventilation induced by wind pressure or stack effect through building openings. Building geometries and openings are specified by the user.

NATVENT, the natural ventilation availability algorithm was developed to calculate:

A. The infiltration during the heating season.

B. The number of hours during the intermediate season that fresh air may be induced by wind pressure.

C. The number of hours of cooling achieved during the cooling season.

These are calculated on an hourly basis using selected working days of local weather data.

An example problem demonstrated that nautral ventilation is feasible for an average high rise office building in Atlanta, Georgia. During the heating season, infiltration through closed weather stripped openings that comprised 15% of the wall area supplied 5.8% of the required fresh air. A wall with 30% openings provided 11.6% of the fresh air requirements in the office. During the intermediate season, wind induced ventilation was available to supply fresh air 100% of the working hours. However, with high winds, control of operable windows is necessary to prevent cooling the occupants below the comfort level. During the cooling season, thermal comfort was restored by wind induced ventilation for 74% of the working hours. During 14% of the cooling season working hours, wind speeds were not available to induce ventilation for comfort. For these hours, fans may be used. During the remaining 12% of the seasonal working hours, mechanical air conditioning is necessary for removal of heat and humidity. These rates assume that windows are constantly operated to provide the optimums opening sizes, particuarly during spring and fall.

4.1 Recommendations for Naturally Ventilated Buildings

The following recommendations have been made based on insight from an extensive literature search of natural ventilation studies and NATVENT output.

A. Limit ventilation during the intermediate season and maximize ventilation during the cooling season by:

1. Selecting windows with maximum operable opening area.
2. Using pivoting windows to "scoop" and direct air flow (Figure 4.1) [63].
3. Locating equal opening areas on all sides of the building so that a change in wind direction will not affect ventilation rate because of a re-alignment with apertures. However, if the wind direction is constant and the building geometry is linear, openings should be oriented normal to the wind incidence angle on the long sides of the building.

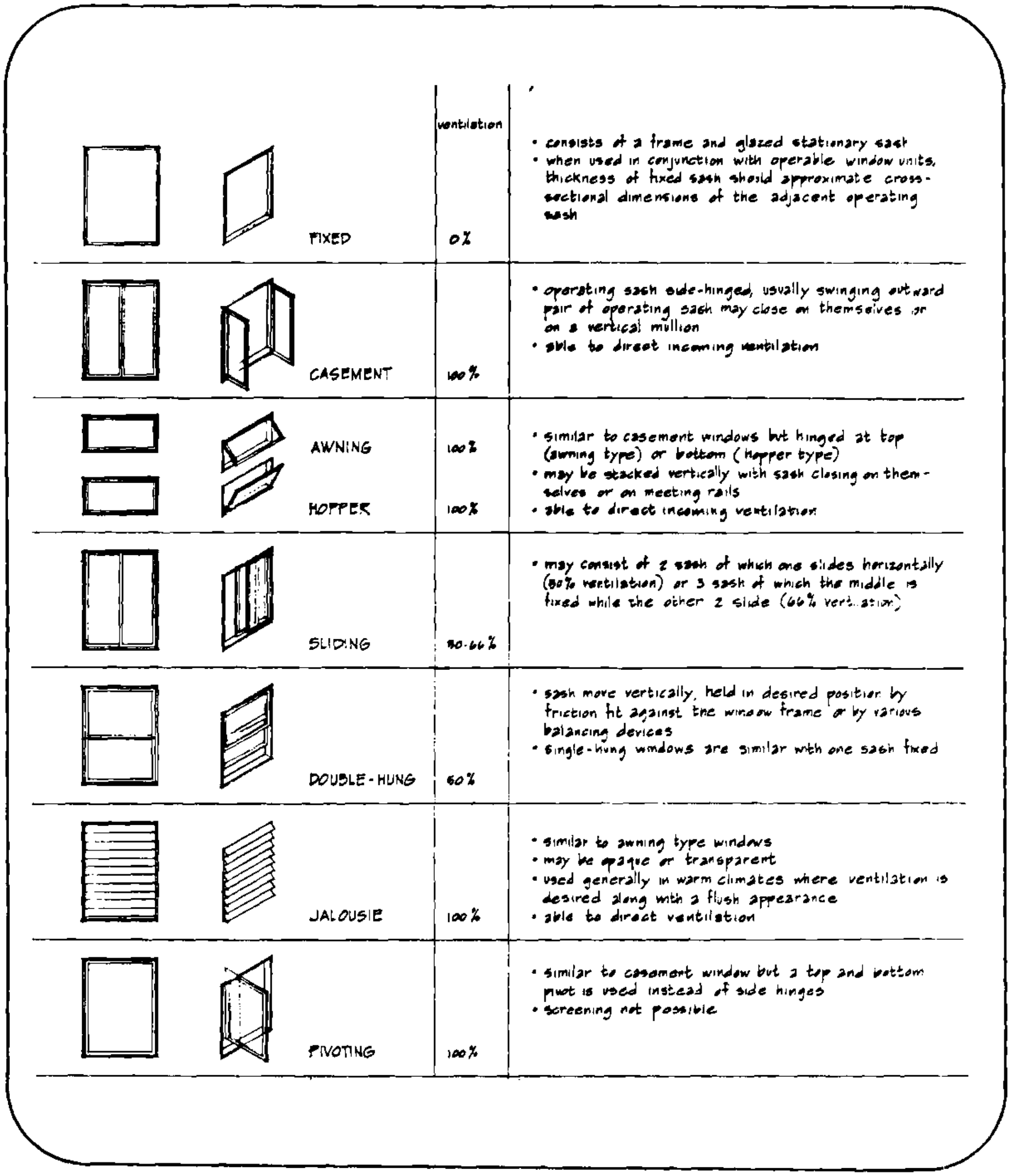


FIGURE 4.1

Operable opening areas for various windows.

4. Locating openings adjacent to living zone.
5. Minimizing internal friction with:
   a. An open office plan;
   b. Fewer partions or rooms in series; and
   c. Large openings (doors, grills, louvers, etc.) located in room partitions.
6. Using landscaping for:
   a. Directing air flow

B. Minimize infiltration during the heating season by:
1. Selecting windows with minimal crack width
2. Minimizing air flow between floors by reducing opening area to the building core as follows:
   a. Minimize crack area around elevator and fire doors.
   b. Guard against door construction particularly when stair shafts or elevator shafts are pierced for electrical and mechanical installations.

4.2 Limitations of NATVENT

The natural ventilation prediction techniques adopted in program NATVENT have several limitations. In the stack effect algorithm, a linear increase of air temperature with building height is assumed. Kreichelt, Kern, and Higgins have shown that calculated flow rates of the equation used differed by only 3% from full scale measurements [1.1].

The major limitations with NATVENT involve the computation of wind induced cooling to restore thermal comfort. The limitations include the use of a simplified comfort algorithm, the application of wind pressure coefficients selected for various building geometries, and the value of the calculated average air velocity at each opening.

NATVENT contains an algorithm that adjusts the air velocity needed to restore thermal comfort when the dry bulb temperature is greater than 78°F, and the relative humidity is greater than 60%. The user specifies a mean radiant temperature if other than 78°F, activity if other than 1.MET, and clothing if other than 1.CLO. The mathematical relationship for adjusting these comfort parameters is based on the assumption that only one variable is changed while the others remain constant. Since thermal comfort is not linear, more development is needed to improve the accuracy of the additive adjustment of temperatures for all comfort parameters.

The wind pressure algorithm in NATVENT can be used for any rectangular building geometry with a height less than six times the width and a length less than four times the width. The pressure coefficients used for these geometries represent average pressures across solid vertical walls. Incuracies develop when these coefficients are used in testing porous building surfaces. To prevent large error, interactive prompts instruct the user to limit opening areas to 30% of the building surface.

NATVENT is capable of calculating the wind induced average air velocity at each opening resulting from any number of rooms in series. Unfortunately, if the user specifies different areas for each inter-room opening and room section in series, average air velocities would be misleading. Air velocities downstream from one opening might blow papers off a desk while air velocities at the next opening may be insufficient to restore thermal comfort. A greater weakness is that lower velocities at other points in the room cannot be calculated by the algorithm.

However, if opening configurations are arranged to induce the air flow at skin surfaces of the occupants in in the living zone, the reliability is improved of the calculated number of hours comfort is achieved.

4.3 Future Work

NATVENT, requires further development in order to eliminate the limitations described. The program should be expanded to include pressure coefficients of an increased number of building geometries with various opening areas. It would be advantageous to build models for wind tunnel testing to measure both pressure coefficients and velocity coefficients.

Validation of the programresults is required by field measurement. Velocity coefficients could be used later to validate the program using the wind speed coefficient method presented in Section 1.5.3 velocities at all points in the room could be calculated and compared to the average air velocity calculated by the computer model at each opening.

At present, the program accesses only one day of weather data for each month. Annual climate climate data is required for more precise determination of cooling potential. This in turn means that an algorithm that reads and writes hourly reduced TMY tapes or 1440 weather data is required. Long range goals include development of software for micro computers for widespread distribution and use of the algorithm.

APPENDIX A

ALGORITHM DESCRIPTIONS

A.1 Interactive Input

A.2 Input Changes

A.3 Fresh Air Requirements

A.4 Adjustment of Comfort Parameters

A.5 Ventilation for Fresh Air vs. Comfort

A.6 Reduction of Ventilation rates for Various Wind Incidence Angles

A.7 Dominating Effect Algorithm

A.8 Output

APPENDIX A

ALGORITHM DESCRIPTIONS

The main program accesses several subroutines to allow a user to enter interactive input needed to calculate the opening sizes and air flow necessary to achieve thermal comfort during the summer months and meet fresh air requirements during the fall, winter, and spring seasons. The sequence of subroutine accessing depends on the user's choice of input runstreams. The principal algorithm components include:

A. Interactive input

B. Determination of pressure coefficients for rectangular building geometries

C. Determination of discharge coefficients for each opening

D. Adjustments for comfort parameters

E. Calculation of ventilation needed for comfort or fresh air requirements based on climate data

F. Determination of the dominating effect

G. Calculation of opening sizes or the ventilation induced by user specified opening sizes for fresh air requirements using a stack effect equation.

H. Calculation of opening sizes or the ventilation induced by user specified opening sizes for thermal comfort using a wind pressure equation

I. Output

Algorithm explanations of ventilation predictions based on the stack effect equation and wind pressure equation used in the computer model can be found in Appendix B and C respectively.

A.1 Interactive Input

Formated and format-free statement comprising the input data prompts are located at the beginning of the main program-NATVENT and in subroutines INPUT, COMFORT, ROOM1, GEOMETRY and CHANGE. Subroutine INPUT is accessed internally from NATVENT to initialize all input needed to run the program. All other subroutines requiring interactive response are accessed according to the user's run stream selection. A flow chart, shown in Figure A.1 indicates that the subroutines containing interactive input and the sequence of accessing.

A key determinant of the path that the interactive runstream will take in subroutine INPUT is the choice of analysis selected by the user. If the user chooses to solve for the opening sizes that will maximize the annual hours that fresh air requirements and thermal comfort is achieved (Figure A.2), the input will include:

A. Sectional area of rooms adjacent to building's
   1. Long face
   2. Short face

B. Ratio of the largest to smallest opening
   1. Winter stack effect
   2. Summer stack effect

If the user chooses to test selected opening sizes for the number of hours per year fresh air requirements and thermal comfort is achieved (Figure A.3), the input will include:

A. Opening Areas

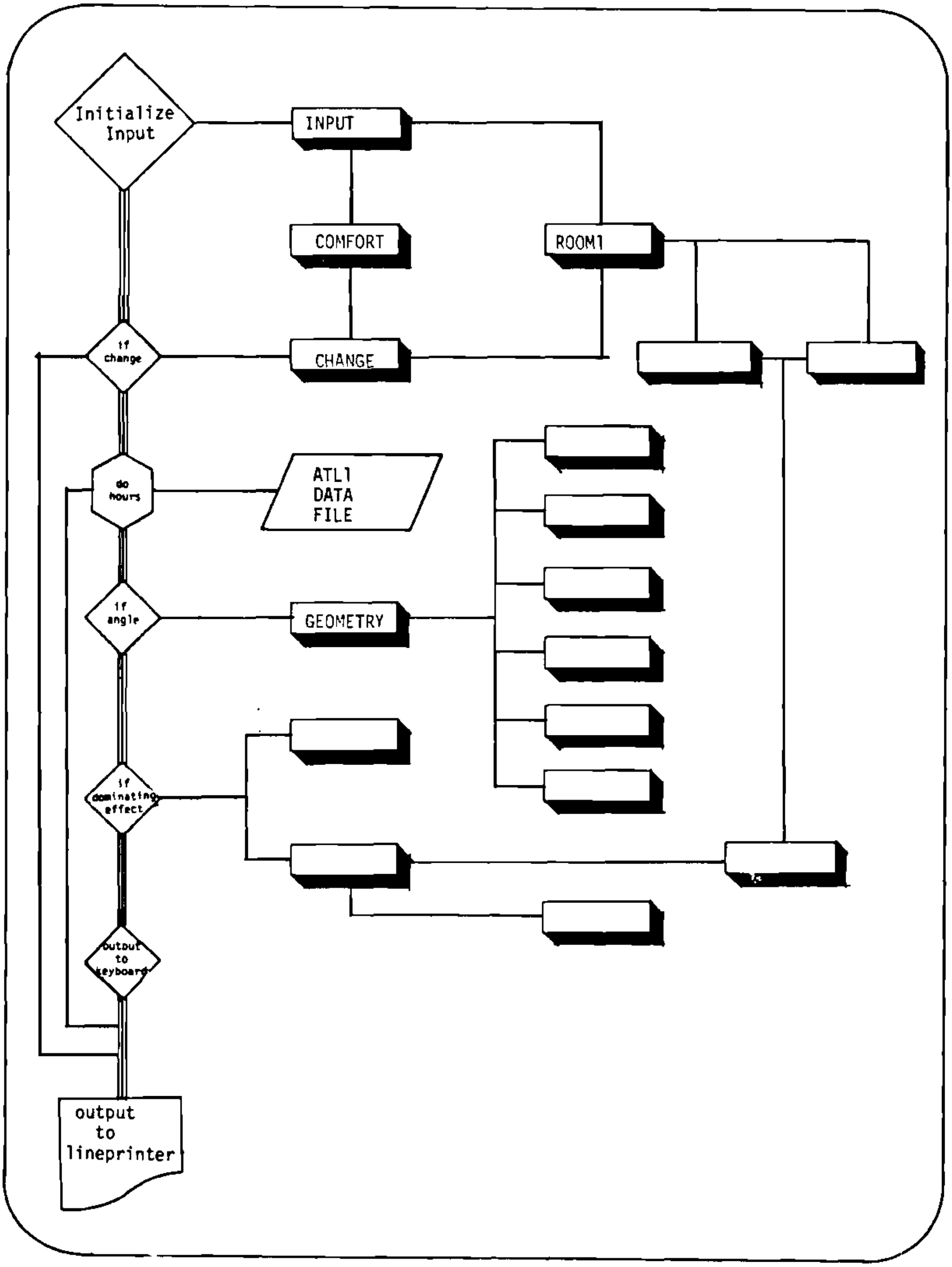


FIGURE A.1

Flow chart illustrating the subroutines that contain interactive input.

```
  191 WRITE(6,192)
  192 FORMAT(1X,'WOULD YOU LIKE THE COMPUTER TO...'
     + /6X,'1) SOLVE FOR THE OPENING SIZES THAT WILL MAXIMIZE THE'
     + /6X,'   ANUAL HOURS OF NATURAL VENTILATION USE'
     + /1X,'OR'
     + /6X,'2) TEST THE PERFORMANCE OF THE OPENING'
     + /6X,'   SIZES SELECTED.'
     + /1X,'(TYPE 1 OR 2)')
      READ (5,*) SOLVE
C
  205 IF (SOLVE .EQ. 2) GO TO 210
C
C
C     INPUT IF SOLVING FOR OPENING SIZES
C
      PRINT(6,*) 'ENTER THE SECTIONAL AREA OF THE SPACE
     +                        ADJACENT TO THE LONG FACE.'
      READ (5,*) SALF
C
      IF (SIDES .EQ. 2) GO TO 206
C
      PRINT(6,*) 'ENTER THE SECTIONAL AREA OF THE SPACE
     +                          ADJACENT TO THE SHORT FACE.'
      READ (5,*) SASF
C
  206 WRITE(6,207)
  207 FORMAT(1X,'ENTER THE RATIO FOR THE LARGEST OPENINGS'
     + /1X,'TO THE SMALLEST OPENINGS WHEN THE'
     + /1X,'WINDOWS ARE CLOSED(WINTER CONDITIONS).')
      READ (5,*) WRATIO
C
  208 WRITE(6,209)
  209 FORMAT(1X,'ENTER THE RATIO FOR THE LARGEST OPENINGS'
     + /1X,'TO THE SMALLEST OPENINGS WHEN THE'
     + /1X,'WINDOWS ARE OPEN(SUMMER CONDITIONS).')
      READ (5,*) SRATIO
C
      IF(SOLVE .EQ. 1) GO TO 220
```

FIGURE A.2

Control of input runstream for calculating opening sizes.

```
C      INPUT IF TESTING OPENING SIZES
C
C
   210 PRINT(6,*) 'ENTER THE TOTAL AREA OF INLETS (WINDOWS CLOSED)
     +               FOR THE LOWER PORTION OF THE BUILDING.'
       READ(5,*) AITW
C
       PRINT(6,*) 'ENTER THE TOTAL AREA OF OUTLETS (WINDOWS CLOSED)
     +               FOR THE UPPER PORTION OF THE BUILDING.'
       READ(5,*) AOTW
C
       IF (AITW .GE. AOTW) GO TO 212
C
       WRATIO=(AOTW/AITW)
       GO TO 214
C
   212 WRATIO=(AITW/AOTW)
C
   214 PRINT(6,*) 'ENTER THE TOTAL AREA OF INLETS (WINDOWS OPEN)
     +                    FOR THE LOWER PORTION OF THE BUILDING.'
       READ(5,*) AITSS
C
       PRINT(6,*) 'ENTER THE TOTAL AREA OF OUTLETS (WINDOWS OPEN)
     +                    FOR THE UPPER PORTION OF THE BUILDING.'
       READ(5,*) AOTSS
C
       IF (AITSS .GE. AOTSS) GO TO 216
C
       SRATIO=(AOTSS/AITSS)
       GO TO 218
   216 SRATIO=(AITSS/AOTSS)
C
   218 PRINT(6,*) 'ENTER THE TOTAL AREA OF OPENING ON THE
     +                 TWO LONG FACES OF THE BUILDING.'
       READ(5,*) LFACE
C
       FACE=((LFACE/2)/IFLOOR)
       PRINT(6,*) 'THE OPENING AREA PER FLOOR FOR ONE LONG SIDE IS'
     + ,FACE,' SQ.FT.'
       NROOM=NROOML
       PRINT(6,*) '    SERIES OF ROOMS PERPENDICULAR TO THE LONG FACE'
       CALL ROOM1
       SUML=SUM
C
       IF (SIDES .EQ. 2) GO TO 220
       PRINT(6,*) 'ENTER THE TOTAL AREA OF OPENING ON THE
     +                 TWO SHORT FACES OF THE BUILDING.'
       READ (5,*) SFACE
C
       IF (SIDES .EQ. 2) GO TO 220
       FACE=((SFACE/2)/IFLOOR)
       PRINT(6,*) 'THE OPENING AREA PER FLOOR FOR ONE SHORT SIDE IS '
     + ,FACE,' SQ.FT.'
       NROOM=NROOMS
       PRINT(6,*) '    SERIES OF ROOMS PERPENDICULAR TO THE SHORT FACE'
       CALL ROOM1
       SUMS=SUM
C
   220 RETURN
       END
```

FIGURE A.3

Control of input runstream if testing specified opening sizes.

1. Windows closed (Winter stack effect. See Appendix B1, B2.)
   a. Area of crack above neutral zone
   b. Area of crack below neutral zone
2. Windows Open (Summer stack effect. See Appendix B3.)
   a. Opening above neutral zone
   b. Opening below neutral zone
3. Total area of opening on building's:
   a. Two long faces
   b. Two short faces
4. Openings in the series of partitions perpendicular to the building's (see Appendix C.1):
   a. Long face
   b. Short face

B. Internal geometries
   1. Sectional area of rooms in series perpendicular to the building's (see Appendix C.1):
      a. Long face
      b. Short face

The path of the interactive runstreams is also affected by the following:

A. Mandatory input
   1. Building geometries (see Appendix C.2)
      a. Height
      b. Length
      c. Width
   2. Number of sides of the building with openings
   3. Number of rooms in series perpendicular to the building's:

a. Long face

b. Short face

B. Optional input

1. Adjustment of comfort parameters (see Appendix A.4)

2. Input changes (see Appendix A.2)

The following input is included in each runstream but does not affect the program's interactive path:

A. Number of floors

B. Vertical distance between inlets and outlets

C. Building's orientation (see Appendix A.7 for the algorithm that determines the angle of incidence of wind).

D. Fresh air requirements (see Appendix A.3)

1. Building's total ventilation rate (variable of stack effect equation. See Appendix B.1)

2. Ventilation rate of the room in series with the maximum fresh air requirements (variable of wind presssure equation. See Appendix A.5 and Appendix C.1).

A.2 Input Changes

A menu in the main program (NATVENT) allows the user to change the input before and after the program is run (Figure A.4). Through this menu, SUBROUTINE CHANGE is accessed for any desired change of input. This subroutine outputs another menu to the keyboard that lists fourteen choices of input changes (Figure A.5). After each selection and change of input, the menu is printed on the screen. this enables the user to change the input without re-entering the values unchanged. However, a change in one of the last five choices of input affects the remaining

```
      CALL INPUT
C
C
   20 WRITE(6,30)
   30 FORMAT (1X,'*****************************************************',
     + /1X,'                    WOULD YOU LIKE TO...',
     + /
     + /1X,'      1)   CHANGE INPUT',
     + /1X,'      2)   RUN PROGRAM',
     + /1X,'      3)   STOP PROGRAM AND SEND OUTPUT TO LINEPRINTER',
     + /
     + /1X,       '**********************************************',
     + /1X,'      (TYPE 1,2,OR 3)')
C
      READ (5,*) MENU1
C
      IF (MENU1 .EQ. 1) CALL CHANGE
      IF (MENU1 .EQ. 1) GO TO 20
      IF (MENU1 .EQ. 2) GO TO 40
      IF (MENU1 .EQ. 3) GO TO 190
      IF (MENU1 .LE. 1 .OR. MENU1 .GE. 3) GO TO 35
      GO TO 40
```

FIGURE A.4

Accessing CHANGE routine from main program.

```
 *************************************************
                 WOULD YOU LIKE TO...

      1)    CHANGE INPUT
      2)    RUN PROGRAM
      3)    STOP PROGRAM AND SEND OUTPUT TO LINEPRINTER

 *************************************************
      (TYPE 1,2,OR 3)
? 1
 WOULD YOU LIKE TO...
       1) CHANGE THE BUILDING HEIGHT
       2) CHANGE THE BUILDING LENGTH
       3) CHANGE THE BUILDING WIDTH
       4) CHANGE THE VERTICAL DISTANCE BETWEEN OPENINGS
       5) CHANGE THE THE ORIENTATION OF THE BUILDING'S LONG FACE
       6) CHANGE THE BUILDING'S VENTILATION RATE
       7) CHANGE THE REQUIRED VENTILATION RATE FOR 1 ROOM
       8) CHANGE THE COMFORT PARAMETERS
       9) CHANGE THE MAXIMUM AREA OF OPENINGS
       10) CHANGE THE OF SIDES OF THE BUILDING WITH OPENINGS
       11) CHANGE THE NUMBER OF ROOMS PARALLEL TO THE LONG FACE
       12) CHANGE THE NUMBER OF ROOMS PARALLEL TO THE SHORT FACE
       13) SOLVE FOR OPENINGS
            CHANGE THE ROOM'S SECTIONAL AREA(S)
            CHANGE THE RATIO OF THE LARGEST TO SMALLEST OPENING
       14) TEST THE PERFORMANCE OF THE OPENINGS SELECTED
            CHANGE AREA OF OPENING ABOVE AND BELOW THE NEUTRAL ZONE
            CHANGE THE SERIES OF OPENING AND ROOM SECTIONAL AREAS
 15) EXIT THIS CHANGE ROUTINE
```

FIGURE A.5

Menu for changing input.

input in the menu. Therefore, an input runstream path is arranged so that only the necessary input follows the change.

A.3 Fresh Air Requirements

It is more economical to use a heat reclaimer when providing for fresh air requirements during the winter months than re-heat air in space cooled by infiltration. Unless a high pressure ventilation system is used, infiltration through the cracks around large windows sized for summer cooling will often be more than is needed for fresh air requirements during the winter season. Therefore, the concern of providing fresh air for naturally ventilated buildings is to select windows with maximum operable opening sizes with minimum areas of crack to reduce mechanical conditioning in all seasons.

Program NATVENT can be used to solve for the optimum size of free opening with a minimum area of crack. Using Table A.1 [64], the fresh air requirements are entered into the program. Based on the users input, NATVENT calculates an opening area for each fluctation in the weather. Calculation of crack areas for the winter season are made using stack effect equations. Calculations of opening sizes needed for summer cooling are made using wind pressure equations. During the fall and spring seasons, when climate conditions are in the thermal comfort zone, air movement is not needed for cooling. However, ventilation is necessary for the removal of odors and toxic gasses. Since sufficient temperature differentials of inside and outside air do not exist during these conditions, NATVENT calculates the area of openings needed to supply fresh air using wind pressure equations. (See Appendix A.5 for the ventilation for comfort vs. fresh air requirement algorithm.)

Ventilation Requirements for Occupants

	Estimated persons/ 1000 ft^2 floor area.[a]	Required ventilation air, per human occupant Minimum cfm	Recommended cfm
RESIDENTIAL			
Single Unit Dwellings			
General Living Areas, Bedrooms, Utility Rooms	5	5	7-10
Kitchens, Baths, Toilet Rooms[a]	—	20	30-50
Multiple Unit Dwellings and Mobile Homes			
General Living Areas, Bedrooms, Utility Rooms	7	5	7-10
Kitchens, Baths, Toilet Rooms[a]	—	20	30-50
Garages[b]	—	1.5[b]	2-3[b]
COMMERCIAL			
Public Rest Rooms	100	15	20-25
General Requirements—Merchandising (Apply to all forms unless specially noted)			
Sales Floors (Basement and Ground Floors)	30	7	10-15
Sales Floor (Upper Floors)	20	7	10-15
Storage Areas (Serving Sales Areas and Storerooms)	5	5	7-10
Dressing Rooms	—	7	10-15
Malls and Arcades	40	7	10-15
Shipping and Receiving Areas	10	15	15-20
Warehouses	5	7	10-15
Elevators	—	7	10-15
Meat Processing Rooms[c]	10	5	5
Pharmacists' Workrooms	10	20	25-30
Pet Shops[b]	—	1.0[b]	1.5-2[b]
Florists[d]	10	5	7
Greenhouses[d,e]	1	5	7-10
Bank Vaults	—	5	5
Dining Rooms	70	10	15-20
Kitchens[f]	20	30	35
Cafeterias, Short Order; Drive-Ins, Seating Areas	100	30	35
Bars (Predominantly Stand-Up)	150	30	40-50
Cocktail Lounges	100	30	35-40
Hotels, Motels, Resorts			
Bedrooms	5	7	10-15
Living Rooms (Suites)	20	10	15-20
Baths, Toilets (attached to bedrooms)[a]	—	20	30-50
Corridors	5	5	7-10
Lobbies	30	7	10-15
Conference Rooms (Small)	70	20	25-30
Assembly Rooms (Large)	140	15	20-25
Cottages (treat as single-unit dwellings) (See also Food Services, Industrial, Merchandising, Barber and Beauty Shops, Garages for associated Hotel/Motel Services)			

TABLE A.1
Ventilation requirements for occupants.

Ventilation Requirements for Occupants (Continued)

	Estimated persons/ 1000 ft² floor area.[a]	Required ventilation air, per human occupant Minimum cfm	Recommended cfm
Dry Cleaners and Laundries			
Commercial[f,g]	10	20	25-30
Storage/Pickup Areas	30	7	10-15
Coin-Operated[g]	20	15	15-20
Barber, Beauty, and Health Services			
Beauty Shops (Hairdressers)	50	25	30-35
Reducing Salons (Exercise Rooms)	20	25	30-35
Sauna Baths and Steam Rooms	—	5	5
Barber Shops	25	7	10-15
Photo Studios			
Camera Rooms, Stages[h]	10	5	7-10
Darkrooms	10	10	15-20
COMMERCIAL			
Shoe Repair Shops (Combined Workrooms/Trade Areas)	10	10	15-20
Garages, Auto Repair Shops, Service Stations			
Parking Garages (enclosed)[b]	—	1.5[b]	2-3[b]
Auto Repair Workrooms (general)[b, i]	—	1.5[b]	2-3[b]
Service Station Offices	20	7	10-15
Theaters			
Ticket Booths	—	5	7-10
Lobbies, (Foyers and Lounges)	150	20	25-30
Auditoriums (No Smoking)	150	5	5-10
Auditoriums (Smoking Permitted)	150	10	10-20
Stages (with Proscenium and Curtains)[h,j]	70	10	12-15
Workrooms	20	10	12-15
Ballrooms (Public)	100	15	20-25
Bowling Alleys (Seating Area)	70	15	20-25
Gymnasiums and Arenas			
Playing Floors-Minimal or No Seating	70	20	25-30
Locker Rooms[k]	20	30[k]	40-50[k]
Spectator Areas	150	20	25-30
Ramps, Foyers, and Lobbies	150	10	15-20
Amusement Parlors and Pool Rooms	25	20	25-30
Tennis, Squash, Handball Courts	—	20	25-30
Swimming Pools	25	15	20-25
Ice-Skating, Curling, and Roller Rinks	70	10	15-20
Transportation			
Waiting Rooms	50	15	20-25
Ticket and Baggage Areas, Corridors, and Gate Areas	50	15	20-25
Control Towers	50	25	30-35
Hangars[l]	2	10	15-20
Platform	150	10	15-20
Concourses	150	10	15-20
Repair Shops	—	10	15-20

Ventilation Requirements for Occupants (Continued)

	Estimated persons/ 1000 ft² floor area.[g]	Required ventilation air, per human occupant Minimum cfm	Recommended cfm
Offices			
General Office Space	10	15	15-25
Conference Rooms	60	25	30-40
Drafting Rooms, Art Rooms	20	7	10-15
Doctors' Consultation Rooms	—	10	10-15
Waiting Rooms	30	10	15-20
Lithographing Rooms[g]	20	7	10-15
Diazo Printing Rooms[g]	20	7	10-15
Computer Rooms	20	5	7-10
Keypunching Rooms	30	7	10-15
Communication			
TV/Radio Broadcasting Booths, or Studios[h]	20	30	35-40
Motion Picture and TV Stages	20	30	35-40
Pressrooms	100	15	20-25
Composing Rooms	30	7	10-15
Engraving Shops	30	7	10-15
Telephone Switchboard Rooms (Manual)	50	7	10-15
Telephone Switchgear Rooms (Automatic)	—	7	10-15
Teletypewriter/Facsimile Rooms	—	5	7-10
INSTITUTIONAL			
Schools			
Classrooms	50	10	10-15
Multiple Use Rooms	70	10	10-15
Laboratories[m]	30	10	10-15
Craft and Vocational Training Shops[m]	30	10	10-15
Music, Rehearsal Rooms	70	10	10-15
Auditoriums	150	5	15-20
Gymnasiums	70	20	5-7.5
Libraries	20	7	25-30
Common Rooms, Lounges	70	10	10-12
Offices	10	7	10-15
Lavatories	100	15	10-15
Locker Rooms[k]	20	30[k]	20-25
Lunchrooms, Dining Halls	100	10	40-50[k]
Corridors	50	15	15-20
Utility Rooms	3	5	20-25
Dormitory Bedrooms	20	7	7-10
			10-15
Hospitals, Nursing and Convalescent Homes			
Foyers	50	20	25-30
Hallways	50	20	25-30
Single, Dual Bedrooms	15	10	15-20
Wards	20	10	15-20
Food Service Centers	20	35	35
Operating Rooms, Delivery Rooms[n]	—	20	—
Amphitheatres	100	10	15-20
Physical Therapy Areas	20	15	20-25
Autopsy Rooms	10	30	40-50
Incinerator Service Areas[o]	—	5	7-10
Ready Rooms, Recovery Rooms[n]	—	15	—
(For Shops, Restaurants, Utility Rooms, Kitchens, Bathrooms, and Other Service Items, see Hotels)			

	Estimated persons/ 1000 ft^2 floor area.[e]	Minimum	Required ventilation air, per human occupant Recommended
		cfm	cfm
Research Institutes			
Laboratories[m]	50	15	20-25
Machine Shops	50	15	20-25
Darkrooms, Spectroscopy Rooms	50	10	15-20
Animal Rooms[n]	20	40	45-50
Military and Naval Installations			
Barracks	20	7	10-15
Toilets/Washrooms	100	15	20-25
Shower Rooms	100	10	15-20
Drill Halls	70	15	20-25
Ready Rooms, MP Stations	40	7	10-15
Indoor Target Ranges[p]	70	20	25-30
Museums			
Exhibit Halls	70	7	10-15
Workrooms	10	10	15-20
Warehouses	5	5	7-10
Correctional Facilities, Police and Fire Stations (see also Gymnasiums, Libraries, Industrial Areas)			
Cell Blocks	20	7	10-15
Eating Halls	70	15	20-25
Guard Stations	40	7	10-15
Veterinary Hospitals			
Kennels, Stalls, Operating Rooms[n]	20	25	30-35
Reception Rooms	30	10	15-20
ORGANIZATIONAL			
Churches, Temples (see Theaters, Schools and Offices)			
Legislative Halls			
Legislative Chambers	70	20	25-30
Committee Rooms and Conference Rooms	70	20	25-30
Foyers, Corridors	50	20	25-30
Offices	10	10	15-20
Press Lounges	20	20	25-30
Press/Radio/TV Booths	20	20	25-30
Public Rest Rooms	20	15	20-25
Private Rest Rooms (for Food Service, Utilities, etc. see Hotels)	—	20	30-50
Survival Shelters[n]	—	5	2.5 —

	BUILDING COMPONENT	SQ.IN.OF OPENING PER LINEAR FT. OF CRACK	SQ.IN.OF OPENING PER SQ.FT.OF SURFACE
WINDOWS	SINGLE HUNG		
	NO WEATHERSTRIPPING	.4	
	WEATHERSTRIPPING	.06	
	DOUBLE HUNG		
	NO WEATHERSTRIPPING	.52	
	WEATHERSTRIPPING	.12	
	HORIZONTALLY PIVOTED		
	NO WEATHERSTRIPPING	.8	
	WEATHERSTRIPPING	.13	
	VERTICALLY PIVOTED		
	NO WEATHERSTRIPPING	.9	
	WEATHERSTRIPPING	.11	
	FIXED	.04	
DOORS			
	NO WEATHERSTRIPPING	.72	
	WEATHERSTRIPPING	.38	
WALLS			
	NO PLASTER		.03
	PLASTER		0
FLOORS			
	SOLID		0
	TOUNGUE & GROOVED		.24
	SQUARE BOARDS		1.3

TABLE A.2

Areas of crack for various building components.

From the output, Table A.2 can be used to select an opening size for summer cooling with a minimum area of crack to reduce winter infiltration. Table A.2 lists the area of opening per linear foot of crack for typical windows and doors. Since natural ventilation is not an energy saver during the winter months, design strategies should include reducing the area of crack specified in the output so that the remaining fresh air can be supplied through an energy recovery unit.

A.4 Calculation of Air Velocites to Restore Thermal Comfort

Comfort charts published by ASHRAE indicate that eighty per cent of the adult population is most comfortable if:

A. The dry bulb temperature ranges from 68° to 78° F.

B. The mean radiant temperature equal 78°F.

C. The relative humidity is 60%.

D. The subject is wearing .6-1. CLO (business suit).

E. The rejection of body heat is 400-500 BTU/HR (office work).

F. The air velocity is less than 45 ft/min.

Program NATVENT assumes that the above radiant temperature, clothing, and activity level exist in the building being analyzed. This section explains the algorithm that solves for the air velocity needed to restore thermal comfort for various dry bulb temperatures and relative humidities.

During winter conditions, the dry bulb temperature of exfiltrating air is assumed to be constant at 78°F. During the warmer seasons, the relative humidity and the dry bulb temperature of the space is allowed to fluctuate with the outdoor climate. Thermal comfort is restored by increasing the air velocity through the space. However, air speeds above

300 feet per minute are not allowable because papers will begin to blow around the room and other psychological disturbances will result. Natvent uses a straight line equation derived from Figure A.6 to solve for the air velocity needed for dry bulb temperatures and relative humidities greater than 78°F. and 60%:

$$Y = (m \cdot x + b) \cdot 30$$

(Equation A.0)

or: VTC = [.15*(RH-60) + (TEMP -78)]*30

Where:

Variable Explanations	Application	Natvent Variable Names
Y = y intercept increase or decrease	Velocity for thermal comfort 30 ft per min. per 1°F.	VTC
M = SLOPE	1°F / 6.6% R.H.	.15
x = X intercept	Relative humidity	RH - 60#
b = Y intercept	Temperature differential between inside and outside air	

A.4.1 Adjustment of Comfort Parameters. The chart in Figure A.6 illustrates that no air velocitities are needed for a temperature of 78°F and a relative humidity of 60% given that the radiant temperature, clothing, and activity remain constant at 78°F, 1.0 CLO, and 520 BTU/Hr. respectively. If the mean radiant temperature is raised one degree, or the clothing level is raised .2 CLO, or the activity level is raised 33 BTU/Hr, either the space temperature should be decreased one degree or the air velocity should be increased 33 feet per minute [45]. Using these relationships, all of the comfort parameters may be adjusted and

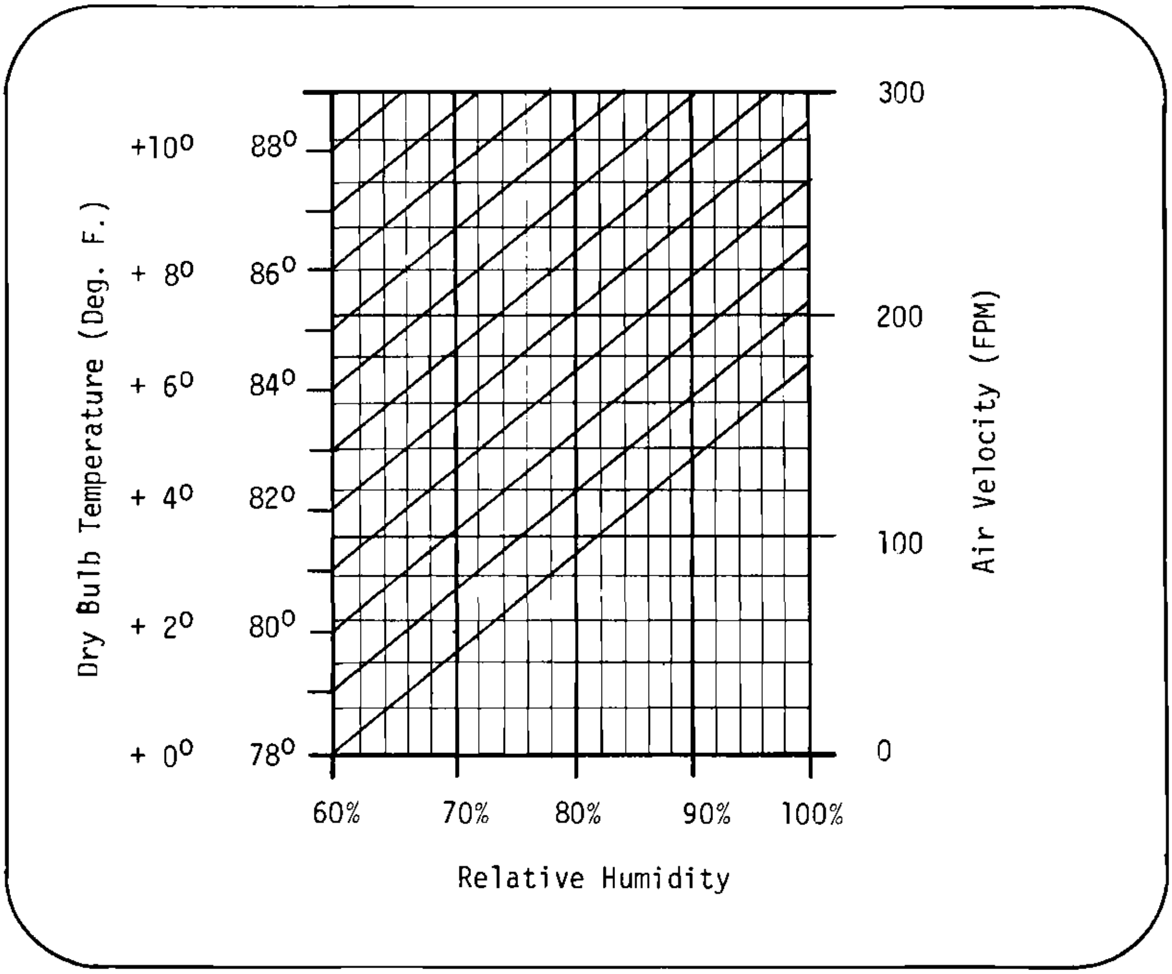


FIGURE A.6

Air velocity needed to restore thermal comfort.

the air velocity needed to restore thermal comfort can be calculated by the equation:

$$VTC = [(.15 * (RH-60) + (TEMP - TEMPC)] * 30 \quad \text{(Equation A.1)}$$

Where:

TEMP: Outdoor temperature. Must be less than 96°F. Temperatures above 96°F induces hot discomfort because heat is transfered to the body regardless of the air speed.

TEMPC: Adjusted indoor dry bulb temperature (°F) needed for thermal comfort based on the specified activity, clothing, and mean radiant temperature. Assume a relative humidity of 60% and an air velocity of 0.

RH: Actual relative humidity (20-100%) relative humidities less than 20% are too dry for comfort.

Program NATVENT initializes the following comfort parameters before solving for the velocity needed to restore thermal comfort for various dry bulb temperatures and relative humidity levels:

Mean Radiant Temperature	=	78°F
Activity Levels	=	520 BTU/HR
Clothing Levels	=	1.0 CLO

However, the program is structured so that an algorithm located in subroutine COMFORT can be accessed from subroutine INPUT and subroutine CHANGE for user specified changes of comfort parameters (Figure A.5). Subroutine comfort is explained in detail in the following three sections.

A.4.2 Mean Radiant Temperature. Since the temperatures of building walls (particularly glass walls) fluctuate with the weather, user interface in subroutine COMFORT includes input for the mean radiant temperature for summer and winter conditions. For ideal comfort, the mean radiant temperature must equal the ideal space temperature. For each degree drop in mean radiant temperature, the space temperature must be raised a degree [45]. For each three degree increases between 78°F and 100°F the space temperature should be lowered a degree. For each five degree increase in temperature above 100°F, the space temperature should be lowered a degree [46]. Figure A.7 graphically illustrates the balance between the mean radiant temperatures and the dry bulb temperatures required for thermal comfort [19]. The computer algorithm (Figure A.8) for these situations follows:

MEAN RADIANT TEMPERATURES LESS THAN 78°F.

$$\text{RADENT W}_{NEW} = 78 - \text{RADENTW}_{OLD} \qquad \text{(Equation A.2)}$$

MEAN RADIANT TEMPERATURES BETWEEN 78°F and 100°F

$$\text{RADENTS}_{NEW} = \frac{78 - \text{RADENTS}_{OLD}}{3} \qquad \text{(Equation A.3)}$$

MEAN RADIANT TEMPERATURES GREATER THAN 100°F

$$\text{RADENTS}_{NEW} = \frac{100 - \text{RADENTS}}{5} - \frac{100 - 78}{3} \qquad \text{(Equation A.4)}$$

WHERE:

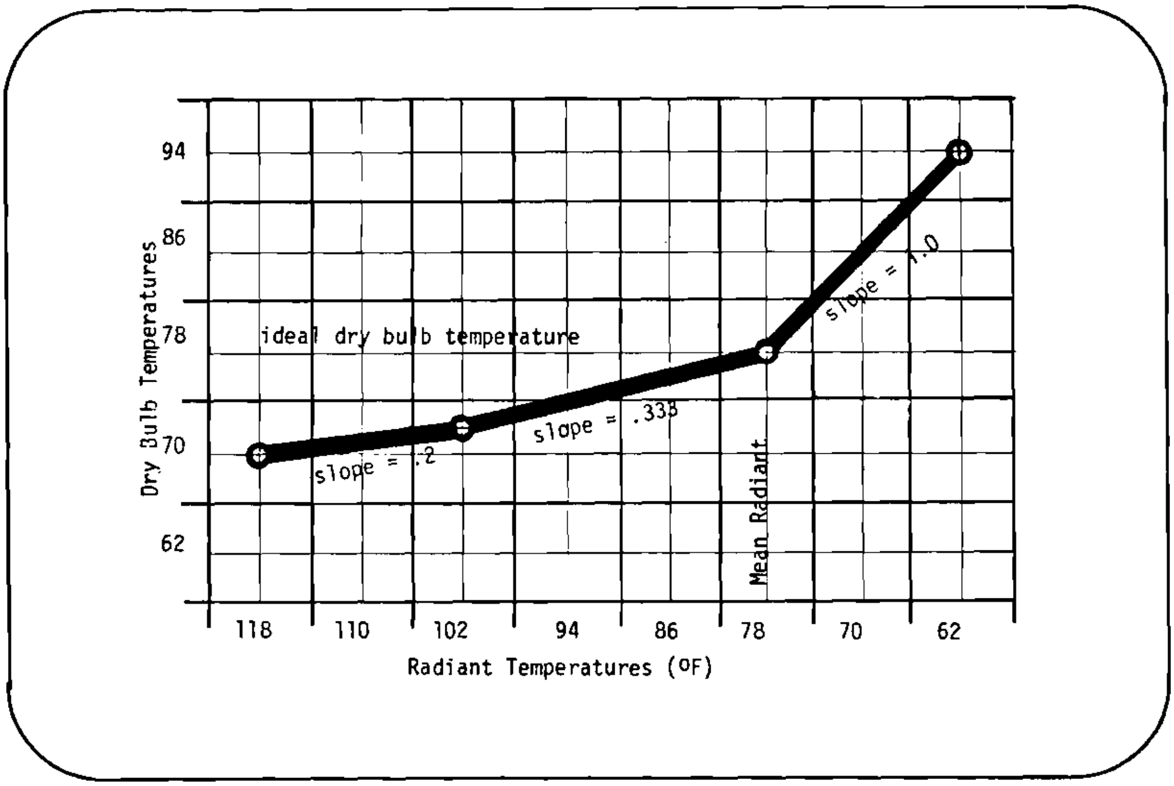


FIGURE A.7

Relationship between various radiant temperatures and drybulb temperatures necessary for thermal comfort.

```
C      MEAN RADIANT TEMPERATURE
C
C
C      NOTE: FOR EVERY DEGREE DROP IN THE MEAN
C      RADIANT TEMPERATURE, THE SPACE TEMPERATURE
C      WILL BE RAISED A DEGREE.
C
  282 WRITE(6,283)
  283 FORMAT(1X,'ENTER THE MEAN RADIANT TEMPERATURE'
     + /1X,'FOR WINTER CONDITIONS.')
       READ(5,*) RADENTW
C
       RADENTW=(78.-RADENTW)
       GO TO 280
C
C      NOTE: WHEN THE MEAN RADIANT TEMPERATURE IS BETWEEN
C      78. AND 100. DEG. F., THE SPACE TEMPERATUTRE WILL
C      BE LOWERED 1 DEG. FOR EVERY 3 DEG. THAT THE RADIANT
C      TEMPERATURE IS RAISED.
C            WHEN THE MEAN RADIANT TEMPERATURE IS ABOVE
C      100. DEG. F., THE SPACE TEMPERATUTRE WILL
C      BE LOWERED 1 DEG. FOR EVERY 5 DEG. THAT THE RADIANT
C      TEMPERATURE IS RAISED.
C
  285 WRITE(6,286)
  286 FORMAT(1X,'ENTER THE MEAN RADIANT TEMPERATURE'
     + /1X,'(GREATER THAN 78. DEG.) FOR SUMMER CONDITIONS.')
       READ(5,*) RADENTS
C
       IF (RADENTS .GE. 100) GO TO 287
C
       RADENTS=((78-RADENTS)/3.)
       GO TO  280
  287 RADENTS=(((100-RADENTS)/5.)-((100-78)/3.))
       GO TO 280
```

FIGURE A.8

Mean radiant temperature algorithm.

$RADENTW_{old}$ = winter

user specified mean radiant temperatures

$RADENTS_{old}$ = summer

$RADENTW_{new}$ = Winter

$RADENTS_{new}$ = Summer

Factor to be added to the ideal indoor dry bulb temperature (78°F) to increase or decrease the temperature in response to the mean radiant temperature so that thermal comfort is restored.

The variables used for adjusting the ideal space temperature (78°) are:

TEMP I = Adjustment of activity levels (see Section A.4.2) and clothing levels (see Section A.4.3). TEMPI = Active + CLO

RADENT = Adjustment for either the mean radiant temperature for winter (RADENTW) or for summer (RADENTS)

TEMPIN = Factor that adjusts the ideal temperature for the above comfort parameters. (TEMPIN = TEMPI + RADENT)

TEMPC = Ideal temperature adjusted (See Figure A.9) for the above comfort parameters (TEMPC = TEMPIN + 78). TEMPC is used in equation A.1 to determine the difference between the desired space temperature (TEMPC) the outdoor temperature (TEMP) to calculate the air velocity needed to restore thermal comfort (Figure A.10).

```
C     TEMPERATURE ADJUSTMENTS IF COMFORT PARAMETERS ARE CHANGED
C
  302                     TEMPI=0.
C     ACTIVITY LEVEL
  303                     TEMPI=ACTIVE
C     CLOTHING
                          TEMPI=TEMPI+CLO
C
      RETURN
C
      END
```

FIGURE A.9

Factor that adjusts ideal temperature for activity and clothing.

```
C     EFFECTIVE TEMPERATURE
                IF(TEMP .LT. 78.) RADENT=RADENTW
                IF(TEMP .GE. 78.) RADENT=RADENTS
                TEMPIN=TEMPI+RADENT
                TEMPC=TEMPIN+78
```

FIGURE A.10

Algorithm for adjusting the ideal temperature for activity, clothing, and mean radiant teamperatures.

NOTE: The mathematical relationship for adjusting the indoor dry bulb temperature for each one of the comfort parameters is based on the assumption that only one variable is changed while the others remain constant. Since thermal comfort is not linear, more development is needed to define the accuracy of the additive adjustment of indoor temperatures for all comfort parameters. The method used is derived from theories presented by Macfarlane [47] and Olivieri [45]. A more appropriate algorithm has been developed by E. Arens at at NBS in the program comfort.

<u>A.4.3 Activity.</u> Program NATVENT initializes the activity level at 520 BTU/hr of heat rejected from the body during office work. However, the user has the option of selecting one of the following activities:

Sleeping	280 BTU/hr
Seated at Rest	400 BTU/hr
Standing Relaxed	480 BTU/hr
Shopping	640 BTU/hr
Housework	1000 BTU/hr
Office Work	520 BTU/hr
Light Factory Work	880 BTU/hr
Heavy Factory Work	1600 BTU/hr
Dancing	1360 BTU/hr

For most people, a 3°F change in temperature is necessary for every 100 BTU/hr change in physical activity. The equation used (Figure A.11) in SUBROUTINE COMFORT adjusts the indoor ideal dry bulb temperature based on an increase or decrease of rejected body heat from 520 BTU/hr follows:

```
C      ACTIVITY LEVEL
C
C
   288 WRITE(5,289)
   289 FORMAT(1X,'SELECT ONE OF THE FOLLOWING ACTIVITIES'
      + /1X,   '1)  SLEEPING'
      + /1X,   '2)  SEATED AT REST'
      + /1X,   '3)  STANDING RELAXED'
      + /1X,   '4)  SHOPPING'
      + /1X,   '5)  HOUSEWORK'
      + /1X,   '6)  OFFICEWORK'
      + /1X,   '7)  LIGHT FACTORY WORK'
      + /1X,   '8)  HEAVY FACTORY WORK'
      + /1X,   '9)  DANCING'
      + /1X,  '(TYPE ONE OF THE ABOVE NUMBERS)')
       READ(5,*) OPERN2
C
       IF (OPERN2 .GE. 1 .AND. OPERN2 .LE. 9) GO TO 284
C
       PRINT(6,*) 'YOU SCREWED UP! TRY AGAIN.'
       GO TO 288
C
   284 GO TO (290,291,292,293,294,295,296,297,298) OPERN2
C
C      A CHANGE OF 3 DEG. F. IS REQUIRED FOR EVERY
C      100 BTU CHANGE IN PHYSICAL ACTIVITY.
C
C      SLEEPING                (280 BTU/HR)
   290 ACTIVE=(((520-280)/100)*3)
       GO  TO 280
C      SEATED AT REST          (400 BTU/HR)
   291 ACTIVE=(((520-400)/100)*3)
       GO  TO 280
C      STANDING RELAXED        (480 BTU/HR)
   292 ACTIVE=(((520-480)/100)*3)
       GO  TO 280
C      SHOPPING                (560 TO 720 BTU/HR
C                              OR 640 BTU/HR AVE.)
   293 ACTIVE=(((520-640)/100)*3)
       GO  TO 280
C      HOUSEWORK               (640 TO 1360 BTU/HR
C                              OR 1000 BTU/HR AVE.)
   294 ACTIVE=(((520-1000)/100)*3)
       GO  TO 280
C      OFFICEWORK              (480 TO 560 BTU/HR
C                              OR 520 BTU/HR AVE.)
   295 ACTIVE=(((520-520)/100)*3)
       GO  TO 280
C      LIGHT FACTORY WORK      (800 TO 960 BTU/HR
C                              OR 880 BTU/HR AVE.)
   296 ACTIVE=(((520-880)/100)*3)
       GO  TO 280
C      HEAVY FACTORY WORK      (1400 TO 1800 BTU/HR
C                              OR 1600 BTU/HR AVE.)
   297 ACTIVE=(((520-1600)/100)*3)
       GO  TO 280
C      DANCING                 (960 TO 1760 BTU/HR
C                              OR 1360 BTU/HR AVE.)
   298 ACTIVE=(((520-1360)/100)*3)
       GO  TO 280
C
```

FIGURE A.11

Algorithm for adjusting ideal temperature for user selected activities.

$$ACTIVE_{new} = \frac{(520 - ACTIVE_{old}) * 3}{100} \qquad \text{(Equation A.5)}$$

WHERE:

$ACTIVE_{old}$ = Heat rejected from selected activity BTU/hr.

$ACTIVE_{new}$ = Change in temperature of space to restore comfort based on a change in physical activity.

See Section A.4.1 for the variables used for adjusting the indoor space temperature.

A.4.4 Clothing. Clothing is rated for its insulation value in units called the CLO. Program NATVENT initializes the clothing level at 1.0 CLO which is equivalent to a typical business suit. However, the user has the option to select one of the following clothing levels:

Beach-wear	.05 CLO
Light Clothing	.75 CLO - Casual Dress
Business Suit	1.0 CLO
Heavy Dress	2.0 CLO - Includes winter coat

For most people, a 1.4°F change in temperature is necessary for every .1 change in CLO units. The equation used (Figure A.12) in subroutine COMFORT that adjusts the ideal dry bulb temperature based on an increase or decrease of clothing insulation from 1.0 CLO follows:

$$CLO_{new} = \frac{(1 - CLO_{old}) * 1.44}{1}$$

OR:

$$CLO_{old} = ((1 - CLO_{old}) * 10) * 1.44 \qquad \text{(Equation A.6)}$$

```
C       CLOTHING LEVEL
C
C
C       NOTE: CLOTHING IS RATED FOR IT'S INSULATION VALUE
C       IN UNITS CALLED THE CLO. EVERY 0.1 CLO IS
C       EQUIVALENT TO A 1.44 DEG. F. CHANGE IN TEMPERATURE.
C
    299 WRITE(6,300)
    300 FORMAT(1X,'ENTER ONE OF THE FOLLOWING CLOTHING LEVELS'
       + /6X,'1) BEACH-WEAR'
       + /6X,'2) LIGHT CLOTHING (CASUAL DRESS)'
       + /6X,'3) BUISNESS SUIT'
       + /6X,'4) HEAVY DRESS (INCLUDES WINTER COAT)'
       + /1X,'(TYPE ONE OF THE ABOVE NUMBERS)')
        READ(5,*) CLOTH
C
        IF (CLOTH .EQ. 1 .OR. CLOTH .EQ. 2 .OR.
       +     CLOTH .EQ. 3 .OR. CLOTH .EQ. 4) GO TO 301
C
        PRINT(6,*) 'YOU SCREWED UP! TRY AGAIN.'
        GO TO 299
C
    301 IF (CLOTH .EQ. 1) CLO=.05
        IF (CLOTH .EQ. 2) CLO=.75
        IF (CLOTH .EQ. 3) CLO=1.
        IF (CLOTH .EQ. 4) CLO=2.
C
        CLO=(((1-CLO)*10)*1.44)
        GO TO 280
C
```

FIGURE A.12

Algorithm for adjusting ideal temperature for user selected clothing levels.

WHERE:

CLO_{old} = Clothing insulation value from selected activity

CLO_{new} = Change in temperature of space to restore comfort based on a change in physical activity.

See Section A.4.1 for the variables used in adjusting the indoor space temperature.

A.5 Ventilation for Fresh Air vs. Comfort

Program NATVENT uses the building's ventilation rate specified by the user (Figure A.13) to size and test the area of crack that induces just enough airflow for fresh air requirements during the winter months (see Appendix A.2). If possible, the building's total area of crack should be smaller than the area of opening calculated because it is more energy efficient to provide the remaining fresh air through an energy recovery unit.

During the fall and spring seasons when no heating or cooling is necessary, program NATVENT tests and sizes openings in the building so that wind induced ventilation will meet fresh air requirements without chilling the occupant. For this situation, user interface includes input for the fresh air requirements for the room in series with the maximum ventilation rate (see Figure A.14). During the summer seasons, NATVENT tests and sizes openings that will induce adequate airflow to restore thermal comfort (see Appendix A.3 and A.4). An algorithm located in the main program uses the weather data to determine the dominating ventilation rate of either the airflow needed for fresh air requirements or the air flow needed to restore comfort before sizing and testing the

```
C
      PRINT(6,*)'ENTER THE BUILDING'S REQUIRED VENTILATION RATE (CFM).
     +SEE THE ASHRAE COOLING AND HEATING LOAD CALCULATION MANUAL    .
     +                   (PAGES 5.12 TO 5.15).'
      READ(5,*) VOT
C
```

FIGURE A.13

Input for fresh air induced by stack effect.

```
      PRINT(6,*) 'ENTER THE VENTILATION RATE OF THE ROOM IN SERIES
     +            WHICH HAS THE HIGHEST VALUE.(SEE ASHRAE MANUAL)'
      READ(5,*) VFA
C
      VFA=(VFA/60)
```

FIGURE A.14

Input for fresh air induced by wind pressure.

```
C
C      TEST IF VELOCITY FOR THERMAL COMFORT IS
C      GREATER THAN VELOCITY FOR FRESH AIR.
C
                 VZ=VFA
                 IF (VTC .GT. VZ) VZ=VTC
```

FIGURE A.15

Airflow that must be supplied by wind or fans.

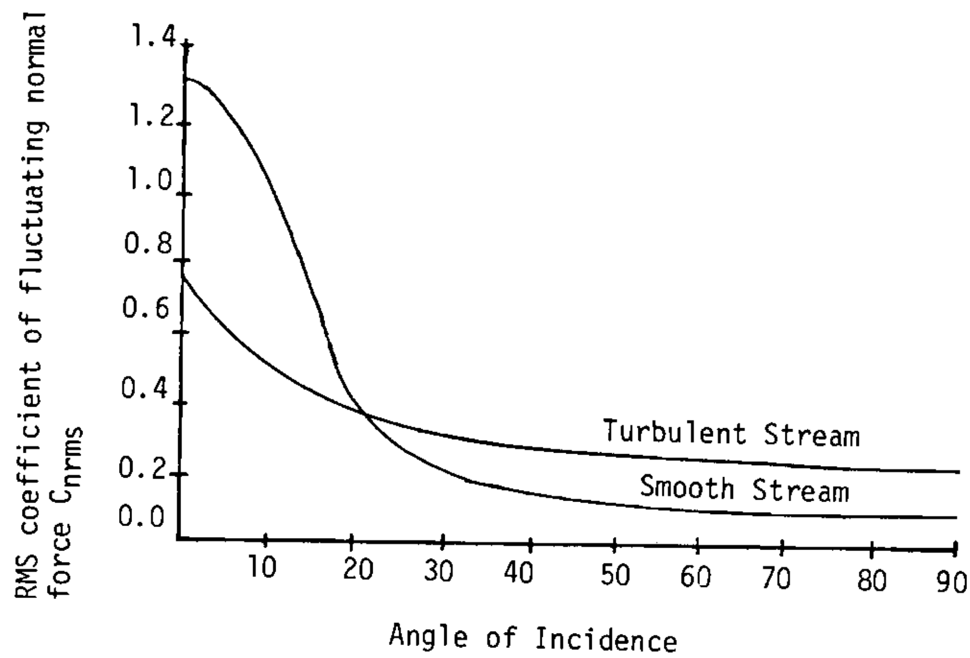


FIGURE A.16

Acting pressures across building openings by a smooth and turbulent air stream at various incidence angles.

area of opening for that particular time of the year (Figure A.15).

A.6 Reduction of Ventilation Rates for Various Wind Incidence Angles

Recent full scale studies have shown that natural ventilation rates resulting from turbulent flow parallel to a building openings are only half the ventilation rate when the wind incidence angle is perpendicular to the opening [2]. Figure A.16 [33] illustrates the pressure differential across building openings for various incidence angles of a smooth and turbulent air stream. The pressure differential across building openings resulting from turbulent airflow at an incidence angle of 90° is only 50% of the pressure differential at 0°. Since there is a definite relation between wind induced surface pressures and wind induced ventilation, Figure A.16 may be used to reduce ventilation rates calculated for normal wind incidence angles as follows:

$$VZZ_{new} = VZZ_{old} - REDUCED \qquad \text{(Equation A.7)}$$

Where:

VZZ_{new} = Ventilation rate reduced according to the wind incidence angle

VZZ_{old} = Ventilation rate calculated for a normal wind incidence angle

REDUCED = Factor that reduces the ventilation rate according to the following incidence angles:

A reduction of 3% per degree for wind incidence angles between 0 and 8 degrees.

REDUCED = VZZ * (AI * .03) (Equation A.8)

A reduction of 24% plus 1% per degree for wind incidence angles between 9 and 20 degrees.

REDUCED = (VZZ * .24) + (V22 *[(AI-8)*.01])

(Equation A.9)

A reduction of 36% plus .4% per degree for wind incidence angles between 21 and 45 degrees.

REDUCED = (VZZ * .36) + (VZZ * [(AI-20)* .004])

(Equation A.10)

A reduction of 46% plus .09% per degree for wind incidence angles between 46 and 90 degrees.

REDUCED = (VZZ * .46) + (VZZ * [(AI-45) 8 .0009)]

(Equation A.11)

Where:

VZZ = ventilation rate calculated at a normal angle of incidence

AI = wind angle of incidence.

The algorithm that reduces the ventilation rate according to the wind incidence angle is located in SUBROUTINE REDUCE (Figure A.17).

<u>A.6.1 Calculation of Wind Incidence Angles.</u> An algorithm in the main program calculates the wind incidence angles based on the relation

```
C*********************************************************************
      SUBROUTINE REDUCE
C*********************************************************************
C
      COMMON/WIND/DIR,ORIENT,AI,AO,CD,CFW,CPL,DP,SFACE,LFACE,VZZ,V,
     +       PATH,RH,RM,RSA,SALF,SASF,SUM,SUML,SUMS,NROOM,FACE,P,SIDES
C
C
C     THIS SUBROUTINE REDUCES VENTILATION RATES BY
C     A PERCENTAGE FOR EACH DEGREE THAT THE WIND INCIDENCE ANGLE IS
C     OFF THE PERPENDICULAR OF THE PERPENDICULAR TO THE OPENING.
C
C
      IF (AI .LE. 8.) GO TO 730
      IF (AI .LE. 20.) GO TO 735
      IF (AI .LE. 45.) GO TO 740
      IF (AI .LE. 90.) GO TO 745
C
C     FACTOR THAT REDUCES VENTILATION BY 3% PER DEGREE
C     WHEN THE WIND INCIDENCE ANGLES ARE BETWEEN 0 AND 8 DEGREES
C
  730 REDUCED=((VZZ)*(AI*.03))
      GO TO 750
C
C     FACTOR THAT REDUCES VENTILATION BY 24% PLUS 1% PER DEGREE
C     WHEN THE WIND INCIDENCE ANGLES ARE BETWEEN 9 AND 20 DEGREES
C
  735 REDUCED=((VZZ*.24)+(VZZ*((AI-8)*.01)))
      GO TO 750
C
C     FACTOR THAT REDUCES VENTILATION BY 36% PLUS .4% PER DEGREE
C     WHEN THE WIND INCIDENCE ANGLES ARE BETWEEN 21 AND 45 DEGREES
C
  740 REDUCED=((VZZ*.36)+(VZZ*((AI-20)*.004)))
      GO TO 750
C
C     FACTOR THAT REDUCES VENTILATION BY 46% PLUS .09% PER DEGREE
C     WHEN THE WIND INCIDENCE ANGLES ARE BETWEEN 45 AND 90 DEGREES
C
  745 REDUCED=((VZZ*.46)+(VZZ*((AI-45)*.0009)))
C
C     VENTILATION REDUCED
C
  750 VZZ=VZZ-REDUCED
C
      RETURN
      END
```

FIGURE A.17

Reduction of ventilation rates according to wind incidence angles.

of the wind direction to the user specified orientation and the number of sides of the building with openings. Program NATVENT is limited to rectangular buildings with openings on four sides or two opposite sides. The maximum wind incidence angle for a building with openings on all four sides is 90 degrees (Figure A.18). The maximum wide incidence angle for a building with openings on two opposite sides is 45 degrees (Figure A.19). The algorithm (Figure A.20) that determines the wind incidence angle is illustrated in the following example (Figure A.21).

1. DIRNEW = ABS (ORIENT - DIR) (Equation A.12)

example: 230 = ABS (90 - 320)

WHERE:

DIR = wind direction clockwise from north (0-360°)

ORIENT = user specified orientation angle on the buildings long face

ABS = absolute value

DIRNEW = the angle clockwise from the opening orientation angle to the wind's directional angle

A logical IF statement will command the computer to skip the following equation if DIRNEW is less than or equal to 180 degrees.

2. DIRNEW = ABS (360 - DIRNEW)

example: 130 = ABS (360 - 230)

From this calculation the actual angle between the user specified orientation angle and the wind's directional angle is determined. A logical IF statement will command the computer to skip the following equation if DIRNEW is less than or equal to 90 degrees.

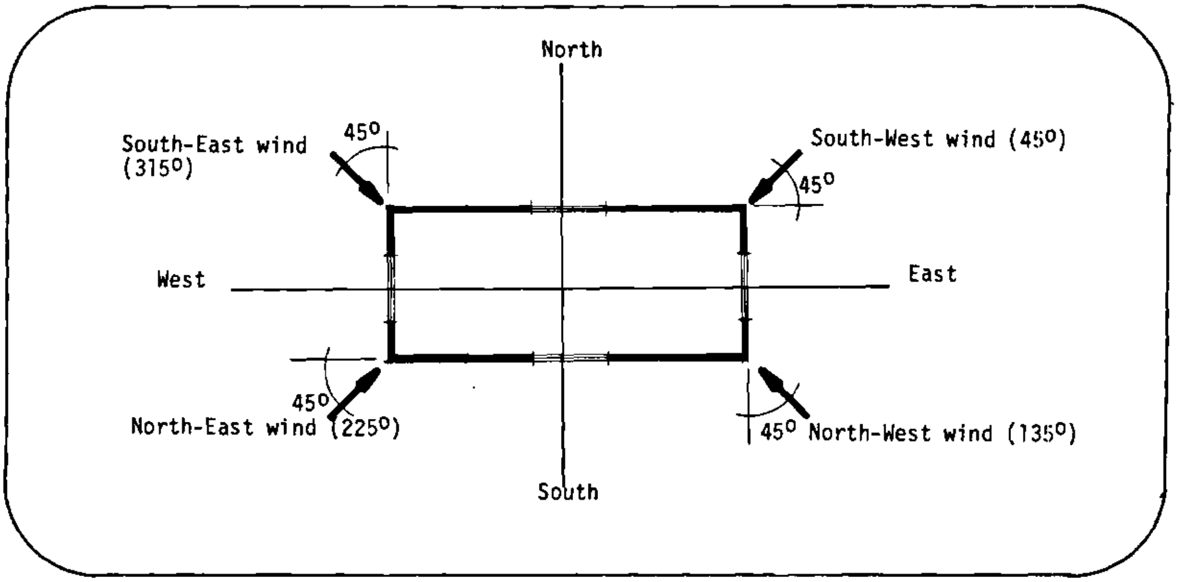


FIGURE A.18

The maximum incidence angle of wind on a building with openings on each side is 45 degrees.

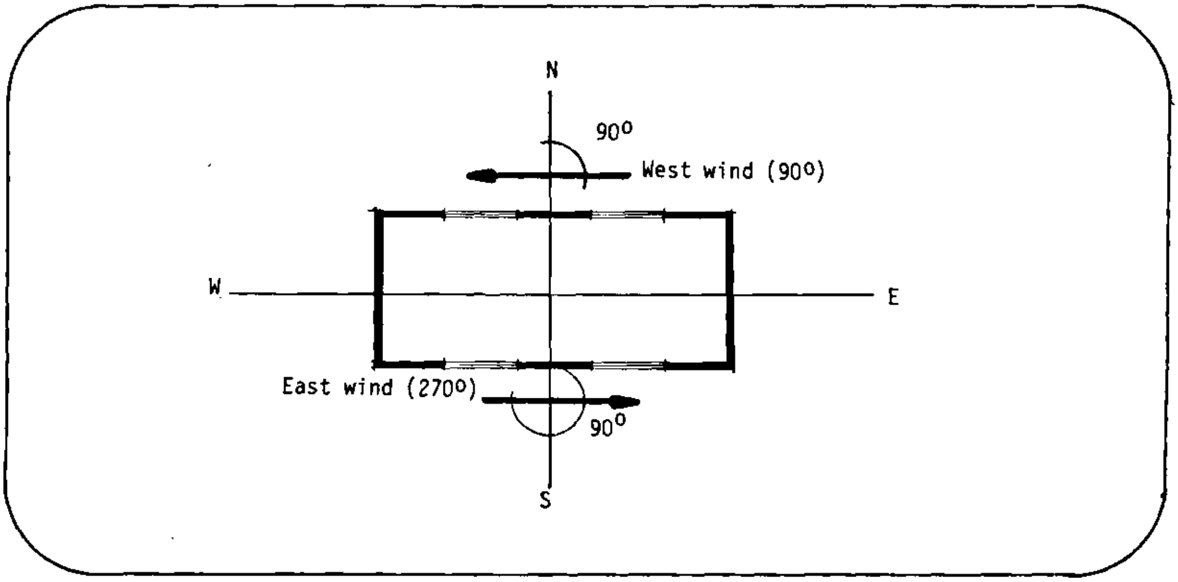


FIGURE A.19

The maximum incidence angle of wind on a building with openings on two opposite sides is 90 degrees.

```
C     CORRECTIONS FOR WIND DIRECTION AND OPENING
C     ORIENTATION YIELDS THE ANGLE OF INCIDENCE.
C
                     DIR=(DIR*10.)
C
                     DIRNEW=ABS(ORIENT-DIR)
C
                     IF (DIRNEW .LE. 180.) GO TO 144
C
                     DIRNEW=360.-DIRNEW
  144                IF (DIRNEW .LE. 90.) GO TO 145
C
                     DIRNEW=ABS(180.-DIRNEW)
  145                IF (SIDES .EQ. 2) PATH=2.
                     IF (SIDES .EQ. 2) GO TO 147
C
                     IF (DIRNEW .LE. 4.5) PATH=2.
                     IF (DIRNEW .LE. 4.5) GO TO 147
C
C     THE PATH OF AIRFLOW THROUGH THE BUILDING IS
C     PERPENDICULAR TO THE SHORT FACE(PATH=1.)
C
                     PATH=1.
                     DIRNEW=ABS(90.-DIRNEW)
                     IF (SOLVE .EQ. 1.) GO TO 148
C
                     SUM=SUMS
                     GO TO 148
C
C     THE PATH OF AIRFLOW THROUGH THE BUILDING IS
C     PERPENDICULAR TO THE LONG FACE(PATH=2.)
C
  147                SUM=SUML
C
  148                AI=DIRNEW
                     CALL GEOMTRY
```

FIGURE A.20

Angle of incidence algorithm.

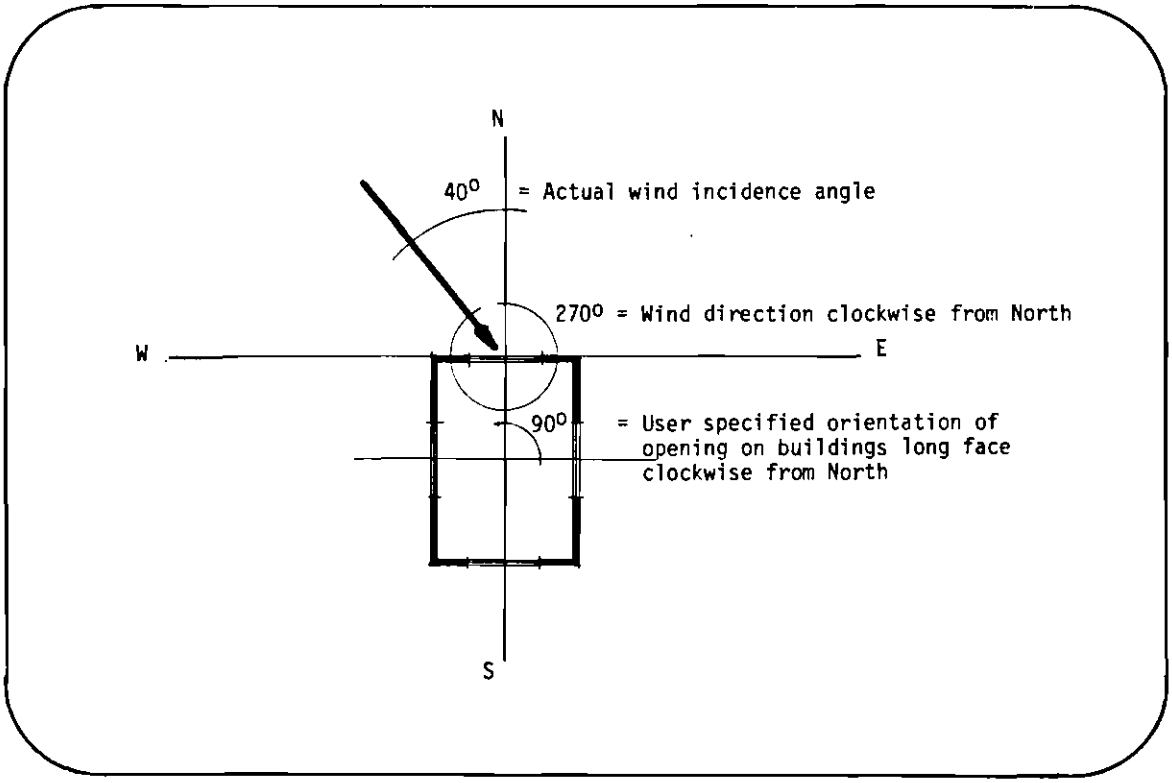


FIGURE A.21

An algorithm in NATVENT calculates the smallest incidence angle of wind based on the user specified orientation and the wind's direction.

3. DIRNEW = ABS (180 - DIRNEW)

example: 50 = ABS (180 - 130)

From this calculation the actual incidence angle is determined for a building with openings on two opposite sides. Logical IF statements will command the computer to skip the following equation if the building has only two sides with openings or DIRNEW is less than or equal to 45 degrees.

4. DIRNEW = ABS (90 - DIRNEW)

example: 40 = ABS (90 - 50) See Figure A.21

From this calculation the actual incidence angle is determined for a building with openings on four sides. If this final calculation is made, the smallest incidence angle occurs at the opening on the building's short face and a variable (PATH) is set to equal 1. This value signifies that the air flow path is perpendicular to the building's short face. If the final calculation is not made, airflow is perpendicular to the long face the variable PATH is set to equal 2. This variable is used throughout the program so that the appropriate discharge and pressure coefficients are used in the calculations.

A.7 Dominating Effect Algorithm

A dominating effect algorithm (Figure A.22) is used in the main program, NATVENT to determine whether ventilation is induced by stack effect or wind pressure. The algorithm is based on the critical temperature differential of inside and outside air and the critical wind speed obtained from the dominating effect equations discussed in Chapter One.

```
C     DETERMINE IF VENTILATION OCCURS BY
C     WIND PRESSURE OR 'STACK EFFECT'.
C
                     IF (TEMP .LT. TEMPC) GO TO 152
                     IF (TEMP .GT. TEMPC .AND. V .LE. 3.5) CALL STACK
                     GO TO 153
C
  152                IF (TEMP .GE. TEMPW) CALL WIND
                     IF (TEMP .GE. TEMPW) GO TO 153
C
                     IF(DT .EQ. 0 .OR. DV .EQ. 0) CALL WIND
                     IF(DT .EQ. 0 .OR. DV .EQ. 0) GO TO 153
C
                     CALL STACK
```

FIGURE A.22

Dominating effect algorithm.

If temperature differentials are greater than 10°F, subroutine STACK is called to calculate one of the following:

A. Area of crack that will induce just enough airflow to meet fresh air requirements (see Appendix B.1).

B. Volume of air that infiltrates through user specified crack areas (see Appendix B.2).

If the outdoor temperature is greater than 78°F and wind speeds are less than 3.5 MPH, subroutine STACK is called to calculate:

C. The temperature of exfiltrating air (out of a solar chimney) to provide an adequate temperature differential so that sufficient air speeds are induced through the living zone to restore thermal comfort (see Appendix B.3).

If temperature differentials are less than 10°F and wind speeds are greater than 3.5 MPH, subroutine WIND (Appendix C) is called to calculate one of the following:

A. The area of opening that will induce adequate airflow to restore thermal comfort.

B. The average velocity of air at each user specified area of opening in series.

A.8 Output

The output format statements are found in the main program, NATVENT. Output is sent to the keyboard after the initial run. At this point, the user has the option to change the input and rerun the program. After the final run, all output for each run is sent to the line printer. A description of the possible types of output is given in Chapter 2.4.

APPENDIX B

STACK EFFECT ALGORITHM

B.1 Area of Crack

B.2 Volume of Infiltration

B.3 Temperature of Exfiltrating Air

APPENDIX B

STACK EFFECT ALGORITHM

The amount of airflow induced through an opening by the stack effect is dependent on the area of opening, the distance between that opening and the neutral zone, and the temperature differential between inside and outside air. The variables in the stack effect equation selected for the computer model (Chapter 1.1.3) can be rearranged so that the following calculations are possible:

A. Area of crack

B. Volume of infiltration

C. Temperature of exfiltration air

All of these equations are contained in SUBROUTINE STACK (Figure B.1, B.2) and are discussed in the following three sections.

B.1 Area of Crack

The area of crack that induces ventilation for fresh air requirements is calculated by the following equations when:

A. The user specifies program NATVENT to calculate the opening sizes that maximize natural ventilation use.

B. The temperature differential between inside and outside air is greater than 10°F.

(Equation B.1)

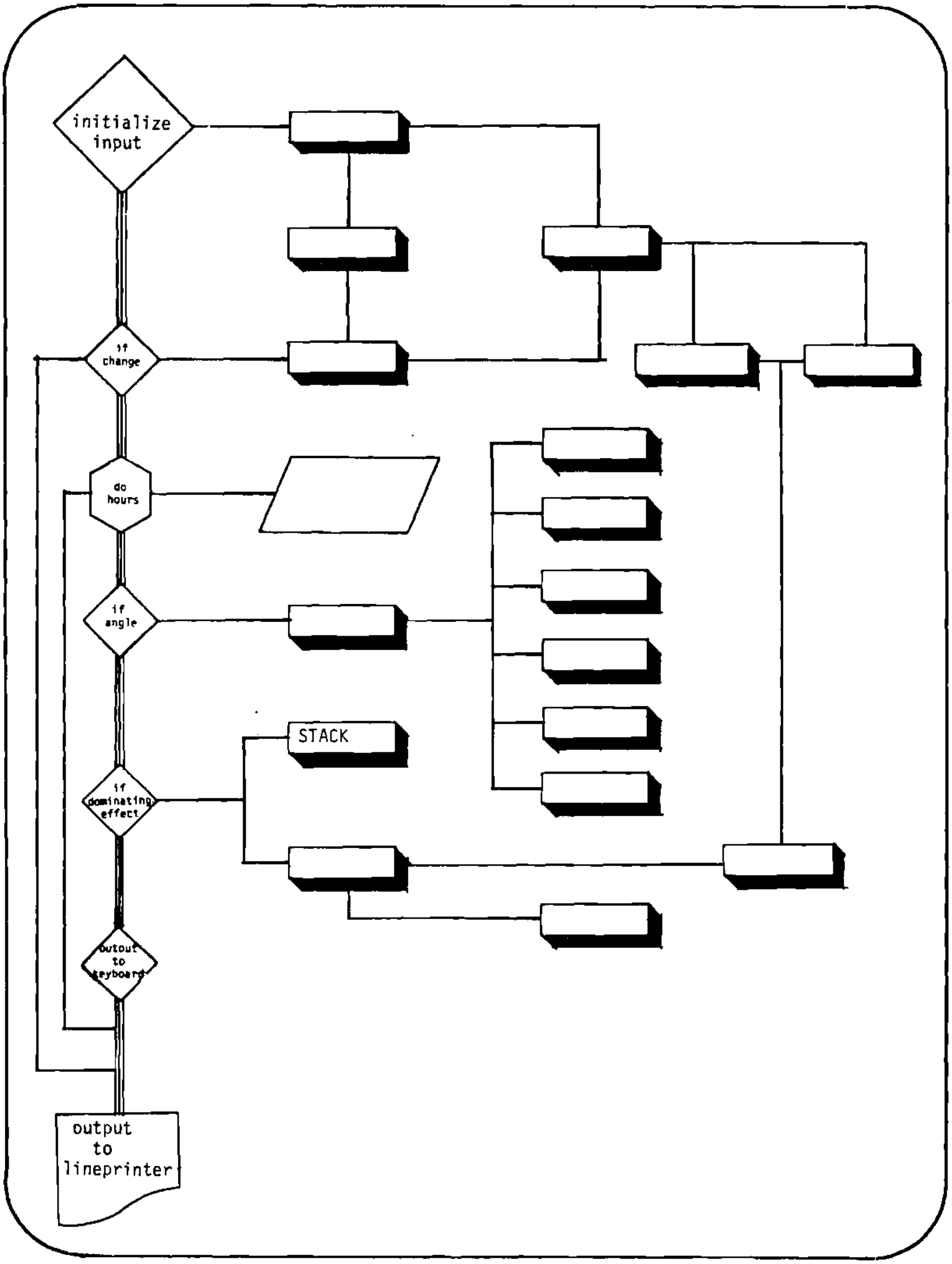


FIGURE B.1

Flow chart illustrating accessing of SUBROUTINE STACK.

```
C*********************************************************************
      SUBROUTINE STACK
C*********************************************************************
C
      COMMON/INPUT/BH,BL,BW,VFA,SA,WRATIO,SRATIO,NROOML,NROOMS,MENU1
      COMMON/STACK/VOT,VOTC,CF,AITW,AOTW,AITSS,AOTSS,G,DV,TEMPC,IFLOOR
      COMMON/BOTH/AIT,AITM,AOT,DT,ITYPE,R,TEMP,TEMPI,VZ,ANGLE,SOLVE
C     THIS SUBROUTINE DETERMINES: 1) THE TOTAL AREA OF INLETS
C     AND OUTLETS NEEDED TO MEET FRESH AIR REQUIREMENTS, 2) THE VOLUME
C     OF AIR INFILTRATING AND EXFILTRATING THROUGH WINDOW AND DOOR
C     CRACKS, 3) THE TEMPERATURE OF EXAUST AIR PASSING THROUGH A
C     SOLAR DEVICE THAT WILL CREATE A SUFFICIENT TEMPERATURE
C     DIFFERENTIAL TO INDUCE A BREEZE THROUGH THE LIVING ZONE SO
C     THAT THERMAL COMFORT IS ACHIEVED. THE STACK EFFECT IS DEPENDANT
C     ON COOLER OUTDOOR TEMPERATURES AND THE VERTICAL
C     DISTANCE BETWEEN INLETS AND OUTLETS.
C
C***************
C     EQUATION 2
C***************
C
      ITYPE='STACK'
C
      IF (TEMP .LT. TEMPC) R=WRATIO
      IF (TEMP .GE. TEMPC) R=SRATIO
C
C
C     OPENING EFFIENCY FOR RATIO OF OUTLET TO INLET
C
C
      CF=((.65*60)*((((R**2)/(1+(R**2)))*(((2*G)/(550))))**.5))
C
       IF (SOLVE .EQ. 2 .AND. TEMP .LE. TEMPC) GO TO 305
      IF (TEMP .GT. TEMPC) GO TO 304
C
C     SOLVE FOR AREA OF OPENING NEEDED FOR FRESH AIR
C
      AOT=((VOT)/((CF)*(((DV)*((DT)/(2)))**.5)))
C
      AIT=(AOT/R)
C
      GO TO 306
C     SOLVE FOR TEMPERATURE OF EXAUST AIR NEEDED TO INDUCE
C     THE REQUIRED AIR VELOCITY FOR THERMAL COMFORT
C
  304 IF (SOLVE .EQ. 2) AOT=AOTSS
C
      VZ=VZ*AOT
C
      TEMPC=(2*(((VZ**2)/(((CF*AOT)**2)*DV))+(TEMP/2)))
C
      VZ=VZ/AOT
C
      GO TO 306
C
C     TEST VELOCITY OF OPENING SELECTED
C
  305 VOTC=((CF*AOTW)*((DV*((DT)/2))**.5))
  306 RETURN
      END
```

FIGURE B.2

Listing of SUBROUTINE STACK.

WHERE:

AOT = Total area of outlet (total area of crack above the neutral zone. See Chapter 1.1)

AIT = Total area of inlet (total area of crack below the neutral zone)

VOT = Volume of infiltration or exfiltration

DV = Distance vertically between the inlets and outlets

DT = Temperature differential between the inside and outside air

R = Ratio of largest to smallest opening

CF = Opening effiency for the ratio of outlet to inlet size and calculated as follows:

$$CF = (.65 * .60) * \sqrt{\frac{R^2}{1 + R^2} * \frac{26}{550}} \qquad \text{(Equation B.2)}$$

WHERE:

G = Gravity (32.2 ft/sec^2)

Providing fresh air by natural means during the winter months is not advisable for energy efficiency. The design strategy should be to reduce the area of crack as calculated above so that the remaining fresh air can be supplied through a heat energy recovery unit.

B.2 Volume of Infiltration

The volume of infiltration through user specified area of inlets is calculated by the following equation when:

A. The user specifies to test the performance of the opening sizes selected.

B. The temperature differential between inside and outside air is greater than 10°F.

$$VOT = (CF * AOT) * \sqrt{DV * \frac{DT}{2}} \qquad \text{(Equation B.3)}$$

If the actual area of crack in the building is less than the crack area that induces ventilation to meet fresh air requirements, the volume of fresh air to be supplied by mechanical means can be determined by entering the differential between these two crack areas.

B.3 Temperature of Exfiltrating Air

The temperature of passively heated exfiltrating air necessary to provide an adequate temperature differential to induce sufficient air speeds for summer cooling is calculated by the following equations when:

A. The user specifies to test the performance of the opening size selected.

B. The temperature differential between inside and outside air is less than 10°F.

C. Wind speeds are less than 3.5 MPH.

$$TEMPC = 2 * \left(\frac{VZ^2}{(CF * AOT)^2 + \frac{TEMP}{2}} \right) \qquad \text{(Equation B.4)}$$

WHERE:

TEMPC = Temperature of air exfiltrating through a solar chimney

TEMP = Temperature of outdoor air

Even though calculating the exaust air temperature necessary to provide stack effect ventilation for summer cooling is possible, it may be difficult to create the desired temperature because of the limited heat transfer possible in a passive solar chimney. Stack effect for summer cooling is most applicable to hot process buildings such as industrial steel mills.

APPENDIX C

WIND PRESSURE ALGORITHM

APPENDIX C

WIND PRESSURE ALGORITHM

The velocity of wind induced airflow through a building is dependent on the following:

A. Wind speed

B. Wind direction vs. orientation of openings

C. Typical wind pressure distribution across the building geometry

D. Area of inlets and outlets

E. Number of rooms in series

   1. Sectional area of each room

   2. Area of each opening in series

Subroutine WIND calculates the area of opening and the wind induced ventilation rate necessary for summer cooling. Subroutine WIND calculates discharge coefficients for openings and wind pressure coefficients for buildings with various rectangular geometries from subroutines WNDSUB1, WNDSUB2, GEOMTRY, WNDSUB4, WNDSUB5, WNDSUB6, WNDSUB7, SNDSUB8, and WNDSUB9 (Figure C.1). These subroutines are discussed in detail in the following sections.

C.1 Discharge Coefficients

Subroutines WNDSUB1 and WNDSUB2 contain discharge coefficient data that is obtained by subroutine WIND through either subroutine ROOM1 or subroutine ROOM2. subroutine ROOM1 contains interactive prompts for

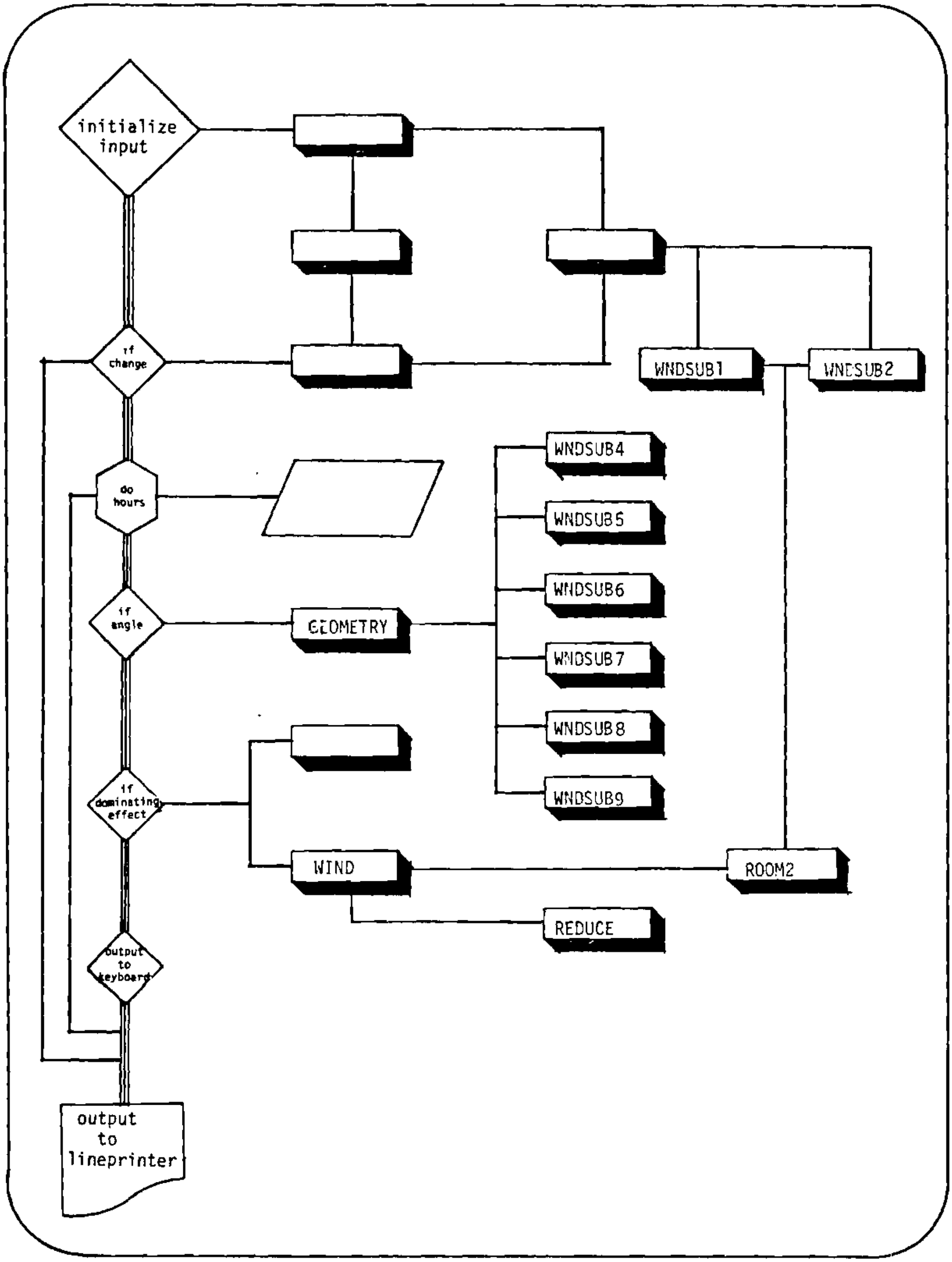


FIGURE C.1

Flow chart illustrating subroutines involved in wind pressure calculations.

input of opening areas and sectional areas of each room in series (Figure C.2). Subroutine ROOM1 calls either subroutine WNDSUB1 or subroutine WNDSUB2 to determine the discharge coefficients for each room in series to calculate the average air velocity at each opening. Opening areas used in subroutine ROOM2 are assigned internally by subroutine WIND (Figure C.3). RROM2 calls either subroutine WNDSUB1 or subroutine WNDSUB2 to determine the discharge coefficients for each room in series to calculate the area of opening that induces adequate air velocities for thermal comfort. Subroutine WNDSUB1 contains discharge coefficients for the inlet in the building's external wall (Figure C.4, see Table 1.10 in Chapter 1.6.) Discharge coefficients are selected based on the ratio of inlet area to the sectional area of the room in series. Subroutine WNDSUB2 contains discharge coefficients for the outlets in the building's internal and external walls (Figure C.5, see Table 1.11 in Chapter 1.6.). Discharge coefficients are selected based on the ratio of the opening area to the sectional area of the room upwind from the opening.

C.2 Wind Pressure Distribution for Rectangular Geometry

Program NATVENT is capable of performing a natural ventilation analysis on any rectangular building geometry that has a length less than four times the width and a height less than six times the width. If the user specifies any other ratios of height and length to width, subroutine GEOMTRY prints these limitations and prompts the user for new input (Figure C.6). An algorithm is subroutine GEOMTRY selects one of the following subroutines based on user specifications of height (H), length (l), and width (w) to obtain the appropriate pressure coefficients:

Each subroutine contains pressure coefficients for wind incidence

```
C***********************************************************************
      SUBROUTINE ROOM1
C***********************************************************************
C
      COMMON/WIND/DIR,ORIENT,AI,AO,CD,CPW,CPL,DP,SFACE,LFACE,VZZ,V,
     +       PATH,RH,RM,RSA,SALF,SASF,SUM,SUML,SUMS,NROOM,FACE,P,SIDES
C
C     THIS SUBROUTINE INTERACTIVELY PROMPTS THE USER FOR THE
C     AREA OF OPENINGS AND THE SECTIONAL AREA OF THE ROOMS IN SERIES
C
C
      SUM=0
      DO 265 N=1,NROOM
C
           IF (N .EQ. 1) GO TO 250
           IF (N .EQ. NROOM) GO TO 260
C
           PRINT(6,*) 'ENTER THE SECTIONAL AREA FOR ROOM-',N
           READ(5,*) RSA
C
  245      PRINT(6,*) 'ENTER THE AREA FOR OUTLET-',N
           READ(5,*) AO
           CALL WNDSUB2
           SUM=RM+SUM
           GO TO 265
C
  250      PRINT(6,*) 'ENTER THE SECTIONAL AREA FOR ROOM-1'
           READ(5,*) RSA1
C
           AO=FACE
           RSA=RSA1
           CALL WNDSUB1
           SUM=RM+SUM
           GO TO 245
  260      PRINT(6,*) 'ENTER THE SECTIONAL AREA FOR ROOM-',NROOM
           READ(5,*) RSAN
C
           AO=FACE
           RSA=RSAN
           CALL WNDSUB2
           SUM=RM+SUM
C
  265 CONTINUE
C
      RETURN
      END
```

FIGURE C.2

Listing of SUBROUTINE ROOM1.

```
C*********************************************************************
      SUBROUTINE ROOM2
C*********************************************************************
C
      COMMON/WIND/DIR,ORIENT,AI,AO,CD,CPW,CPL,DP,SFACE,LFACE,VZZ,V,
     +       PATH,RH,RM,RSA,SALF,SASF,SUM,SUML,SUMS,NROOM,FACE,P,SIDES
C
C
C
C     SUM=0
C     DO 240 N=1,NROOM
C
           IF (N .GT. 1.) GO TO 230
C
           CALL WNDSUB1
           SUM=RM+SUM
C
  230      CALL WNDSUB2
           SUM=RM+SUM
      PRINT(6,*) 'SUM=',SUM
C
  240 CONTINUE
C
      RETURN
      END
```

FIGURE C.3

Listing of SUBROUTINE ROOM2.

```
C*********************************************************************
      SUBROUTINE WNDSUB1
C*********************************************************************
C
      COMMON/WIND/DIR,ORIENT,AI,AO,CD,CPW,CPL,DP,SFACE,LFACE,VZZ,V,
     +        PATH,RH,RM,RSA,SALF,SASF,SUM,SUML,SUMS,NROOM,FACE,P,SIDES
C
C
C
C     THIS SUBROUTINE PROVIDES THE DISCHARGE COEFFICIENTS
C     FOR THE AREA OF INLETS DEVIDED BY THE SECTIONAL
C     AREA OF THE FIRST ROOM IN SERIES.
C
C     PRINT(6,*) 'AO=',AO,' RSA=',RSA
      X=ABS(AO/RSA)
C
      IF (X .GE. 0.0 .AND. X .LT. 0.1) CD=.55
      IF (X .GE. 0.1 .AND. X .LT. 0.2) CD=.65
      IF (X .GE. 0.2 .AND. X .LT. 0.5) CD=.70
      IF (X .GE. 0.5 .AND. X .LT .0.7) CD=.75
      IF (X .GE. 0.7 .AND. X .LT. .85) CD=.85
      IF (X .GE. .85) CD=.90
C
C     PRINT(6,*) 'CD=',CD
      RM=(1/((CD**2)*(AO**2)))
      RETURN
      END
C
```

FIGURE C.4

Listing of SUBROUTINE WNDSUB1.

```
C*********************************************************************
      SUBROUTINE WNDSUB2
C*********************************************************************
C
      COMMON/WIND/DIR,ORIENT,AI,AO,CD,CPW,CPL,DP,SFACE,LFACE,VZZ,V,
     +        PATH,RH,RM,RSA,SALF,SASF,SUM,SUML,SUMS,NROOM,FACE,F,SIDES
      COMMON/BOTH/AIT,AITM,ADT,DT,ITYPE,R,TEMP,TEMPI,VZ,ANGLE,SOLVE
C
C
C     THIS SUBROUTINE PROVIDES THE DISCHARGE COEFFICIENTS FOR
C     THE RATIO OF OUTLET AREA DEVIDED BY ROOM SECTIONAL AREA.
C
C     PRINT(6,*) 'AO=',AO,' RSA=',RSA
      X=ABS(AO/RSA)
C
  400 IF (X .EQ. 0.0) CD=.63
      IF (X .GT. 0.0 .AND. X .LE. 0.2) CD=.64
      IF (X .GT. 0.2 .AND. X .LE. 0.4) CD=.67
      IF (X .GT. 0.4 .AND. X .LE. 0.6) CD=.71
      IF (X .GT. 0.6 .AND. X .LE. 0.8) CD=.81
      IF (X .GT. 0.8) CD =1.0
C
C     PRINT(6,*) 'CD=',CD
      RM=(1/((CD**2)*(AO**2)))
      RETURN
      END
```

FIGURE C.5

Listing of SUBROUTINE WNDSUB2.

```
C***********************************************************************
      SUBROUTINE GEOMTRY
C***********************************************************************
      COMMON/INPUT/BH,BL,BW,VFA,SA,WRATIO,SRATIO,NROOML,NROOMS,MENU1
      COMMON/WIND/DIR,ORIENT,AI,AO,CD,CPW,CPL,DP,SFACE,LFACE,VZZ,V,
     +          PATH,RH,RM,RSA,SALF,SASF,SUM,SUML,SUMS,NROOM,FACE,P,SIDES
C     THIS SUBROUTINE SELECTS ONE OF THE FOLLOWING SUBROUTINES
C     CONTAINING WIND PRESSURE DISTRIBUTION BASED ON THE
C     BUILDING'S GEOMETRY.
C
      GO TO 646
  640 WRITE(6,645)
  645 FORMAT(1X,'THIS PROGRAM IS LIMITED TO RECTILINEAR BUILDINGS'
     + /1X,'WITH A HEIGHTH LESS THAN SIX TIMES THE WIDTH AND A'
     + /1X,'LENGTH LESS THAN 4 TIMES THE WIDTH.')
C
      PRINT(6,*) 'ENTER THE BUILDING HEIGHT (ROUND TO
     +              NEAREST TENTH OF A FOOT).'
      READ(5,*) BH
C
      PRINT(6,*) 'ENTER THE BUILDING LENGTH (ROUND TO
     +              NEAREST TENTH OF A FOOT).'
      READ(5,*) BL
C
      PRINT(6,*) 'ENTER THE BUILDING WIDTH (ROUND TO
     +              NEAREST TENTH OF A FOOT).'
      READ(5,*) BW
C
C     RATIO OF HEIGHTH TO WIDTH
C
  646 HEIGHT=(BH/BW)
C
C     RATIO OF LENGTH TO WIDTH
C
      LENGTH=(BL/BW)
C
      IF (HEIGHT .LT. .5) GO TO 650
      IF (HEIGHT .LT. 1.15) GO TO 660
      IF (HEIGHT .LT. 6) GO TO 670
      GO TO 640
C
  650 IF (LENGTH .LT. 1.15) CALL WNDSUB4
      IF (LENGTH .LT. 1.15) GO TO 690
      IF (LENGTH .LT. 4.) CALL WNDSUB5
      IF (LENGTH .LT. 4.) GO TO 690
      GO TO 640
C
  660 IF (LENGTH .LT. 1.15) CALL WNDSUB6
      IF (LENGTH .LT. 1.15) GO TO 690
      IF (LENGTH .LT. 4.)  CALL WNDSUB7
      IF (LENGTH .LT. 4.) GO TO 690
      GO TO 640
C
  670 IF (LENGTH .LT. 1.15) CALL WNDSUB8
      IF (LENGTH .LT. 1.15) GO TO 690
      IF (LENGTH .LT. 4.)  CALL WNDSUB9
      IF (LENGTH .LT. 4.) GO TO 690
      GO TO 640
C
  690 RETURN
      END
```

FIGURE C.6
Listing of SUBROUTINE GEOMTRY.

angles of zero and ninety degrees to the building's long face. The appropriate coefficients are selected for each iteration based on the wind incidence angle (see Section A.6.1).

C.3 Wind Pressure Calculations

An algorithm in subroutine WIND (Figure C.7) calculates the area of opening and the average velocity at each opening that is necessary to restore thermal comfort for hot and humid climate conditions. The equations used for both calculation follows:

$$A = (CPW - CPL) * V^2 \qquad \text{(Equation C.1)}$$

$$RM = \frac{1}{CD^2 * AO^2} \qquad \text{(Equation C.2)}$$

(Calculated in subroutines WNDAT1 and WNDAT2)

$$SUM = RM_1 + RM_2 + \dots + RM_N \qquad \text{(Equation C.3)}$$

(Calculated in subroutines ROOM1 and ROOM2)

$$VZZ = ABS\left(\frac{\frac{A}{SUM}}{AO}\right) \qquad \text{(Equation C.4)}$$

WHERE:

CPW = pressure coefficient of building's windward side

CPL = pressure coefficient of building's leeward side

V = reference wind speed

```
C*********************************************************************
      SUBROUTINE WIND
C*********************************************************************
C
      COMMON/INPUT/BH,BL,BW,VFA,SA,WRATIO,SRATIO,NROOML,NROOMS,MENU1
      COMMON/WIND/DIR,ORIENT,AI,AO,CD,CPW,CPL,DP,SFACE,LFACE,VZZ,V,
     +       PATH,RH,RM,RSA,SALF,SASF,SUM,SUML,SUMS,NROOM,FACE,P,SIDES
      COMMON/BOTH/AIT,AITM,AOT,DT,ITYPE,R,TEMP,TEMPI,VZ,ANGLE,SOLVE
C
C
C
C     THIS SUBROUTINE DETERMINES: 1) THE TOTAL AREA OF INLETS
C     AND OUTLETS NEEDED TO PROVIDE THERMAL COMFORT
C     WITH THE GIVEN CLIMATIC CONDITIONS AND INTERNAL
C     ARRANGEMENT OF SPACES OR 2) THE AIR FLOW GENERATED BY WIND
C     ON OPENING CONFIGURATIONS SPECIFIED BY THE USER.
C
      ITYPE='WIND'
      TEMPC=TEMP
C
C***************
C     EQUATION
C***************
C
      IF (TEMP .GT. TEMPC) TEMPC=TEMP
C
      IF (V .GT. 300.) V=300.
C
      A=((CPW-CPL)*.5)*(V**2.)
C
      IF (SOLVE .EQ. 2) GO TO 360
C
C     THIS PROGRAM IS LIMITED TO A MAXIMUM AREA OF OPENING
C     OF 30% THE BUILDINGS SURFACE AREA WHICH IS APPROXIMATELY
C     40% OF THE ROOM'S SECTIONAL AREA. OPENING SIZES ARE
C     INCREASED BY 5% OF THE ROOM'S SECTIONAL AREA UNTILL
C     THE MAXIMUM OPENING SIZE IS REACHED OR WHEN THE
C     ALGORITHM SOLVES FOR A VELOCITY THAT WILL INDUCE
C     THERMAL COMFORT.
C
      DO 350 NN=1,8
          P=(.05*NN)
          SUM=0
C
          IF (SIDES .EQ. 2) GO TO 310
          IF (PATH .LE. 2.) GO TO 310
C
          NROOM=NROOMS
          RSA=SASF
          AO=(SASF*P)
C     PRINT(6,*) 'AO=',AO,' RSA=',RSA
          CALL ROOM2
          GO TO 320
C
  310     NROOM=NROOML
          RSA=SALF
          AO=(SALF*P)
C     PRINT(6,*) 'AO=',AO,' RSA=',RSA
          CALL ROOM2
      PRINT(6,*)'A=',A,' SUM=',SUM,' AO=',AO
```

FIGURE C.7
Listing of SUBROUTINE WIND.

```
C
  320 IF(SUM .EQ. 0) GO TO 390
C
          VZZ=ABS((A/SUM)/AO)
C
C     TEST
C
           AOT=AO
           AIT=AO
           CALL REDUCE
           IF (VZZ .GE. VZ) GO TO 390
C
  350 CONTINUE
      GO TO 390
C
  360 IF (SIDES .EQ. 2) GO TO 370
      IF (AI .LE. 4.5) GO TO 370
C
      SUM=SUMS
      AOT=SFACE/2
      AIT=SFACE/2
      GO TO 380
C
  370 SUM=SUML
      AOT=LFACE/2
      AIT=LFACE/2
C
C     PRINT(6,*)'A=',A,' SUM=',SUM,' AO=',AO
C
  380 IF (SUM .EQ. 0) GO TO 390
      VZZ=ABS((A/SUM)/AO)
C
      CALL REDUCE
C
  390 RETURN
      END
C
```

FIGURE C.7 (cont.)

CD = Opening discharge coefficient

AO = Area of opening

Vzz = Average air velocity at each opening

If the user specifies for NATVENT to test the performance of the opening sizes selected, the average air velocity at each opening is calculated and compared to the velocity needed to restore thermal comfort. If the user specifies for NATVENT to calculate the opening sizes that maximize natural ventilation use, an algorithm in WIND assigns an opening size of five percent of the rooms sectional area. If the resulting ventilation rate is less than the air velocity needed to restore thermal comfort, the opening size is increased five percent. These iterations continue until either an opening size that induces adequate ventilation is determined or the maximum area of opening is reached. Since program NATVENT uses pressure coefficients from a solid surface, the opening areas are limited to thirty percent of the building's surface which is approximately forty percent of the room's sectional area.

C.4 Wind Tunnel Instrumentation

Further development of program NATVENT should include comparison of results from wind tunnels. The following sections discuss wind tunnel instrumentation to be used for this purpose.

C.4.1 Wind Tunnel Types; Requirements for Studying Natural Ventilation. There are two basic types of wind tunnels:

A. The closed circuit (Figure C.8a); and

B. The open circuit (Figure C.8b) [48].

Since there is no inlet suction or outlet pressure in the closed circuit

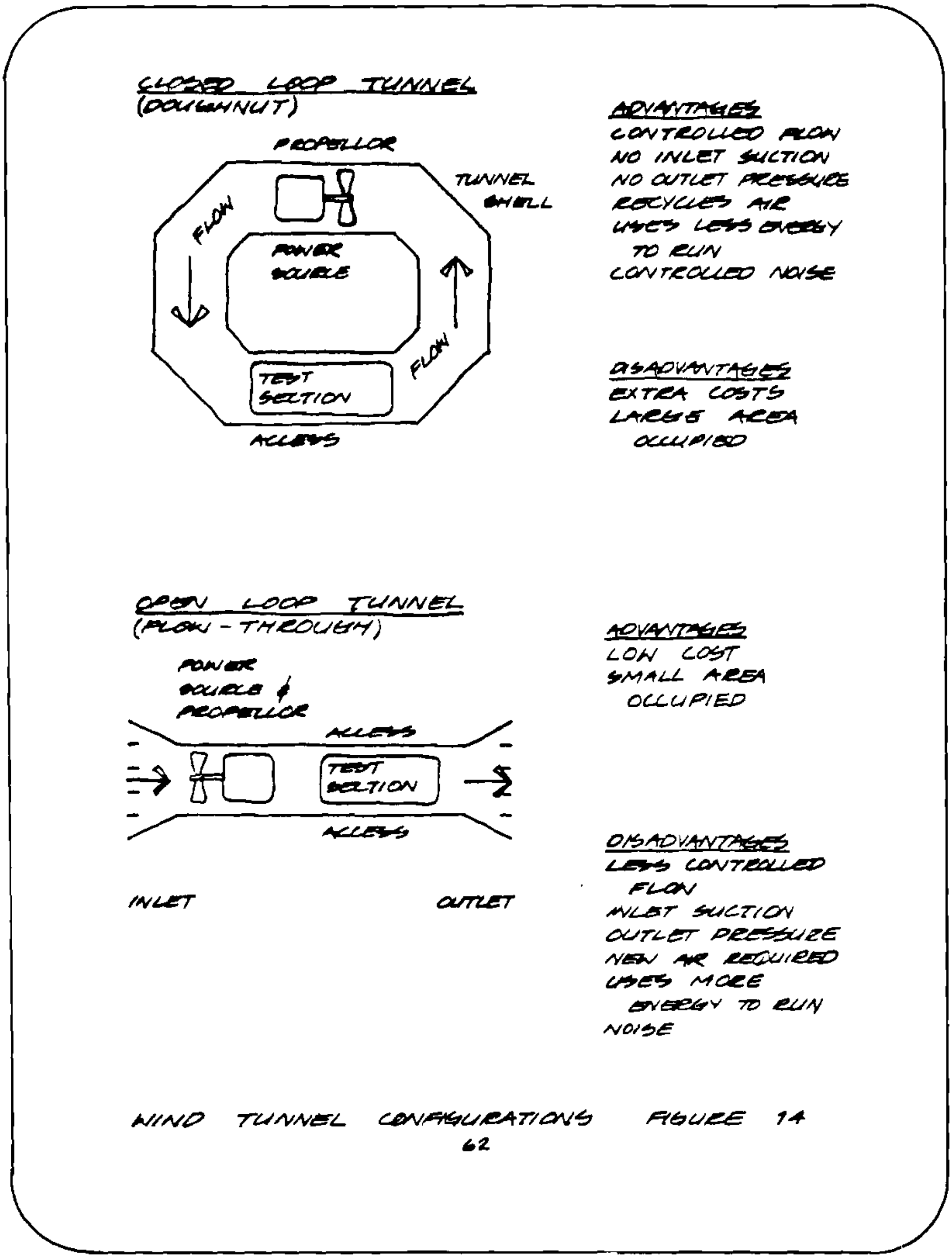


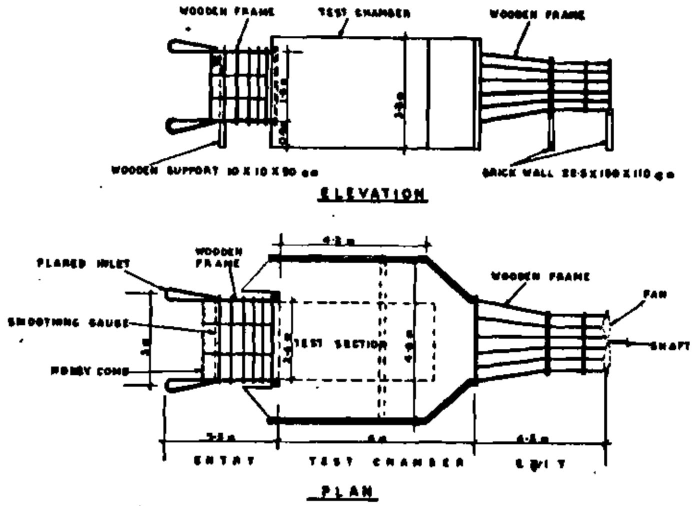
FIGURE C.8

Wind tunnel types.

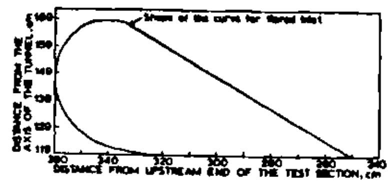
tunnel, one can obtain a much more controlled flow and a lower noise level than from the open circuit tunnel, the recycling of air also results in lower energy levels. Unfortunately the higher capital costs and the larger area occupied by the closed circuit tunnel is often restrictive.

For the purposes of natural ventilation study, the size of the test section is of greatest importance. Since models of fair size are necessary for the simulation of airflow patterns in and around buildings, the test section should be as large as possible. Model blockage should be kept to less than 3% of the wind tunnel cross section to avoid distorted measurements [49]. For convenience of measurement, the models should be easily accessible while under test. Furthermore, the air stream in the test section should be free from turbulence and local variations. It should also be possible to produce vertical velocity gradient similar to that of natural wind over different terrains. The set-up should be usable for qualitative as well as quantitative investigations. Setting the turbulence factor and the periodicity of flow is only necessary for quantitative studies. As qualitive studies are conducted at very low speeds and quantative ones at comparatively higher speeds. The speed of the air stream in the tunnel should be variable. The construction details of an open circuit wind tunnel that meets these requirements has been described by Ishwar Chand [50] (Figure C.9)

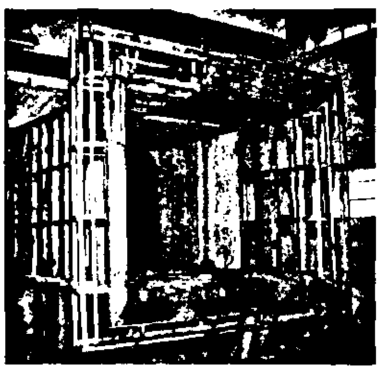
<u>C.4.2 Simulation of the Velocity Gradient.</u> One of the problems of early wind tunnel tests was the difficulty in simulating the velocity gradient of wind and the boundary conditions of the terrain. The simulation of natural wind and a turbulent boundary layer necessitated a



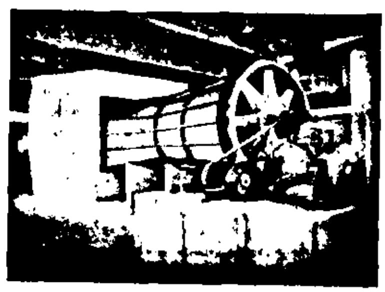
Plan and elevation of the wind tunnel



– Shape of the curve for flared inlet



Bell mouth entry under construction



Mechanical transmission system for varying the speed of the fan

FIGURE C.9

A low speed wind tunnel for studying natural ventilation in buildings described by Ishwar Chand.

large test section with randomly and evenly spaced elements to create a long fetch with the appropriate tunnel floor roughness (Figure C.10).

D.E. Sexton of the building research station, England, simplified the velocity gradient problem by placing a series of horizontal slats at the tunnel entrance. The spacing could be varied so that the slats progressively separated above ground level creating the desired velocity gradient [11]. The primary advantage to Sexton's invention was that capital cost could be lowered because the system could be adopted to any wind tunnel size, the test chamber could be smaller, and the tedious time consuming model making of the roughness elements could be eliminated.

Several active and passive devices for simulating earth surface winds have been developed from Sexton's inventions [51,52,53]. Passive devices range from solid trips, to rods and screens. Active devices include co-flowing jets [54] counterflowing jets [55], normal flowing jets [56], and horizontal cross jets [57]. Active devices are more appropriate for more elaborate wind tunnels with large test sections. However, if the test section is within a few diameters of the tunnel entrance, a passive device could be used at less cost.

C.4.3 Instrumenetation for Velocity Coefficient Method. Instruments for wind tunnel measurements can be classified according to the type of turbulent levels which they best monitor. Since in natural ventilation studies require a range of conditioned study, where low wind speeds, moderate turbulence levels, or high turbulence levels may exist, it is important to know which instruments are most appropriate.

C.4.3.1 Low Wind Speed. Because of the friction on air movement through openings and around interior partitions, air velocities will always be less than the free wind speeds upstream from the inlets.

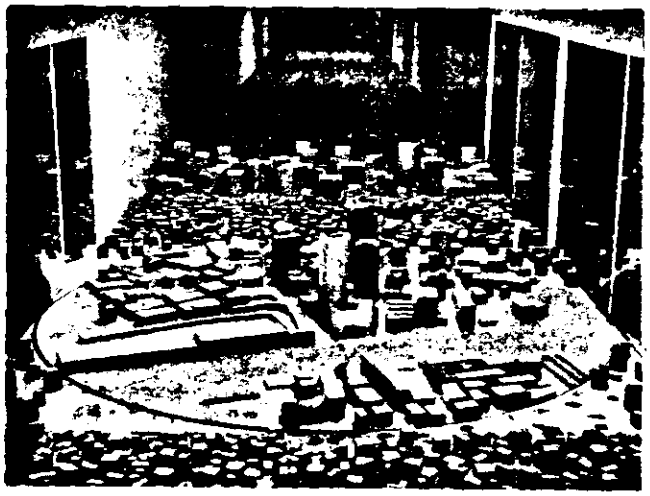


FIGURE C.10

Upstream view of the University of Western Ontario Boundary Layer Wind Tunnel with a model of a Tall building and its "proximity" in the foreground.

Therefore, if windspeeds are low or if the inlets are shielded by adjacent structures, special instrumentation is needed to measure the lower internal air speeds. The portable Ion Discharge Anemometer can be used for accurate measurements of low wind speeds; however, it is unsuitable for unsteady measurements. Other methods are available for measuring sporadic velocities; unfortunately, data reduction is much more complex [43].

C.4.3.2 Moderate Turbulence Levels. Moderate turbulence levels are most common and desirable for naturally ventilated buildings. It has been found in full scale studies [44] that actual ventilation rates were much higher as a result of turbulence than theory suggested for any wind incidence angle other than those normal to the buildings inlets and outlets.

The instrumentation required to monitor moderate turbulence levels in wind tunnels must be capable of measuring the gradient speed and determining the mean and turbulent flow properties within the boundary layer. For these purposes, pressure probe techniques [58] and hot wire techniques, are more than adequate. Fluidic anemometers [59] may also be used even though most available ones are too large for the geometric scales that are commonly used. Laser velocimetry is another method by which moderate turblence levels may be monitored. However, because of capital cost and the complexity of laser velocimetry, hot wire techniques and annemometry are recommended [43].

C.4.3.3 High Turbulence Levels. The least desirable turbulence level for naturally ventilated buildings is that found near the ground in street canyons. Besides needing a control for gusting to prevent papers from being blown around the room, the problems of high turbulence levels would also be accompanied with the problem of noise and air pollution from street traffic.

The instrumentation required to monitor high turbulence levels must be capable of monitoring the instantaneous flow reversals and the fluctuating wind speeds near the surface in a turbulent boundary layer. Single-ended hot film probes extended upward above ground can be used to measure air velocities at points of interest (Figure C.11) [43]. Since hot film probes are limited to air speed measurements, small wind vanes or flags are commonly used simultaneously to monitor wind direction [60]. A typical image of time exposure photographs of the flags will show a circle that indicates the degree of fluctation with a bright pie shaped section that indicates the prevailing wind direction. Smoke studies and shadow graphs of helium plumes may also be used for recording air movement. Such flow visualization techniques are more informative of wind flow regimes than small wind vanes. Because of simplicity in use and informative value, smoke studies are often preferred.

C.4.4 Instrumentation for Developing Pressure Coefficients. The optimum instrumentation for pressure measurement for small areas must, (1) provide sufficient dynamic response, (2) adequately measure low pressures (+2.5 PSI), and (3) be capable of measuring several surface points over a short time span. The dynamic response of several surface points have often been measured simultaneously using several standard scanivalves in parallel, each having a pressure switch capable of handling 48 different pressure inputs [43]. Recently differential transducers with high sensitivity and high natural frequency suitable for use in scanivalues have become available.

Since the model size is dictated by the scaling of the atmospheric

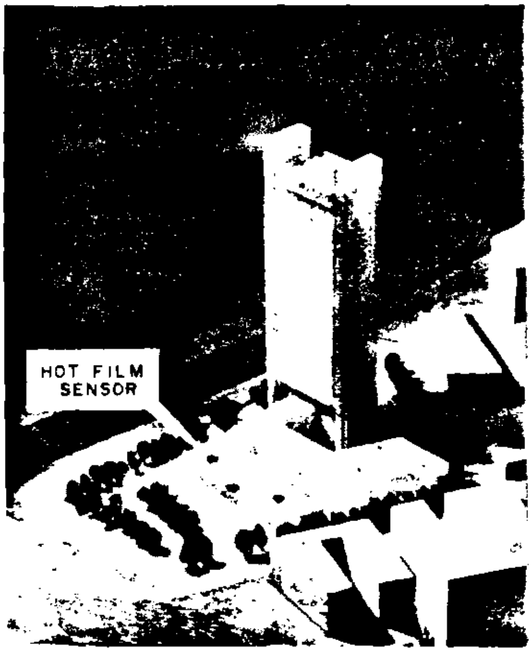


FIGURE C.11

Typical Plaza Wind Speed Measuring Instrumentation.

boundary layer and tunnel blockage of less than 3%, the bulk of the instrumentation should be outside the test section. Typical lengths of tubes joining the surface pressure taps to the pressure switch outside the test section is approximately two feet. Tubing length should be kept at a minimum because frequency response drops with increasing lengths.

APPENDIX D

DATA FILE

D.1 Atlanta, Georgia Climate Data

```
1   JAN
2   35.,67.,6.,29.
3   40.,57.,4.,30.
4   48.,42.,5.,31.
5   53.,32.,7.,33.
6   56.,25.,6.,31.
7   58.,22.,5.,31.
8   60.,21.,5.,23.
9   61.,21.,7.,30.
10  61.,20.,7.,26.
11  57.,26.,7.,26.
12  FEB
13  29.,75.,6.,30.
14  31.,36.,10.,30.
15  36.,50.,9.,30.
16  38.,46.,10.,30.
17  40.,41.,9.,30.
18  40.,41.,11.,28.
19  40.,41.,12.,28.
20  39.,45.,9.,29.
21  38.,48.,11.,29.
22  37.,50.,6.,30.
23  MAR
24  45.,74.,16.,28.
25  43.,71.,17.,28.
26  44.,71.,11.,30.
27  45.,68.,15.,30.
28  44.,71.,14.,30.
29  43.,73.,16.,28.
30  42.,76.,16.,29.
31  41.,70.,16.,29.
32  41.,70.,15.,29.
33  40.,70.,16.,29.
34  APR
35  70.,57.,8.,23.
36  74.,52.,9.,22.
37  75.,50.,11.,22.
38  78.,49.,8.,21.
39  78.,45.,9.,24.
40  79.,42.,,9.,22.
41  80.,42.,10.,21.
42  79.,45.,10.,18.
43  79.,45.,10.,18.
44  78.,47.,7.,18.
45  MAY
46  75.,58.,8.,4.
47  77.,56.,9.,4.
48  80.,52.,8.,4.
49  82.,53.,6.,6.
50  83.,49.,7.,4.
51  84.,46.,7.,4.
52  85.,40.,5.,8.
53  85.,36.,5.,4.
54  84.,38.,3.,6.
55  84.,43.,7.,6.
56  JUNE
57  86.,53.,6.,32.
58  89.,50.,5.,36.
59  91.,49.,5.,33.
60  93.,46.,6.,34.
61  92.,45.,8.,1.
62  95.,41.,8.,32.
63  94.,47.,5.,25.
64  95.,43.,5.,25.
65  95.,43.,5.,32.
66  85.,61.,12.,24
67  JULY
68  76.,85.,6.,30.
69  78.,77.,7.,26.
70  78.,77.,5.,32.
71  78.,77.,4.,32.
72  80.,74.,5.,30.
73  80.,77.,6.,35.
74  82.,72.,8.,32.
75  83.,67.,6.,32.
76  83.,67.,6.,30.
77  83.,65.,6.,30.
78  AUG
79  72.,97.,2.,12.
80  77.,88.,3.,13.
81  81.,82.,4.,12.
82  83.,77.,7.,12.
83  83.,74.,7.,10.
84  84.,72.,9.,11.
85  85.,70.,7.,15.
86  82.,67.,8.,4.
87  84.,70.,9.,7.
88  83.,70.,7.,11.
89  SEPT
90  66.,93.,8.,6.
91  68.,87.,7.,4.
92  70.,81.,8.,4.
93  74.,74.,7.,6.
94  76.,67.,7.,5.
95  77.,64.,6.,6.
96  77.,64.,6.,7.
97  76.,67.,6.,8.
98  77.,62.,5.,4.
99  75.,64.,5.,4.
100 OCT
101 47.,61.,4.,21.
102 55.,45.,6.,23.
103 60.,35.,10.,24.
104 62.,30.,7.,21.
105 64.,29.,8.,18.
106 67.,28.,5.,20.
107 67.,28.,8.,20.
108 68.,29.,10.,24.
109 67.,28.,9.,24.
110 63.,40.,6.,24.
111 NOV
112 38.,73.,8.,28.
113 42.,60.,13.,31.
114 44.,53.,13.,30.
115 45.,47.,10.,31.
116 47.,41.,11.,29.
117 47.,36.,11.,28.
118 46.,33.,12.,30.
119 44.,31.,10.,30.
120 42.,32.,10.,30.
121 38.,39.,12.,30.
122 DEC
123 39.,51.,5.,8.
124 40.,53.,5.,8.
125 41.,55.,3.,8.
126 41.,49.,5.,8.
127 40.,44.,8.,8.
128 40.,44.,8.,8.
129 40.,44.,7.,7.
130 39.,44.,7.,9.
131 39.,40.,8.,8.
132 38.,43.,5.,8.
```

FIGURE D

Listing of local hourly (9:00 - 18:00) dry bulb temperature, (°F), relative humidity, wind speed (knots), and wind direction (tenths of a degree clock wise from north) for Atlanta, Georgia.

APPENDIX E

PROGRAM LISTING

```
      PROGRAM NATVENT (INPUT,OUTPUT,DATIN,DATOUT,TAPE5=INPUT,
     +   TAPE6=OUTPUT,TAPE1=DATIN,TAPE2=DATOUT)
C
      COMMON/INPUT/BH,BL,BW,VFA,SA,WRATIO,SRATIO,NROOML,NROOMS,MENU1
      COMMON/STACK/VOT,VOTC,CF,AITW,AOTW,AITSS,AOTSS,G,DV,TEMPC,IFLOOR
      COMMON/WIND/DIR,ORIENT,AI,AO,CD,CFW,CFL,DP,SFACE,LFACE,VZZ,V,
     +        PATH,RH,RM,RSA,SALF,SASF,SUM,SUML,SUMS,NROOM,FACE,P,SIDES
      COMMON/BOTH/AIT,AITM,AOT,DT,ITYPE,R,TEMP,TEMPI,VZ,ANGLE,SOLVE
      COMMON/COMFORT/RADENTW,RADENTS,ACTIVE,CLO
C
C
      WRITE(6,5)
    5 FORMAT(1X,'*****************************************************'
     + /1X,'              A NATURAL VENTILATION MODEL',
     +/1X,'                   BY DAVE NUTT 1981',
     +/1X,       '*****************************************************')
C
C
C     THIS FORTRAN PROGRAM CHECKS THE YEARLY PATTERN OF
C     TEMPERATURE, WIND VELOCITY,AND WIND DIRECTION TO DETERMINE
C     IF NATURAL VENTILATION OCCURS BY THE 'STACK EFFECT' OR
C     BY WIND PRESSURE. THE PROGRAM THEN PROCEEDS TO DETERMINE
C     THE AREA OF OPENINGS NEEDED TO PRODUCE THE DESIRED AIR FLOW
C     FOR THERMAL COMFORT.FROM THE OUTPUT THE USER CAN SELECT THE
C     OPENING SIZE FOR WINTER AND SUMMER CONDITIONS THAT MAXIMIZES
C     THE NUMBER OF HOURS PER YEAR THAT THERMAL COMFORT
C     IS ACHIEVED.
C
C
C*********************************************************************
C  EQUATION 1   VARIABLE LIST   DEFINITION
C*********************************************************************
C
C                         VT      FACTOR WHICH DETERMINES
C                                 THE VENTILATION TYPE
C                         V       VELOCITY (FT/SEC**2)
                          G       =32.2
C                                 GRAVITY (32.2 FT/SEC**2)
C                         BH      BUILDING HEIGHT (FT)
C                         DT      INSIDE MINUS OUTSIDE TEMP.
                          U       =((2.*10)**3.)
C                                 CONSTANT MULTIPLIED BY DT
C                         TEMP    OUTSIDE TEMPERATURE
C                         TEMPC   INSIDE TEMPERATURE
                          TEMPI= 0
C                                 ADJUSTMENTS FOR COMFORT PARAMETERS
C                         RH      RELATIVE HUMIDITY
C                         V       WIND SPEEDS
C                         DIR     WIND DIRECTION
C
C
C*********************************************************************
C  EQUATION 2   VARIABLE LIST   DEFINITION
C*********************************************************************
C
C                         AITW    TOTAL AREA OF INLETS (SQ.FT.)
C                                 WINTER CONDITIONS
C                         AOTW    TOTAL AREA OF OUTLETS (SQ.FT.)
C                                 WINTER CONDITIONS
C                         AITSS    TOTAL AREA OF INLETS (SQ.FT.)
C                                 SUMMER STACK EFFECT
C                         AOTSS    TOTAL AREA OF OUTLETS (SQ.FT.)
```

FIGURE E
Listing of PROGRAM NATVENT.

```
      C                         VOT     REQUIRED VENTILATION RATE
      C                                 (FT/SEC**2.)
      C                         CF      CORRECTION FACTOR
      C                                 (INLET/OUTLET)
      C                         DV      DISTANCE VERTICALLY BETWEEN
      C                                 INLETS AND OUTLETS
      C                         DT      INSIDE MINUS OUTSIDE TEMP.
      C                         R       RATIO OF LARGER TO
      C                                 SMALLER OPENINGS
                                RADENTW=0.
      C                                 EFFECT OF MEAN RADIANT TEMP.
      C                                 WINTER CONDITIONS
                                RADENTS=0.
      C                                 EFFECT OF MEAN RADIANT TEMP.
      C                                 SUMMER CONDITIONS
                                ACTIVE =0.
      C                                 EFFECT OF ACTIVITY LEVEL
                                CLO    =0.
      C                                 EFFECT OF CLOTHING
      C                                 INSULATION VALUE
      C                         WRATIO  WINTER RATIO OF
      C                                 OUTLETS TO INLETS
      C
      C
      C*******************************************************************
      C  EQUATION 3   VARIABLE LIST   DEFINITION
      C*******************************************************************
      C
      C                         BL      BUILDING LENGTH
      C                         BW      BUILDING WIDTH
      C                         VFA     VENTILATION RATE FOR
      C                                 FRESH AIR REQUIREMENTS
      C                         VTC     VENTILATION RATE FOR
      C                                 THERMAL COMFORT
      C                         VZ      VENTILATION RATE FOR FRESH AIR
      C                                 AND THERMAL COMFORT REQUIREMENTS
      C                         ANGLE   ORIENTATION ANGLE OF OPENINGS
      C                         ORIENT  ANGLE/10
      C                                 CLOCKWISE FROM NORTH
      C                         SIDES   NUMBER OF SIDES THAT THE
      C                                 BUILDING HAS OPENINGS
      C                         AITM    MAXIMUM AREA FOR BUILDING'S INLETS
      C                                 (SQ.FT.)
      C                         P       PERCENT OF WALL OPENING
      C                                 TO ROOM SIZE
      C                         NROOML  NUMBER OF ROOMS IN SERIES
      C                                 PERPENDICULAR TO SHORT FACE
      C                         NROOMS  NUMBER OF ROOMS IN SERIES
      C                                 PERPENDICULAR TO LONG FACE
      C                         AO      AREA OF OPENINGS
      C                         AIT     AREA OF INLETS
      C                         AOT     AREA OF OUTLETS
      C                         LFACE   AREA OF OPENINGS (PER FLOOR) ON
      C                                 THE TWO LONG FACES OF THE BLDG.
      C                         SFACE   AREA OF OPENINGS (PER FLOOR) ON
      C                                 THE TWO SHORT FACES OF THE BLDG.
      C                         SALF    SECTIONAL AREA OF SPACE (SQ.FT.)
      C                                 PERPENDICULAR TO LONG FACE
      C                         SALS    SECTIONAL AREA OF SPACE (SQ.FT.)
      C                                 PERPENDICULAR TO SHORT FACE
      C                         RSA     ROOM SECTIONAL AREA
      C                         RSA1      "       "       "   ROOM-1
      C                         RSAN      "       "       "   ROOM-N
      C                         CD      DISCHARGE COEFFICIENT
      C                         DIR     DIRECTION OF WIND AS
      C                                 LISTED IN CLIMATIC DATA
```

```
C                            DIRNEW WIND ANGLE IN RESPECT
C                                   TO THE INLETS
C                            AI     ANGLE OF INCIDENCE
C                                   OR DIRNEW * 10
C                            CPW    PRESSURE DISTRIBUTION DATA
C                                   OF WINDWARD SIDE
C                            CPL    PRESSURE DISTRIBUTION DATA
C                            DP     DIFFERENCE IN PRESSURE
C                                   ACROSS THE BUILDING'S SURFACE
C                            SRATIO SUMMER RATIO OF
C                                   OUTLETS TO INLETS
C                            SA     SURFACE AREA PER FLOOR
C                                   OF BUILDING'S SKIN
C
C
C*****************************************************************
C
C
      CALL INPUT
C
C
   20 WRITE(6,30)
   30 FORMAT (1X,'*************************************************',
     + /1X,'                 WOULD YOU LIKE TO...',
     + /
     + /1X,'      1)   CHANGE INPUT',
     + /1X,'      2)   RUN PROGRAM',
     + /1X,'      3)   STOP PROGRAM AND SEND OUTPUT TO LINEPRINTER',
     + /
     + /1X,       '*************************************************',
     + /1X,'      (TYPE 1,2,OR 3)')
C
      READ (5,*) MENU1
C
      IF (MENU1 .EQ. 1) CALL CHANGE
      IF (MENU1 .EQ. 1) GO TO 20
      IF (MENU1 .EQ. 2) GO TO 40
      IF (MENU1 .EQ. 3) GO TO 190
      IF (MENU1 .LE. 1 .OR. MENU1 .GE. 3) GO TO 35
      GO TO 40
   35 PRINT (6,*) 'YOU SCREWED UP! TRY AGAIN.'
      GO TO 20
C
C
C*****************************************************************
C     PRINT USER'S INPUT
C*****************************************************************
C
C
C     OUTPUT TO LINEPRINTER
C
C
   40 IF (SOLVE .EQ. 2) GO  TO 50
C
      PRINT(2,*) 'THE COMPUTER WILL SOLVE FOR OPENING SIZES.'
      GO TO 52
C
   50 PRINT(2,*)'THE COMPUTER WILL TEST THE OPENING SIZE YOU SELECTED'
C
C
   52 WRITE(2,55)
   55 FORMAT //1X,'**************************************************'
     + /7X,            'INPUT FOR BUILDING'S EXTERNAL GEOMETRY'
     +/1X,       '**************************************************')
C
   60 PRINT(2,*) 'THE BUILDING HEIGHT IS ',BH,' FT.'
```

```
C
      PRINT(2,*) 'THE BUILDING LENGTH IS ',BL,' FT.'
C
      PRINT(2,*) 'THE BUILDING WIDTH IS ',BW,' FT.'
C
      PRINT(2,*)'THE AREA PER FLOOR OF THE BUILDING'S SKIN IS ',
     + SA,' SQ.FT.'
C
      PRINT(2,*)'THE ORIENTATION OF THE BUILDING'S LONG FACE IS ',
     + ANGLE,' DEG.'
C
C
      WRITE(2,62)
   62 FORMAT(1X,'*************************************************',
     + /7X,             'INPUT FOR BUILDING'S INTERNAL GEOMETRY'
     +/1X,        '*************************************************')
C
      PRINT(2,*) 'THERE ARE ',NROOML
     + ,' ROOMS PERPENDICULAR TO THE LONG FACE OF THE BUILDING.'
C
      IF (SIDES .EQ. 2) GO TO 63
C
C
      PRINT(2,*) 'THERE ARE ',NROOMS
     + ,' ROOMS PERPENDICULAR TO THE SHORT FACE OF THE BUILDING.'
C
C
C
   63 IF (SOLVE .EQ. 2) GO TO 64
C
C
C*****************************************************************
C     INPUT IF COMPUTER IS SOLVING FOR OPENING SIZES
C*****************************************************************
C
C
      PRINT(2,*) 'THE SECTIONAL AREA OF THE ROOM(S) PERPENDICULAR
     +                  TO THE LONG FACE IS ',SALF,' SQ.FT.'
C
      IF (SIDES .EQ. 2) GO TO 64
C
      PRINT(2,*) 'THE SECTIONAL AREA OF THE ROOM(S) PERPENDICULAR
     +                  TO THE SHORT FACE IS ',SASF,' SQ.FT.'
C
C
   64 WRITE(2,65)
   65 FORMAT(1X,'*************************************************',
     + /12X,             'INPUT FOR FRESH AIR REQUIREMENTS'
     +/1X,        '*************************************************')
C
      PRINT(2,*) 'THE BUILDINGS REQUIRED VENTILATION RATE IS ',VOT
     + ,' CFM.'
C
      PRINT(2,*)'AIRFLOW THROUGH THE ROOM WITH THE MAXIMUM FRESH AIR
     +   REQUIREMENTS IS ',VFA,' FPM.'
C
      IF (RADENTW .EQ. 0 .AND. RADENTS .EQ. 0 .AND.
     +     ACTIVE .EQ. 0 .AND. CLO .EQ. 0) GO TO 75
C
      WRITE(2,70)
   70 FORMAT(1X,'*************************************************',
     + /1X,             'INPUT FOR COMFORT PARAMETERS'
     +/1X,        '*************************************************')
C
C
      PRINT(2,*) 'RADIATION CHANGES THE ROOM TEMPERATURE ',
```

```
      + RADENTW,' DEG. DURING WINTER CONDITIONS.'
C
       PRINT(2,*) 'RADIATION CHANGES THE ROOM TEMPERATURE ',
      + RADENTS,' DEG. DURING SUMMER CONDITIONS.'
C
       PRINT(2,*) 'THE ACTIVITY LEVEL CHANGES THE ROOM TEMPERATURE ',
      + ACTIVE,' DEG.'
C
       PRINT(2,*) 'THE CLOTHING LEVEL CHANGES THE ROOM TEMPERATURE ',
      + CLO,' DEG.'
C
C
    75 WRITE(2,80)
    80 FORMAT(1X,'*************************************************',
      + /12X,'              INPUT FOR OPENINGS'
      +/1X,         '*************************************************')
C
       PRINT(2,*) 'OPENINGS ARE ON ',SIDES,' SIDES OF THE BUILDING.'
C
       PRINT(2,*)'THE MAXIMUM AREA FOR THE INLET IS ',AITM,' SQ.FT.'
C
       PRINT(2,*)'THE VERTICAL DISTANCE BETWEEN OPENINGS IS ',DV,' FT.'
C
       PRINT(2,*) 'THE RATIO OF OPENINGS IN THE WINTER IS ',WRATIO
C
       PRINT(2,*) 'THE RATIO OF OPENINGS IN THE SUMMER IS ',SRATIO
C
C
       IF (SOLVE .EQ. 1) GO TO 100
C
C
C*****************************************************************
C      INPUT IF USER IS TESTING AN OPENING SIZE
C*****************************************************************
C
C
       PRINT(2,*) 'THE AREA OF INLETS FOR WINTER STACK EFFECT IS ',
      + AITW,' SQ.FT.'
C
       PRINT(2,*) 'THE AREA OF OUTLETS FOR WINTER STACK EFFECT IS ',
      + AOTW,' SQ.FT.'
C
       PRINT(2,*) 'THE AREA OF INLETS FOR SUMMER STACK EFFECT IS ',
      + AITSS,' SQ.FT.'
C
       PRINT(2,*) 'THE AREA OF OUTLETS FOR  STACK EFFECT IS ',
      + AOTSS,' SQ.FT.'
C
       PRINT(2,*) 'THE OPENINGS ON THE BUILDING'S 2 LONG FACES IS ',
      + LFACE,' SQ.FT.'
C
       PRINT(2,*) 'THE OPENINGS ON THE BUILDING'S 2 SHORT FACES IS ',
      + SFACE,' SQ.FT.'
C
C
C
C
C
C*****************************************************************
C      START CALCULATIONS
C*****************************************************************
C
C
C
C      ITERATIONS FOR 12 MONTHS
```

```
  100 REWIND 1
            DO 180 L=1,12
                 READ(1,141) MO
  141            FORMAT(A4)
C
                 IF (SOLVE .EQ. 1) GO TO 120
C
C
C***************
C     HEADING
C***************
C
C
  105 WRITE(2,110) MO
  110 FORMAT(///25X,'DATE',2X,A4,1X,'21'///
     +         7X,'WIND',3X,'VENT',3X,'WIND',7X,'VOLUMETRIC',
     +         2X,'TEMP',3X,'TEMP',2X,'TYPE',4X,'IS'
     + /
     +         7X,'SPEED',2X,'SPEED',2X,'INCIDENCE',3X,'AIR FLOW',
     +         3X,'AIR',4X,'AIR',4X,'OF',3X,'COMFORT'
     + /
     +         1X,'HOUR',2X,'(MPH)',2X,'(FPM)',2X,'ANGLE',8X,'(CFM)',
     +         4X,'ENTER',3X,'EXIT',2X,'VENT',2X,'ACHIEVED?')
               GO TO 142
C
  120 WRITE(2,130) MO
  130 FORMAT(///25X,'DATE',2X,A4,1X,'21'///
     +         14X,'WIND',3X,'TEMP',2X,'TEMP',2X,'WIND',6X,'TYPE',
     +         4X,'OUTLET',4X,'INLET',3X,'IS'
     + /
     +         14X,'SPEED',2X,'AIR',3X,'AIR',3X,'INCIDENCE',2X,'OF',
     +         6X,'AREA',5X,'AREA',2X,'COMFORT'
     + /
     +         8X,'HOUR',2X,'(MPH)',2X,'ENTER',1X,'EXIT',
     +         2X,'ANGLE',5X,'VENT',5X,'SQFT',5X,'SQFT',2X,'ACHIEVED'/)
C
C
C     ITERATIONS FOR 10 WORKING HOURS(9:00-18:00)
C
  142            DO 170 M=1,10
C
C     HOUR
C
                      IHR=(100*M)+800
C
C***************
C  READ DATA FL.
C***************
                      READ(1,*) TEMP,RH,V,DIR
C
C     CORRECTIONS FOR WIND DIRECTION AND OPENING
C     ORIENTATION YIELDS THE ANGLE OF INCIDENCE.
C
                      DIR=(DIR*10.)
C
                      DIRNEW=ABS(ORIENT-DIR)
C
                      IF (DIRNEW .LE. 180.) GO TO 144
C
                      DIRNEW=360.-DIRNEW
  144                 IF (DIRNEW .LE. 90.) GO TO 145
C
                      DIRNEW=ABS(180.-DIRNEW)
  145                 IF (SIDES .EQ. 2) PATH=2.
                      IF (SIDES .EQ. 2) GO TO 147
```

```
                           IF (DIRNEW .LE. 4.5) PATH=2.
                           IF (DIRNEW .LE. 4.5) GO TO 147
C
C          THE PATH OF AIRFLOW THROUGH THE BUILDING IS
C          PERPENDICULAR TO THE SHORT FACE(PATH=1.)
C
                           PATH=1.
                           DIRNEW=ABS(90.-DIRNEW)
                           IF (SOLVE .EQ. 1.) GO TO 148
C
                           SUM=SUMS
                           GO TO 148
C
C          THE PATH OF AIRFLOW THROUGH THE BUILDING IS
C          PERPENDICULAR TO THE LONG FACE(PATH=2.)
C
      147                  SUM=SUML
C
      148 AI=DIRNEW
                           CALL GEOMTRY
C
C          CONVERSION FOR WIND VELOCITIES FROM KNOTS TO MPH
C
                           V=(V*1.15)
C
C          CONVERSION FOR WIND VELOCITIES FROM MILES/HR TO FT/MIN
C
                           V=((5280.*V)/(60*60))
C
C          REDUCTION OF WIND VELOCITY FOR 80% OCCURANCE
                           V=(V/2.)
C          EFFECTIVE TEMPERATURE
                           IF(TEMP .LT. 78.) RADENT=RADENTW
                           IF(TEMP .GE. 78.) RADENT=RADENTS
                           TEMPIN=TEMPI+RADENT
                           TEMPC=TEMPIN+78
C
C          TEMPERATURE AT WHICH FRESH AIR MUST BE INDUCED BY WIND
C
                           TEMPW=(TEMPC-10)
C
C          CORRECTIONS FOR WIND VELOCITIES TO INDUCE THERMAL COMFORT
C
C          STRAIGHT LINE EQUATION
C          Y=MX+B
C          M=SLOPE(0.15)
C          X=RELATIVE HUMIDITY(RH)
C          B=DRY BULB TEMPERATURE DIFFERENTIAL(TEMP)
                           IF (RH .LT. 20) GO TO 154
C
C
      151                  VTC=((((0.15*(RH-60))+(TEMP-TEMPC)))*30.)
C
C          TEST FOR MAXIMUM AIR VELOCITY
C
                           IF (VTC .GT. 300) GO TO 154
C
C          TEST IF VELOCITY FOR THERMAL COMFORT IS
C          GREATER THAN VELOCITY FOR FRESH AIR.
C
                           VZ=VFA
                           IF (VTC .GT. VZ) VZ=VTC
C
C          CORRECTIONS FOR INSIDE TEMP. MINUS OUTSIDE TEMP.
C
                           DT=(TEMPC-TEMP)
```

```
C
C     DETERMINE IF VENTILATION OCCURS BY
C     WIND PRESSURE OR 'STACK EFFECT'.
C
                     IF (TEMP .LT. TEMPC) GO TO 152
                     IF (TEMP .GT. TEMPC .AND. V .LE. 3.5) CALL STACK
                     GO TO 153
C
  152                IF (TEMP .GE. TEMPW) CALL WIND
                     IF (TEMP .GE. TEMPW) GO TO 153
C
                     IF(DT .EQ. 0 .OR. DV .EQ. 0) CALL WIND
                     IF(DT .EQ. 0 .OR. DV .EQ. 0) GO TO 153
C
                     CALL STACK
                     GO TO 158
C
C     IS THE CALCULATED OPENING GREATER THAN THE SPECIFIED MAXIMUM?
C
  153                IF (VZZ .LT. VZ) GO TO 155
                     ANSWER='YES'
                     GO TO 160
C
  154                ITYPE='NONE'
                     ANSWER='NO'
                     VZZ=0.
                     AIT=0.0
                     AOT=0.0
                     GO TO 160
C
  155                ITYPE='MINOR'
                     ANSWER='NO'
                     AIT=AITM
                     AOT=AITM
                     GO TO 160
C
  158                ANSWER='YES'
C
  160                V=((V*(60*60))/5280.)
C
C
C*****************************************************************
C     OUTPUT
C*****************************************************************
C
C
                     IF (SOLVE .EQ. 1) GO TO 166
                     IF (TEMP .LT. TEMPW) GO TO 164
C
  162 WRITE(2,163)IHR,V,VZZ,AI,TEMP,TEMPC,ITYPE,ANSWER
  163 FORMAT(1X,I4,2X,F4.1,3X,F5.1,2X,F5.1,18X,F5.1,
     +        2X,F5.1,2X,A5,2X,A5)
                     GO TO 170
C
  164 WRITE(2,165)IHR,V,AI,VDTC,TEMP,TEMPC,ITYPE
  165 FORMAT(1X,I4,2X,F4.1,10X,F5.1,6X,F9.4,2X,
     +        F5.1,2X,F5.1,2X,A5)
                     GO TO 170
C
  166                IF (TEMP .LT. TEMPW) GO TO 168
C
      WRITE(2,167)IHR,V,TEMP,TEMPC,AI,ITYPE,AOT,AIT,ANSWER
  167 FORMAT (8X,I4,2X,F4.1,2X,F5.1,2X,F5.1,2X,F5.1,
     +         3X,A5,2X,F7.2,2X,F7.2,2X,A3)
                     GO TO 170
```

```
  168 WRITE(2,169)IHR,V,TEMP,TEMPC,AI,ITYPE,AOT,AIT
  169 FORMAT (8X,I4,2X,F4.1,2X,F5.1,2X,F5.1,2X,F5.1,
     +          3X,A5,2X,F7.2,2X,F7.2)
C
  170           CONTINUE
  180       CONTINUE
C
      GO TO 20
  190 STOP
      END
C
C
C*****************************************************************
      SUBROUTINE INPUT
C*****************************************************************
C
      COMMON/INPUT/BH,BL,BW,VFA,SA,WRATIO,SRATIO,NROOML,NROOMS,MENU1
      COMMON/STACK/VOT,VOTC,CF,AITW,AOTW,AITSS,AOTSS,G,DV,TEMPC,IFLOOR
      COMMON/WIND/DIR,ORIENT,AI,AO,CD,CPW,CPL,DP,SFACE,LFACE,VZZ,V,
     +       PATH,RH,RM,RSA,SALF,SASF,SUM,SUML,SUMS,NROOM,FACE,P,SIDES
      COMMON/BOTH/AIT,AITM,AOT,DT,ITYPE,R,TEMP,TEMPI,VZ,ANGLE,SOLVE
      COMMON/COMFORT/RADENTW,RADENTS,ACTIVE,CLO
C
C
C
  191 WRITE(6,192)
  192 FORMAT(1X,'WOULD YOU LIKE THE COMPUTER TO...'
     + /6X,'1) SOLVE FOR THE OPENING SIZES THAT WILL MAXIMIZE THE'
     + /6X,'   ANUAL HOURS OF NATURAL VENTILATION USE'
     + /1X,'OR'
     + /6X,'2) TEST THE PERFORMANCE OF THE OPENING'
     + /6X,'   SIZES SELECTED.'
     + /1X,'(TYPE 1 OR 2)')
      READ (5,*) SOLVE
C
      IF (SOLVE .EQ. 1. .OR. SOLVE .EQ. 2.) GO TO 193
      PRINT(6,*) 'YOU SCREWED UP! TRY AGAIN.'
      GO TO 191
C
  193 PRINT(6,*) 'ENTER THE BUILDING HEIGHTH (ROUND TO
     +             NEAREST TENTH OF A FOOT).'
      READ(5,*) BH
C
      PRINT(6,*) 'ENTER THE BUILDING LENGTH (ROUND TO
     +             NEAREST TENTH OF A FOOT).'
      READ(5,*) BL
C
      PRINT(6,*) 'ENTER THE BUILDING WIDTH (ROUND TO
     +             NEAREST TENTH OF A FOOT).'
      READ(5,*) BW
C
      CALL GEOMTRY
C
      PRINT(6,*) 'ENTER THE NUMBER OF FLOORS'
      READ(5,*) IFLOOR
C
C
      WRITE(6,194)
  194 FORMAT(1X,'ENTER THE DISTANCE VERTICALLY BETWEEN THE CENTERS'
     + /1X,'OF THE INLETS(GROUND FLOOR) AND THE OUTLETS(TOP FLOOR).'
     + /1X,'NOTE: IF AIR MOVEMENT BETWEEN FLOORS IS PREVENTED BY'
     + /1X,'CORRIDOR DOORS, STAIR DOORS, ETC, THE DISTANCE VERTICALLY
     + /1X,'BETWEEN POINTS OF IN-FILLTRATION AND EX-FILLTRATION'
     + /1X,'WILL BE HALF THE WINDOW HEIGHT ON THAT FLOOR.')
      READ(5,*) DV
```

```
      PRINT(6,*) 'ENTER THE ORIENTATION ANGLE OF THE BUILDING'S LONG
     + FACE CLOCKWISE FROM DUE NORTH(0. TO 360.DEGREES).'
      READ(5,*) ANGLE
      ORIENT=ANGLE
C
      PRINT(6,*)'ENTER THE BUILDING'S REQUIRED VENTILATION RATE (CFM).
     +SEE THE ASHRAE COOLING AND HEATING LOAD CALCULATION MANUAL
     +                    (PAGES 5.12 TO 5.15).'
      READ(5,*) VOT
C
      PRINT(6,*) 'ENTER THE VENTILATION RATE OF THE ROOM IN SERIES
     +             WHICH HAS THE HIGHEST VALUE.(SEE ASHRAE MANUAL)'
      READ(5,*) VFA
C
      VFA=(VFA/60)
C
  195 WRITE(6,196)
  196 FORMAT(1X,'THIS PROGRAM ASSUMES THAT:'
     + /7X,'A) THE MEAN RADIANT TEMPERATURE EQUALS 78 DEG. F.'
     + /7X,'B) THE HEAT REJECTED FROM THE BODY IS'
     + /7X,'   520 BTU/HR (OFFICE WORK)'
     + /7X,'C) THE CLOTHING INSULATION IS'
     + /7X,'   1.0 CLO (BUISNESS SUIT)'
     + //1X,'DO YOU WISH TO ADJUST ANY OF THESE COMFORT PARAMETERS'
     + /1X,'TO CHANGE THE IDEAL INDOOR TEMPERATURE FROM 78 DEG. F.?'
     + /1X,'      1) YES'
     + /1X,'      2) NO'
     + /1X,'(TYPE 1 OR 2)')
      READ(5,*) ANSR
C
      IF (ANSR .EQ. 1. .OR. ANSR .EQ. 2.) GO TO 197
      PRINT(6,*) 'YOU SCREWED UP! TRY AGAIN.'
      GO TO 195
C
  197 IF (ANSR .EQ. 2) GO TO 198
      CALL COMFORT
C
  198 SA=(2*((BH/IFLOOR)*(BL+BW)))
      PRINT(6,*) 'THE AREA PER FLOOR OF THE BUILDING'S SKIN IS ',SA
      AITM=SA*.3
C
  199 WRITE(6,200) AITM
  200 FORMAT(/1X,'THIS PROGRAM IS LIMITED TO THE CALCULATION'
     + /1X,'OF VENTILATION RATES FOR MAXIMUM OPENINGS 30 PERCENT OF'
     + /1X,'THE BUILDING'S SURFACE AREA.FOR YOUR BUILDING'
     + /1X,'THE MAX. AREA OF OPENING IS ',F9.2,' SQ.FT. PER FLOOR.'/)
C
  201 WRITE(6,202)
  202 FORMAT(1X,'HOW MANY SIDES OF THE BUILDING HAVE OPENINGS?'
     + /1X,'      1) TWO SIDES'
     + /1X,'      2) FOUR SIDES'
     + /1X,'(TYPE 1 OR 2)')
      READ(5,*) SIDES
C
      SIDES=(SIDES*2)
C
      IF (SIDES .EQ. 2. .OR. SIDES .EQ. 4.) GO TO 203
      PRINT(6,*) 'YOU SCREWED UP! TRY AGAIN.'
      GO TO 201
C
  203 PRINT(6,*) 'IF WIND PASSES THROUGH THE BUILDING PERPENDICULAR TO
     +           THE LONG FACE, WHAT IS THE NUMBER OF ROOMS IN SERIES?'
      READ(5,*) NROOML
C
      IF (SIDES .EQ. 2) GO TO 205
```

```
      PRINT(6,*) 'IF WIND PASSES THROUGH THE BUILDING PERPENDICULAR TO
     +            THE SHORT FACE, WHAT IS THE NUMBER OF ROOMS IN SERIES?'
      READ(5,*) NROOMS
C
C
  205 IF (SOLVE .EQ. 2) GO TO 210
C
C
C     INPUT IF SOLVING FOR OPENING SIZES
C
      PRINT(6,*) 'ENTER THE SECTIONAL AREA OF THE SPACE
     +                  ADJACENT TO THE LONG FACE.'
      READ (5,*) SALF
C
      IF (SIDES .EQ. 2) GO TO 206
C
      PRINT(6,*) 'ENTER THE SECTIONAL AREA OF THE SPACE
     +                    ADJACENT TO THE SHORT FACE.'
      READ (5,*) SASF
C
  206 WRITE(6,207)
  207 FORMAT(1X,'ENTER THE RATIO FOR THE LARGEST OPENINGS'
     + /1X,'TO THE SMALLEST OPENINGS WHEN THE'
     + /1X,'WINDOWS ARE CLOSED(WINTER CONDITIONS).')
      READ (5,*) WRATIO
C
  208 WRITE(6,209)
  209 FORMAT(1X,'ENTER THE RATIO FOR THE LARGEST OPENINGS'
     + /1X,'TO THE SMALLEST OPENINGS WHEN THE'
     + /1X,'WINDOWS ARE OPEN(SUMMER CONDITIONS).')
      READ (5,*) SRATIO
C
      IF(SOLVE .EQ. 1) GO TO 220
C
C
C     INPUT IF TESTING OPENING SIZES
C
C
  210 PRINT(6,*) 'ENTER THE TOTAL AREA OF INLETS (WINDOWS CLOSED)
     +             FOR THE LOWER PORTION OF THE BUILDING.'
      READ(5,*) AITW
C
      PRINT(6,*) 'ENTER THE TOTAL AREA OF OUTLETS (WINDOWS CLOSED)
     +             FOR THE UPPER PORTION OF THE BUILDING.'
      READ(5,*) AOTW
C
      IF (AITW .GE. AOTW) GO TO 212
C
      WRATIO=(AOTW/AITW)
      GO TO 214
C
  212 WRATIO=(AITW/AOTW)
C
  214 PRINT(6,*) 'ENTER THE TOTAL AREA OF INLETS (WINDOWS OPEN)
     +                  FOR THE LOWER PORTION OF THE BUILDING.'
      READ(5,*) AITSS
C
      PRINT(6,*) 'ENTER THE TOTAL AREA OF OUTLETS (WINDOWS OPEN)
     +                  FOR THE UPPER PORTION OF THE BUILDING.'
      READ(5,*) AOTSS
C
      IF (AITSS .GE. AOTSS) GO TO 216
C
      SRATIO=(AOTSS/AITSS)
      GO TO 218
```

```
  216 SRATIO=(AITSS/AOTSS)
C
  218 PRINT(6,*) 'ENTER THE TOTAL AREA OF OPENING ON THE .
     +                  TWO LONG FACES OF THE BUILDING.'
      READ(5,*) LFACE
C
      FACE=((LFACE/2)/IFLOOR)
      PRINT(6,*) 'THE OPENING AREA PER FLOOR FOR ONE LONG SIDE IS'
     + ,FACE,' SQ.FT.'
      NROOM=NROOML
      PRINT(6,*) '    SERIES OF ROOMS PERPENDICULAR TO THE LONG FACE'
      CALL ROOM1
      SUML=SUM
C
      IF (SIDES .EQ. 2) GO TO 220
      PRINT(6,*) 'ENTER THE TOTAL AREA OF OPENING ON THE
     +                   TWO SHORT FACES OF THE BUILDING.'
      READ (5,*) SFACE
C
      IF (SIDES .EQ. 2) GO TO 220
      FACE=((SFACE/2)/IFLOOR)
      PRINT(6,*) 'THE OPENING AREA PER FLOOR FOR ONE SHORT SIDE IS '
     + ,FACE,' SQ.FT.'
      NROOM=NROOMS
      PRINT(6,*) '    SERIES OF ROOMS PERPENDICULAR TO THE SHORT FACE'
      CALL ROOM1
      SUMS=SUM
C
  220 RETURN
      END
C
C*******************************************************************
      SUBROUTINE ROOM1
C*******************************************************************
C
      COMMON/WIND/DIR,ORIENT,AI,AO,CD,CPW,CPL,DP,SFACE,LFACE,VZZ,V,
     +         PATH,RH,RM,RSA,SALF,SASF,SUM,SUML,SUMS,NROOM,FACE,F,SIDES
C
C     THIS SUBROUTINE INTERACTIVELY PROMPTS THE USER FOR THE
C     AREA OF OPENINGS AND THE SECTIONAL AREA OF THE ROOMS IN SERIES
C
C
      SUM=0
      DO 265 N=1,NROOM
C
           IF (N .EQ. 1) GO TO 250
           IF (N .EQ. NROOM) GO TO 260
C
           PRINT(6,*) 'ENTER THE SECTIONAL AREA FOR ROOM-',N
           READ(5,*) RSA
C
  245      PRINT(6,*) 'ENTER THE AREA FOR OUTLET-',N
           READ(5,*) AO
           CALL WNDSUB2
           SUM=RM+SUM
           GO TO 265
C
  250      PRINT(6,*) 'ENTER THE SECTIONAL AREA FOR ROOM-1'
           READ(5,*) RSA1
C
           AO=FACE
           RSA=RSA1
           CALL WNDSUB1
           SUM=RM+SUM
           GO TO 245
```

```
  260      PRINT(6,*) 'ENTER THE SECTIONAL AREA FOR ROOM-',NROOM
           READ(5,*) RSAN
C
           AO=FACE
           RSA=RSAN
           CALL WNDSUB2
           SUM=RM+SUM
C
  265 CONTINUE
C
      RETURN
      END
C******************************************************************
      SUBROUTINE ROOM2
C******************************************************************
C
      COMMON/WIND/DIR,ORIENT,AI,AO,CD,CPW,CPL,DP,SFACE,LFACE,VZZ,V,
     +     PATH,RH,RM,RSA,SALF,SASF,SUM,SUML,SUMS,NROOM,FACE,P,SIDES
C
C
C
C     SUM=0
C     DO 240 N=1,NROOM
C
           IF (N .GT. 1.) GO TO 230
C
           CALL WNDSUB1
           SUM=RM+SUM
C
  230      CALL WNDSUB2
           SUM=RM+SUM
      PRINT(6,*) 'SUM=',SUM
C
  240 CONTINUE
C
      RETURN
      END
C******************************************************************
      SUBROUTINE COMFORT
C******************************************************************
C
      COMMON/COMFORT/RADENTW,RADENTS,ACTIVE,CLO
      COMMON/BOTH/AIT,AITM,AOT,DT,ITYPE,R,TEMP,TEMPI,VZ,ANGLE,SOLVE
C
      INTEGER OPERN,OPERN2
C
C
C
C     THIS SUBROUTINE WILL ADJUST THE INDOOR TEMPERATURE IF
C     THE MEAN RADIANT TEMPERATURE IS LESS THAN OR GREATER
C     THAN 78 DEG. F.,IF THE ACTIVITY LEVEL IS CHANGED
C     FROM OFFICE WORK, AND/OR THE CLOTHING LEVEL IS
C     CHANGED FROM 1.0 CLO.
C
  280 WRITE(6,275)
  275 FORMAT(1X,'WHICH ONE OF THE FOLLOWING COMFORT'
     + /1X,'PARAMETERS WOULD YOU LIKE TO ADJUST ?'
      + /1X,   '1)  RADIANT TEMPERATURES IN THE WINTER'
      + /1X,   '2)  RADIANT TEMPERATURES IN THE SUMMER'
      + /1X,   '3)  ACTIVITY LEVEL'
      + /1X,   '4)  CLOTHING LEVEL'
      + /1X,   '5)  NONE'
      + /1X,   '(TYPE ONE OF THE ABOVE NUMBERS)')
      READ(5,*) OPERN
C
      IF (OPERN .GE..1 .AND. OPERN .LE. 5) GO TO 281
```

```
C
      PRINT (6,*) 'YOU SCREWED UP! TRY AGAIN.'
      GO TO 280
C
  281 GO TO (282,285,288,299,302) OPERN
C
C
C     MEAN RADIANT TEMPERATURE
C
C
C     NOTE: FOR EVERY DEGREE DROP IN THE MEAN
C     RADIANT TEMPERATURE, THE SPACE TEMPERATURE
C     WILL BE RAISED A DEGREE.
C
  282 WRITE(6,283)
  283 FORMAT(1X,'ENTER THE MEAN RADIANT TEMPERATURE'
     + /1X,'FOR WINTER CONDITIONS.')
      READ(5,*) RADENTW
C
      RADENTW=(78.-RADENTW)
      GO TO 280
C
C     NOTE: WHEN THE MEAN RADIANT TEMPERATURE IS BETWEEN
C     78. AND 100. DEG. F., THE SPACE TEMPERATUTRE WILL
C     BE LOWERED 1 DEG. FOR EVERY 3 DEG. THAT THE RADIANT
C     TEMPERATURE IS RAISED.
C            WHEN THE MEAN RADIANT TEMPERATURE IS ABOVE
C     100. DEG. F., THE SPACE TEMPERATUTRE WILL
C     BE LOWERED 1 DEG. FOR EVERY 5 DEG. THAT THE RADIANT
C     TEMPERATURE IS RAISED.
C
  285 WRITE(6,286)
  286 FORMAT(1X,'ENTER THE MEAN RADIANT TEMPERATURE'
     + /1X,'(GREATER THAN 78. DEG.) FOR SUMMER CONDITIONS.')
      READ(5,*) RADENTS
C
      IF (RADENTS .GE. 100) GO TO 287
C
      RADENTS=((78-RADENTS)/3.)
      GO TO  280
  287 RADENTS=(((100-RADENTS)/5.)-((100-78)/3.))
      GO TO 280
C
C
C     ACTIVITY LEVEL
C
C
  288 WRITE(5,289)
  289 FORMAT(1X,'SELECT ONE OF THE FOLLOWING ACTIVITIES'
     + /1X,   '1)  SLEEPING'
     + /1X,   '2)  SEATED AT REST'
     + /1X,   '3)  STANDING RELAXED'
     + /1X,   '4)  SHOPPING'
     + /1X,   '5)  HOUSEWORK'
     + /1X,   '6)  OFFICEWORK'
     + /1X,   '7)  LIGHT FACTORY WORK'
     + /1X,   '8)  HEAVY FACTORY WORK'
     + /1X,   '9)  DANCING'
     + /1X,  '(TYPE ONE OF THE ABOVE NUMBERS)')
      READ(5,*) OPERN2
C
      IF (OPERN2 .GE. 1 .AND. OPERN2 .LE. 9) GO TO 284
C
      PRINT(6,*) 'YOU SCREWED UP! TRY AGAIN.'
      GO TO 288
C
```

```
  284 GO TO (290,291,292,293,294,295,296,297,298) OPERN2
C
C     A CHANGE OF 3 DEG. F. IS REQUIRED FOR EVERY
C     100 BTU CHANGE IN PHYSICAL ACTIVITY.
C
C     SLEEPING                    (280 BTU/HR)
  290 ACTIVE=(((520-280)/100)*3)
      GO  TO 280
C
C     SEATED AT REST              (400 BTU/HR)
  291 ACTIVE=(((520-400)/100)*3)
      GO  TO 280
C
C     STANDING RELAXED            (480 BTU/HR)
  292 ACTIVE=(((520-480)/100)*3)
      GO  TO 280
C
C     SHOPPING                    (560 TO 720 BTU/HR
C                                 OR 640 BTU/HR AVE.)
  293 ACTIVE=(((520-640)/100)*3)
      GO  TO 280
C
C     HOUSEWORK                   (640 TO 1360 BTU/HR
C                                 OR 1000 BTU/HR AVE.)
  294 ACTIVE=(((520-1000)/100)*3)
      GO  TO 280
C
C     OFFICEWORK                  (480 TO 560 BTU/HR
C                                 OR 520 BTU/HR AVE.)
  295 ACTIVE=(((520-520)/100)*3)
      GO  TO 280
C
C     LIGHT FACTORY WORK          (800 TO 960 BTU/HR
C                                 OR 880 BTU/HR AVE.)
  296 ACTIVE=(((520-880)/100)*3)
      GO  TO 280
C
C     HEAVY FACTORY WORK          (1400 TO 1800 BTU/HR
C                                 OR 1600 BTU/HR AVE.)
  297 ACTIVE=(((520-1600)/100)*3)
      GO  TO 280
C
C     DANCING                     (960 TO 1760 BTU/HR
C                                 OR 1360 BTU/HR AVE.)
  298 ACTIVE=(((520-1360)/100)*3)
      GO  TO 280
C
C
C     CLOTHING LEVEL
C
C
C     NOTE: CLOTHING IS RATED FOR IT'S INSULATION VALUE
C     IN UNITS CALLED THE CLO. EVERY 0.1 CLO IS
C     EQUIVALENT TO A 1.44 DEG. F. CHANGE IN TEMPERATURE.
C
  299 WRITE(6,300)
  300 FORMAT(1X,'ENTER ONE OF THE FOLLOWING CLOTHING LEVELS'
     + /6X,'1) BEACH-WEAR'
     + /6X,'2) LIGHT CLOTHING (CASUAL DRESS)'
     + /6X,'3) BUISNESS SUIT'
     + /6X,'4) HEAVY DRESS (INCLUDES WINTER COAT)'
     + /1X,'(TYPE ONE OF THE ABOVE NUMBERS)')
      READ(5,*) CLOTH
C
      IF (CLOTH .EQ. 1 .OR. CLOTH .EQ. 2 .OR.
     +    CLOTH .EQ. 3 .OR. CLOTH .EQ. 4) GO TO 301
```

```
C
      PRINT(6,*) 'YOU SCREWED UP! TRY AGAIN.'
      GO TO 299
C
  301 IF (CLOTH .EQ. 1) CLO=.05
      IF (CLOTH .EQ. 2) CLO=.75
      IF (CLOTH .EQ. 3) CLO=1.
      IF (CLOTH .EQ. 4) CLO=2.
C
      CLO=(((1-CLO)*10)*1.44)
      GO TO 280
C
C     TEMPERATURE ADJUSTMENTS IF COMFORT PARAMETERS ARE CHANGED
C
  302                   TEMPI=0.
C     ACTIVITY LEVEL
  303                   TEMPI=ACTIVE
C     CLOTHING
                        TEMPI=TEMPI+CLO
C
      RETURN
C
      END
C*******************************************************************
      SUBROUTINE STACK
C*******************************************************************
C
      COMMON/INPUT/BH,BL,BW,VFA,SA,WRATIO,SRATIO,NROOML,NROOMS,MENU1
      COMMON/STACK/VOT,VOTC,CF,AITW,AOTW,AITSS,AOTSS,G,DV,TEMPC,IFLOOR
      COMMON/BOTH/AIT,AITM,AOT,DT,ITYPE,R,TEMP,TEMPI,VZ,ANGLE,SOLVE
C
C
C
C     THIS SUBROUTINE DETERMINES: 1) THE TOTAL AREA OF INLETS
C     AND OUTLETS NEEDED TO MEET FRESH AIR REQUIREMENTS, 2) THE VOLUME
C     OF AIR INFILTRATING AND EXFILTRATING THROUGH WINDOW AND DOOR
C     CRACKS, 3) THE TEMPERATURE OF EXAUST AIR PASSING THROUGH A
C     SOLAR DEVICE THAT WILL CREATE A SUFFICIENT TEMPERATURE
C     DIFFERENTIAL TO INDUCE A BREEZE THROUGH THE LIVING ZONE SO
C     THAT THERMAL COMFORT IS ACHIEVED. THE STACK EFFECT IS DEPENDANT
C     ON COOLER OUTDOOR TEMPERATURES AND THE VERTICAL
C     DISTANCE BETWEEN INLETS AND OUTLETS.
C
C***************
C     EQUATION 2
C***************
C
      ITYPE='STACK'
C
      IF (TEMP .LT. TEMPC) R=WRATIO
      IF (TEMP .GE. TEMPC) R=SRATIO
C
C
C     OPENING EFFIENCY FOR RATIO OF OUTLET TO INLET
C
C
      CF=((.65*60)*((((R**2)/(1+(R**2)))*(((2*G)/(550))))**.5))
C
       IF (SOLVE .EQ. 2 .AND. TEMP .LE. TEMPC) GO TO 305
      IF (TEMP .GT. TEMPC) GO TO 304
C
C     SOLVE FOR AREA OF OPENING NEEDED FOR FRESH AIR
C
      AOT=((VOT)/((CF)*(((DV)*((DT)/(2)))**.5)))
C
      AIT=(AOT/R)
```

```
      GO TO 306
C
C
C
C     SOLVE FOR TEMPERATURE OF EXAUST AIR NEEDED TO INDUCE
C     THE REQUIRED AIR VELOCITY FOR THERMAL COMFORT
C
  304 IF (SOLVE .EQ. 2) AOT=AOTSS
C
      VZ=VZ*AOT
C
      TEMPC=(2*(((VZ**2)/(((CF*AOT)**2)*DV))+(TEMP/2)))
C
      VZ=VZ/AOT
C
      GO TO 306
C
C
C     TEST VELOCITY OF OPENING SELECTED
C
  305 VOTC=((CF*AOTW)*((DV*((DT)/2))**.5))
C
C
  306 RETURN
      END
C
C*****************************************************************
      SUBROUTINE WIND
C*****************************************************************
C
      COMMON/INPUT/BH,BL,BW,VFA,SA,WRATIO,SRATIO,NROOML,NROOMS,MENU1
      COMMON/WIND/DIR,ORIENT,AI,AO,CD,CPW,CPL,DP,SFACE,LFACE,VZZ,V,
     +        PATH,RH,RM,RSA,SALF,SASF,SUM,SUML,SUMS,NROOM,FACE,P,SIDES
      COMMON/BOTH/AIT,AITM,AOT,DT,ITYPE,R,TEMP,TEMPI,VZ,ANGLE,SOLVE
C
C
C
C     THIS SUBROUTINE DETERMINES: 1) THE TOTAL AREA OF INLETS
C     AND OUTLETS NEEDED TO PROVIDE THERMAL COMFORT
C     WITH THE GIVEN CLIMATIC CONDITIONS AND INTERNAL
C     ARRANGEMENT OF SPACES OR 2) THE AIR FLOW GENERATED BY WIND
C     ON OPENING CONFIGURATIONS SPECIFIED BY THE USER.
C
      ITYPE='WIND'
      TEMPC=TEMP
C
C**************
C     EQUATION
C**************
C
      IF (TEMP .GT. TEMPC) TEMPC=TEMP
C
      IF (V .GT. 300.) V=300.
C
      A=((CPW-CPL)*.5)*(V**2.)
C
      IF (SOLVE .EQ. 2) GO TO 360
C
C     THIS PROGRAM IS LIMITED TO A MAXIMUM AREA OF OPENING
C     OF 30% THE BUILDINGS SURFACE AREA WHICH IS APPROXIMATELY
C     40% OF THE ROOM'S SECTIONAL AREA. OPENING SIZES ARE
C     INCREASED BY 5% OF THE ROOM'S SECTIONAL AREA UNTILL
C     THE MAXIMUM OPENING SIZE IS REACHED OR WHEN THE
C     ALGORITHM SOLVES FOR A VELOCITY THAT WILL INDUCE
C     THERMAL COMFORT.
```

```
C
      DO 350 NN=1,8
           P=(.05*NN)
           SUM=0
C
           IF (SIDES .EQ. 2) GO TO 310
           IF (PATH .LE. 2.) GO TO 310
C
           NROOM=NROOMS
           RSA=SASF
           AO=(SASF*P)
C     PRINT(6,*) 'AO=',AO,' RSA=',RSA
           CALL ROOM2
           GO TO 320
C
  310      NROOM=NROOML
           RSA=SALF
           AO=(SALF*P)
C     PRINT(6,*) 'AO=',AO,' RSA=',RSA
           CALL ROOM2
C     PRINT(6,*)'A=',A,' SUM=',SUM,' AO=',AO
C
  320 IF(SUM .EQ. 0) GO TO 390
C
          VZZ=ABS((A/SUM)/AO)
C
C     TEST
C
           AOT=AO
           AIT=AO
           CALL REDUCE
           IF (VZZ .GE. VZ) GO TO 390
C
  350 CONTINUE
      GO TO 390
C
  360 IF (SIDES .EQ. 2) GO TO 370
      IF (AI .LE. 4.5) GO TO 370
C
      SUM=SUMS
      AOT=SFACE/2
      AIT=SFACE/2
      GO TO 380
C
  370 SUM=SUML
      AOT=LFACE/2
      AIT=LFACE/2
C
C     PRINT(6,*)'A=',A,' SUM=',SUM,' AO=',AO
C
  380 IF (SUM .EQ. 0) GO TO 390
      VZZ=ABS((A/SUM)/AO)
C
      CALL REDUCE
C
  390 RETURN
      END
C
C*********************************************************************
      SUBROUTINE WNDSUB1
C*********************************************************************
C
      COMMON/WIND/DIR,ORIENT,AI,AO,CD,CPW,CPL,DP,SFACE,LFACE,VZZ,V,
     +        PATH,RH,RM,RSA,SALF,SASF,SUM,SUML,SUMS,NROOM,FACE,P,SIDES
```

```
        THIS SUBROUTINE PROVIDES THE DISCHARGE COEFFICIENTS
C       FOR THE AREA OF INLETS DEVIDED BY THE SECTIONAL
C       AREA OF THE FIRST ROOM IN SERIES.
C
C       PRINT(6,*) 'AO=',AO,' RSA=',RSA
        X=ABS(AO/RSA)
C
        IF (X .GE. 0.0 .AND. X .LT. 0.1) CD=.55
        IF (X .GE. 0.1 .AND. X .LT. 0.2) CD=.65
        IF (X .GE. 0.2 .AND. X .LT. 0.5) CD=.70
        IF (X .GE. 0.5 .AND. X .LT .0.7) CD=.75
        IF (X .GE. 0.7 .AND. X .LT. .85) CD=.85
        IF (X .GE. .85) CD=.90
C
C       PRINT(6,*) 'CD=',CD
        RM=(1/((CD**2)*(AO**2)))
        RETURN
        END
C
C*********************************************************************
        SUBROUTINE WNDSUB2
C*********************************************************************
C
        COMMON/WIND/DIR,ORIENT,AI,AO,CD,CPW,CPL,DP,SFACE,LFACE,VZZ,V,
     +          PATH,RH,RM,RSA,SALF,SASF,SUM,SUML,SUMS,NROOM,FACE,P,SIDES
        COMMON/BOTH/AIT,AITM,AOT,DT,ITYPE,R,TEMP,TEMPI,VZ,ANGLE,SOLVE
C
C
C       THIS SUBROUTINE PROVIDES THE DISCHARGE COEFFICIENTS FOR
C       THE RATIO OF OUTLET AREA DEVIDED BY ROOM SECTIONAL AREA.
C
C       PRINT(6,*) 'AO=',AO,' RSA=',RSA
        X=ABS(AO/RSA)
C
    400 IF (X .EQ. 0.0) CD=.63
        IF (X .GT. 0.0 .AND. X .LE. 0.2) CD=.64
        IF (X .GT. 0.2 .AND. X .LE. 0.4) CD=.67
        IF (X .GT. 0.4 .AND. X .LE. 0.6) CD=.71
        IF (X .GT. 0.6 .AND. X .LE. 0.8) CD=.81
        IF (X .GT. 0.8) CD =1.0
C
C       PRINT(6,*) 'CD=',CD
        RM=(1/((CD**2)*(AO**2)))
        RETURN
        END
C*********************************************************************
        SUBROUTINE WNDSUB3
C*********************************************************************
C
        COMMON/WIND/DIR,ORIENT,AI,AO,CD,CPW,CPL,DP,SFACE,LFACE,VZZ,V,
     +          PATH,RH,RM,RSA,SALF,SASF,SUM,SUML,SUMS,NROOM,FACE,P,SIDES
C
C
C       THIS SUBROUTINE PROVIDES THE PRESSURE DISTRIBUTION DATA
C       OF A LOW SET HOUSE WITH OPENINGS IN THE CENTER OF WALL.
C
        IF (AI .GE. 0.0 .AND. AI .LT. 22.5) GO TO 510
        IF (AI .GE. 22.5 .AND. AI .LT. 45.) GO TO 520
        IF (AI .GE. 45. .AND. AI .LT. 67.5) GO TO 530
        IF (AI .GE. 67.5 .AND. AI .LT. 90.) GO TO 540
        IF (AI .EQ. 90.) GO TO 550
        IF (AI .GE. 90. .AND. AI .LT. 112.5)GO TO 560
        IF(AI .GE. 112.5 .AND. AI .LT. 135.)GO TO 570
        IF(AI .GE. 135. .AND. AI .LT. 157.5)GO TO 580
        IF(AI .GE. 157.5 .AND. AI .LE. 180.)GO TO 590
```

```
  510 CPW=.5
      CPL=(-.1)
      GO TO 600
  520 CPW=.25
      CPL=(-.75)
      GO TO 600
  530 CPW=.1
      CPL=(-.125)
      GO TO 600
  540 CPW=(-.5)
      CPL=(-.175)
      GO TO 600
  550 CPW=(-.4)
      CPL=(-.4)
      GO TO 600
  560 CPW=(-.175)
      CPL=(-.5)
      GO TO 600
  570 CPW=(-.125)
      CPL=.1
      GO TO 600
  580 CPW=(-.75)
      CPL=.25
      GO TO 600
  590 CPW=(-.1)
      CPL=.5
C
  600 RETURN
      END
C
C**********************************************************************
      SUBROUTINE GEOMTRY
C**********************************************************************
C
      COMMON/INPUT/BH,BL,BW,VFA,SA,WRATIO,SRATIO,NROOML,NROOMS,MENU1
      COMMON/WIND/DIR,ORIENT,AI,AO,CD,CPW,CPL,DP,SFACE,LFACE,VZZ,V,
     +       PATH,RH,RM,RSA,SALF,SASF,SUM,SUML,SUMS,NROOM,FACE,P,SIDES
C
C
C     THIS SUBROUTINE SELECTS ONE OF THE FOLLOWING SUBROUTINES
C     CONTAINING WIND PRESSURE DISTRIBUTION BASED ON THE
C     BUILDING'S GEOMETRY.
C
      GO TO 646
  640 WRITE(6,645)
  645 FORMAT(1X,'THIS PROGRAM IS LIMITED TO RECTILINEAR BUILDINGS'
     + /1X,'WITH A HEIGHTH LESS THAN SIX TIMES THE WIDTH AND A'
     + /1X,'LENGTH LESS THAN 4 TIMES THE WIDTH.')
C
      PRINT(6,*) 'ENTER THE BUILDING HEIGHT (ROUND TO
     +            NEAREST TENTH OF A FOOT).'
      READ(5,*) BH
C
      PRINT(6,*) 'ENTER THE BUILDING LENGTH (ROUND TO
     +            NEAREST TENTH OF A FOOT).'
      READ(5,*) BL
C
      PRINT(6,*) 'ENTER THE BUILDING WIDTH (ROUND TO
     +            NEAREST TENTH OF A FOOT).'
      READ(5,*) BW
C
C     RATIO OF HEIGHTH TO WIDTH
C
  646 HEIGHT=(BH/BW)
C
```

```
           RATIO OF LENGTH TO WIDTH
      C
           LENGTH=(BL/BW)
      C
           IF (HEIGHT .LT. .5) GO TO 650
           IF (HEIGHT .LT. 1.15) GO TO 660
           IF (HEIGHT .LT. 6) GO TO 670
           GO TO 640
      C
       650 IF (LENGTH .LT. 1.15) CALL WNDSUB4
           IF (LENGTH .LT. 1.15) GO TO 690
           IF (LENGTH .LT. 4.) CALL WNDSUB5
           IF (LENGTH .LT. 4.) GO TO 690
           GO TO 640
      C
       660 IF (LENGTH .LT. 1.15) CALL WNDSUB6
           IF (LENGTH .LT. 1.15) GO TO 690
           IF (LENGTH .LT. 4.)  CALL WNDSUB7
           IF (LENGTH .LT. 4.) GO TO 690
           GO TO 640
      C
       670 IF (LENGTH .LT. 1.15) CALL WNDSUB8
           IF (LENGTH .LT. 1.15) GO TO 690
           IF (LENGTH .LT. 4.)  CALL WNDSUB9
           IF (LENGTH .LT. 4.) GO TO 690
           GO TO 640
      C
       690 RETURN
           END
      C
      C*****************************************************************
           SUBROUTINE WNDSUB4
      C*****************************************************************
      C
           COMMON/WIND/DIR,ORIENT,AI,AO,CD,CPW,CPL,DP,SFACE,LFACE,VZZ,V,
          +       PATH,RH,RM,RSA,SALF,SASF,SUM,SUML,SUMS,NROOM,FACE,P,SIDES
      C
      C    THIS SUBROUTINE CONTAINS THE PRESSURE COEFFICIENTS
      C    FOR A RECTILENEAR BUILDING WITH A HEIGHT LESS THAN
      C    1/2 THE WIDTH AND A LENGTH LESS THAN 3/2 THE WIDTH
      C    AT WIND INCIDENCE ANGLES OF 0 AND 90 DEGREES.
      C
           IF (SIDES .EQ. 4) GO TO 700
      C
           CPW=.7
           CPL=(-.2)
           GO TO 702
      C
       700 CPW=.7
           CPL=((-.2)+(-.5)+(-.5))
      C
      C
       702 RETURN
           END
      C
      C
      C*****************************************************************
           SUBROUTINE WNDSUB5
      C*****************************************************************
      C
           COMMON/WIND/DIR,ORIENT,AI,AO,CD,CPW,CPL,DP,SFACE,LFACE,VZZ,V,
          +       PATH,RH,RM,RSA,SALF,SASF,SUM,SUML,SUMS,NROOM,FACE,P,SIDES
      C
      C
      C    THIS SUBROUTINE CONTAINS THE PRESSURE COEFFICIENTS
           FOR A RECTILENEAR BUILDING WITH A HEIGHT LESS THAN
```

```
C      1/2 THE WIDTH AND A LENGTH LESS THAN 4 TIMES THE WIDTH
C      AT WIND INCIDENCE ANGLES OF 0 AND 90 DEGREES.
C
       IF (SIDES .EQ. 4) GO TO 704
C
       CPW=.7
       CPL=(-.25)
       GO TO 708
C
   704 IF (PATH .EQ. 1.) GO TO 706
C
       CPW=.7
       CPL=((-.25)+(-.6)+(-.6))
C
   706 CPW=.7
       CPL=((-.25)+(-.6)+(-.6))
       CPL=((-1)+(-.5)+(-.5))
C
C
   708 RETURN
       END
C
C******************************************************************
       SUBROUTINE WNDSUB6
C******************************************************************
C
       COMMON/WIND/DIR,ORIENT,AI,AO,CD,CPW,CPL,DP,SFACE,LFACE,VZZ,V,
      +        PATH,RH,RM,RSA,SALF,SASF,SUM,SUML,SUMS,NROOM,FACE,P,SIDES
C
C
C
C      THIS SUBROUTINE CONTAINS THE PRESSURE COEFFICIENTS
C      FOR A RECTILENEAR BUILDING WITH A HEIGHT LESS THAN
C      3/2 THE WIDTH AND A LENGTH LESS THAN 3/2 THE WIDTH
C      AT WIND INCIDENCE ANGLES OF 0 AND 90 DEGREES.
C
C
       IF (SIDES .EQ. 4) GO TO 710
C
       CPW=.7
       CPL=(-.25)
       GO TO 712
C
   710 CPW=.7
       CPL=((-.25)+(-.6)+(-.6))
C
C
   712 RETURN
       END
C
C******************************************************************
       SUBROUTINE WNDSUB7
C******************************************************************
C
       COMMON/WIND/DIR,ORIENT,AI,AO,CD,CPW,CPL,DP,SFACE,LFACE,VZZ,V,
      +        PATH,RH,RM,RSA,SALF,SASF,SUM,SUML,SUMS,NROOM,FACE,P,SIDES
C
C
C      THIS SUBROUTINE CONTAINS THE PRESSURE COEFFICIENTS
C      FOR A RECTILENEAR BUILDING WITH A HEIGHT LESS THAN
C      3/2 THE WIDTH AND A LENGTH LESS THAN 4 TIMES THE WIDTH
C      AT WIND INCIDENCE ANGLES OF 0 AND 90 DEGREES.
C
       IF (SIDES .EQ. 4) GO TO 714
C
       CPW=.7
```

```
      CPL=(-.3)
      GO TO 718
C
  714 IF (PATH .EQ. 1) GO TO 716
C
      CPW=.7
      CPL=((-.3)+(-.7)+(-.7))
      GO TO 718
C
  716 CPW=.7
      CPL=((-1)+(-.5)+(-.5))
C
C
  718 RETURN
      END
C
C
C********************************************************************
      SUBROUTINE WNDSUB8
C********************************************************************
C
      COMMON/WIND/DIR,ORIENT,AI,AO,CD,CPW,CPL,DP,SFACE,LFACE,VZZ,V,
     +         PATH,RH,RM,RSA,SALF,SASF,SUM,SUML,SUMS,NROOM,FACE,P,SIDES
C
C
C     THIS SUBROUTINE CONTAINS THE PRESSURE COEFFICIENTS
C     FOR A RECTILENEAR BUILDING WITH A HEIGHT LESS THAN
C     6 TIMES THE WIDTH AND A LENGTH LESS THAN 3/2 THE WIDTH
C     AT WIND INCIDENCE ANGLES OF 0 AND 90 DEGREES.
C
      IF (SIDES .EQ. 4) GO TO 720
C
      CPW=.8
      CPL=(-.25)
      GO TO 722
C
  720 CPW=.8
      CPL=((-.25)+(-.8)+(-.8))
C
C
  722 RETURN
      END
C
C
C********************************************************************
      SUBROUTINE WNDSUB9
C********************************************************************
C
      COMMON/WIND/DIR,ORIENT,AI,AO,CD,CPW,CPL,DP,SFACE,LFACE,VZZ,V,
     +         PATH,RH,RM,RSA,SALF,SASF,SUM,SUML,SUMS,NROOM,FACE,P,SIDES
C
C
C     THIS SUBROUTINE CONTAINS THE PRESSURE COEFFICIENTS
C     FOR A RECTILENEAR BUILDING WITH A HEIGHT LESS THAN
C     6 TIMES THE WIDTH AND A LENGTH LESS THAN 4 TIMES THE
C     WIDTH AT WIND INCIDENCE ANGLES OF 0 AND 90 DEGREES.
C
      IF (SIDES .EQ. 4) GO TO 724
C
      CPW=.7
      CPL=(-.4)
      GO TO 728
C
  724 IF (PATH .EQ. 1) GO TO 726
C
      CPW=.7
```

```
      CPL=((-.4)+(-.7)+(-.7))
      GO TO 728
C
  726 CPW=.8
      CPL=((-1)+(-.5)+(-.5))
C
C
  728 RETURN
      END
C
C
C*****************************************************************
      SUBROUTINE REDUCE
C*****************************************************************
C
      COMMON/WIND/DIR,ORIENT,AI,AO,CD,CPW,CPL,DP,SFACE,LFACE,VZZ,V,
     +        PATH,RH,RM,RSA,SALF,SASF,SUM,SUML,SUMS,NROOM,FACE,P,SIDES
C
C
C     THIS SUBROUTINE REDUCES VENTILATION RATES BY
C     A PERCENTAGE FOR EACH DEGREE THAT THE WIND INCIDENCE ANGLE IS
C     OFF THE PERPENDICULAR OF THE PERPENDICULAR TO THE OPENING.
C
C
      IF (AI .LE. 8.) GO TO 730
      IF (AI .LE. 20.) GO TO 735
      IF (AI .LE. 45.) GO TO 740
      IF (AI .LE. 90.) GO TO 745
C
C     FACTOR THAT REDUCES VENTILATION BY 3% PER DEGREE
C     WHEN THE WIND INCIDENCE ANGLES ARE BETWEEN 0 AND 8 DEGREES
C
  730 REDUCED=((VZZ)*(AI*.03))
      GO TO 750
C
C     FACTOR THAT REDUCES VENTILATION BY 24% PLUS 1% PER DEGREE
C     WHEN THE WIND INCIDENCE ANGLES ARE BETWEEN 9 AND 20 DEGREES
C
  735 REDUCED=((VZZ*.24)+(VZZ*((AI-8)*.01)))
      GO TO 750
C
C     FACTOR THAT REDUCES VENTILATION BY 36% PLUS .4% PER DEGREE
C     WHEN THE WIND INCIDENCE ANGLES ARE BETWEEN 21 AND 45 DEGREES
C
  740 REDUCED=((VZZ*.36)+(VZZ*((AI-20)*.004)))
      GO TO 750
C
C     FACTOR THAT REDUCES VENTILATION BY 46% PLUS .09% PER DEGREE
C     WHEN THE WIND INCIDENCE ANGLES ARE BETWEEN 45 AND 90 DEGREES
C
  745 REDUCED=((VZZ*.46)+(VZZ*((AI-45)*.0009)))
C
C     VENTILATION REDUCED
C
  750 VZZ=VZZ-REDUCED
C
      RETURN
      END
C
C*****************************************************************
      SUBROUTINE CHANGE
C*****************************************************************
C
      COMMON/INPUT/BH,BL,BW,VFA,SA,WRATIO,SRATIO,NROOML,NROOMS,MENU1
      COMMON/STACK/VOT,VOTC,CF,AITW,AOTW,AITSS,AOTSS,G,DV,TEMPC,IFLOOR
      COMMON/WIND/DIR,ORIENT,AI,AO,CD,CPW,CPL,DP,SFACE,LFACE,VZZ,V,
```

```
     +        PATH,RH,RM,RSA,SALF,SASF,SUM,SUML,SUMS,NROOM,FACE,P,SIDES
      COMMON/BOTH/AIT,AITM,AOT,DT,ITYPE,R,TEMP,TEMPI,VZ,ANGLE,SOLVE
      COMMON/COMFORT/RADENTW,RADENTS,ACTIVE,CLO
C
      INTEGER OPERN3
C
C     THIS SUBROUTINE USES A MENU TO ALLOW THE
C     USER TO CHANGE INPUT BEFORE RUNNING THE PROGRAM.
C
  800 WRITE(6,805)
  805 FORMAT(1X,'WOULD YOU LIKE TO...'
     + /7X,'1) CHANGE THE BUILDING HEIGHT'
     + /7X,'2) CHANGE THE BUILDING LENGTH'
     + /7X,'3) CHANGE THE BUILDING WIDTH'
     + /7X,'4) CHANGE THE VERTICAL DISTANCE BETWEEN OPENINGS'
     + /7X,'5) CHANGE THE THE ORIENTATION OF THE BUILDING'S LONG FACE'
     + /7X,'6) CHANGE THE BUILDING'S VENTILATION RATE'
     + /7X,'7) CHANGE THE REQUIRED VENTILATION RATE FOR 1 ROOM'
     + /7X,'8) CHANGE THE COMFORT PARAMETERS'
     + /7X,'9) CHANGE THE MAXIMUM AREA OF OPENINGS'
     + /7X,'10) CHANGE THE OF SIDES OF THE BUILDING WITH OPENINGS'
     + /7X,'11) CHANGE THE NUMBER OF ROOMS PARALLEL TO THE LONG FACE'
     + /7X,'12) CHANGE THE NUMBER OF ROOMS PARALLEL TO THE SHORT FACE'
     + /7X,'13) SOLVE FOR OPENINGS')
  806 WRITE(6,808)
  808 FORMAT(12X,'CHANGE THE ROOM'S SECTIONAL AREA(S)'
     + /12X,'CHANGE THE RATIO OF THE LARGEST TO SMALLEST OPENING'
     + /7X,'14) TEST THE PERFORMANCE OF THE OPENINGS SELECTED'
     + /12X,'CHANGE AREA OF OPENING ABOVE AND BELOW THE NEUTRAL ZONE'
     + /12X,'CHANGE THE SERIES OF OPENING AND ROOM SECTIONAL AREAS'
     + /1X,'15) EXIT THIS CHANGE ROUTINE')
      READ(5,*) OPERN3
C
      IF(OPERN3  .GE. 1 .AND. OPERN3 .LE. 15) GO TO 810
C
      PRINT(6,*) 'YOU SCREWED UP! TRY AGAIN.'
      GO TO 800
C
  810 GO TO (815,820,825,830,840,845,850,855,860,870,
     + 880,885,900,905,925) OPERN3
C
C
  815 PRINT(6,*) 'ENTER THE BUILDING HEIGHT (ROUND TO
     +              NEAREST TENTH OF A FOOT).'
      READ(5,*) BH
      GO TO 800
C
  820 PRINT(6,*) 'ENTER THE BUILDING LENGTH (ROUND TO
     +              NEAREST TENTH OF A FOOT).'
      READ(5,*) BL
      GO TO 800
C
  825 PRINT(6,*) 'ENTER THE BUILDING WIDTH (ROUND TO
     +              NEAREST TENTH OF A FOOT).'
      READ(5,*) BW
      GO TO 800
C
  830 WRITE(6,835)
  835 FORMAT(1X, 'ENTER THE DISTANCE VERTICALLY BETWEEN THE CENTERS'
     + /1X,'OF THE INLETS(GROUND FLOOR) AND THE OUTLETS(TOP FLOOR).'
     + /1X,'NOTE: IF AIR MOVEMENT BETWEEN FLOORS IS PREVENTED BY'
     + /1X,'CORRIDOR DOORS, STAIR DOORS, ETC, THE DISTANCE VERTICALLY'
     + /1X,'BETWEEN POINTS OF IN-FILLTRATION AND EX-FILLTRATION'
     + /1X,'WILL BE HALF THE WINDOW HEIGHT ON THAT FLOOR.')
      READ(5,*) DV
      GO TO 800
```

```
  840 PRINT(6,*) 'ENTER THE ORIENTATION ANGLE OF THE BUILDING'S LONG
     + FACE CLOCKWISE FROM DUE NORTH(0. TO 360.DEGREES).'
      READ(5,*) ANGLE
      ORIENT=(ANGLE/10.)
      GO TO 800
C
  845 PRINT(6,*)'ENTER THE BUILDING'S REQUIRED VENTILATION RATE (CFM).
     +SEE THE ASHRAE COOLING AND HEATING LOAD CALCULATION MANUAL
     +                    (PAGES 5.12 TO 5.15).'
      READ(5,*) VOT
      GO TO 800
C
  850 PRINT(6,*) 'ENTER THE VENTILATION RATE OF THE ROOM IN SERIES
     +              WHICH HAS THE HIGHEST VALUE.(SEE ASHRAE MANUAL)'
      READ(5,*) VFA
      VFA=(VFA/60)
      GO TO 800
C
  855 CALL COMFORT
      GO TO 800
C
  860 PRINT(6,*)'ENTER THE AREA PER FLOOR OF THE BUILDING'S SKIN'
      READ(5,*) SA
C
      AITM=SA*.3
C
      WRITE(6,865) AITM
  865 FORMAT(1X,'THIS PROGRAM IS LIMITED TO THE CALCULATION'
     + /1X,'OF VENTILATION RATES FOR MAXIMUM OPENINGS 30 PERCENT OF'
     + /1X,'THE BUILDING'S SURFACE AREA.FOR YOUR BUILDING'
     + /1X,'THE MAXIMUM AREA OF OPENING IS ',F5.1,' SQ.FT.')
      GO TO 800
C
  870 WRITE(6,875)
  875 FORMAT(1X,'HOW MANY SIDES OF THE BUILDING HAVE OPENINGS?'
     + /1X,'      1) TWO SIDES'
     + /1X,'      2) FOUR SIDES'
     + /1X,'(TYPE 1 OR 2)')
      READ(5,*) SIDES
C
      SIDES=(SIDES*2)
C
      IF (SIDES .EQ. 2. .OR. SIDES .EQ. 4.) GO TO 880
      PRINT(6,*) 'YOU SCREWED UP! TRY AGAIN.'
      GO TO 870
C
  880 PRINT(6,*) 'IF WIND PASSES THROUGH THE BUILDING PARALLEL TO THE
     +               LONG FACE, WHAT IS THE NUMBER OF ROOMS IN SERIES?'
      READ(5,*) NROOML
C
      IF (SIDES .EQ. 2) GO TO 890
C
  885 PRINT(6,*) 'IF WIND PASSES THROUGH THE BUILDING PARALLEL TO THE
     +              SHORT FACE, WHAT IS THE NUMBER OF ROOMS IN SERIES?'
      READ(5,*) NROOMS
C
  890 WRITE(6,895)
  895 FORMAT(1X,'WOULD YOU LIKE THE COMPUTER TO...'
     + /6X,'1) SOLVE FOR THE OPENING SIZES THAT WILL MAXIMIZE THE'
     + /6X,'   HOURS THAT THERMAL COMFORT IS ACHIEVED'
     + /1X,'OR'
     + /6X,'2) TEST THE OPENING SIZES THAT YOU INPUT FOR'
     + /6X,'   THE NUMBER OF HOURS PER YEAR THERMAL'
     + /6X,'   COMFORT IS ACHIEVED.'
     + /1X,'(TYPE 1 OR 2)')
```

```
      READ (5,*) SOLVE
C
      IF (SOLVE .EQ. 1. .OR. SOLVE .EQ. 2.) GO TO 910
      PRINT(6,*) 'YOU SCREWED UP! TRY AGAIN.'
      GO TO 890
C
  900 SOLVE=1
      GO TO 910
C
  905 SOLVE=2
C
  910 IF (SOLVE .EQ. 2) GO TO 915
C
C
C     INPUT IF SOLVING FOR OPENING SIZES
C
C
      PRINT(6,*) 'ENTER THE SECTIONAL AREA OF THE SPACE
     +                    ADJACENT TO THE LONG FACE.'
      READ (5,*) SALF
C
      IF (SIDES .EQ. 2) GO TO 914
C
      PRINT(6,*) 'ENTER THE SECTIONAL AREA OF THE SPACE
     +                      ADJACENT TO THE SHORT FACE.'
      READ (5,*) SASF
C
  914 PRINT(6,*) 'ENTER THE RATIO OF OUTLETS TO INLETS (WINTER).'
      READ (5,*) WRATIO
C
      PRINT(6,*) 'ENTER THE RATIO OF OUTLETS TO INLETS (SUMMER).'
      READ (5,*) SRATIO
C
      IF(SOLVE .EQ. 1) GO TO 920
C
C
C     INPUT IF TESTING OPENING SIZES
C
C
  915 PRINT(6,*) 'ENTER THE TOTAL AREA OF INLETS (WINDOWS CLOSED)
     +                    FOR THE LOWER PORTION OF THE BUILDING.'
      READ(5,*) AITW
C
      PRINT(6,*) 'ENTER THE TOTAL AREA OF OUTLETS (WINDOWS CLOSED)
     +                    FOR THE UPPER PORTION OF THE BUILDING.'
      READ(5,*) AOTW
C
      WRATIO=(AOTW/AITW)
C
      PRINT(6,*) 'ENTER THE TOTAL AREA OF INLETS (WINDOWS OPEN)
     +               FOR THE LOWER PORTION OF THE BUILDING.'
      READ(5,*) AITSS
C
      PRINT(6,*) 'ENTER THE TOTAL AREA OF OUTLETS (WINDOWS OPEN)
     +               FOR THE UPPER PORTION OF THE BUILDING.'
      READ(5,*) AOTSS
C
      SRATIO=(AOTSS/AITSS)
C
      PRINT(6,*) 'ENTER THE TOTAL AREA OF OPENING ON THE
     +                TWO LONG FACES OF THE BUILDING.'
      READ(5,*) LFACE
C
      FACE=((LFACE/2)/IFLOOR)
      PRINT(6,*)'THE OPENING AREA PER FLOOR FOR ONE LONG SIDE IS '
     + ,FACE,' SQ.FT.'
```

```
      NROOM=NROOML
      PRINT(6,*) '      SERIES OF ROOMS PARALLEL TO THE LONG FACE'
      CALL ROOM1
      SUML=SUM
C
      IF (SIDES .EQ. 2) GO TO 920
C
      PRINT(6,*) 'ENTER THE TOTAL AREA OF OPENING ON THE
     +                TWO SHORT FACES OF THE BUILDING.'
      READ (5,*) SFACE
C
      FACE=((SFACE/2)/IFLOOR)
      PRINT(6,*)'THE OPENING AREA PER FLOOR FOR ONE SHORT SIDE IS '
     + ,FACE,' SQ.FT.'
      NROOM=NROOMS
      PRINT(6,*) '      SERIES OF ROOMS PARALLEL TO THE SHORT FACE'
      CALL ROOM1
      SUMS=SUM
C
  920 GO TO 800
C
  925 RETURN
      END
```

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