Digital Analogue for Natural Ventilation Calculations

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A DIGITAL ANALOGUE FOR NATURAL VENTILATION CALCULATIONS.

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SUMMARY

The report describes a digital analogue written in 1900 Fortran, which is suitable for computing natural ventilation rates in multi-storey buildings. The assumptions made, data requirements and output available are listed. A print-out of the programme is given.

1. INTRODUCTION

1.1. Digital analogue techniques are being used to produce design information on infiltration and natural ventilation in buildings. This is being done despite the lack of any comparative studies to establish the accuracy of the assumptions and data used in the analogue techniques. A major part of the work in the thesis was concerned with comparative studies between a digital analogue model and full scale and model scale studies. From these studies it was hoped to gain information on the inherent accuracy of the digital analogue method and the data requirements in order to improve design methods. Consequently a programme was written which calculates natural ventilation or infiltration rates in a simple building.

1.2. The programme used the same basic assumptions as used by other natural ventilation prediction programmes. These are:

(1) that the building is considered as a series of compartments, each of which has a limited number of air flow paths into and out of it through which natural ventilation or infiltration may occur.

(2) that each flow path has a characteristic flow resistance, representing a doorway, window, air duct or open area, which may be expressed by an equation relating air flow through it to pressure difference acting across it.

(3) that there is no resistance to air flow inside each compartment of the building.

(4) that wind forces and stack effect produce external pressures outside each external opening in the building which are time-invariant over the period of time considered in the calculation.

(5) that the internal air temperature in the building is uniform throughout the building.

2. PROGRAMME SPECIFICATION

2.1. In the programme the maximum number of compartments which may be analysed was 211. These consisted of a maximum of 200 single rooms, up to 10 corridors, one for each floor of the building, and one common stairwell. The single rooms were assumed to be distributed as a maximum of 20 on each of up to 10 floors, each floor being able to have a unique number of rooms. The rooms could be of any required size as ventilation rates were expressed directly in m^3/hr from a knowledge of the room opening characteristics. Each single room was assumed to have two ventilation openings, one connecting it with the exterior of the building and one connecting it with the corridor on that floor. The stairwell compartment was assumed to be linked to each corridor and to have no other ventilation openings. The stairwell compartment could be used to represent either one or several stairwells all opening onto the central corridor. Some representative building plans suitable for analysis by this type of programme are shown in Figure 2.

2.2. Each room in the building, and the openings in and out of that room, were identified by a floor number and room number. The lowest floor is taken to be floor 1. The rooms could be numbered in any order, thus allowing the user to choose a numbering system suited to the building plan. Each opening in the building was assumed to have air flow resistance characteristic values which were used in an equation of the form:

$$V = C.L. \, (dP)^{1/n} \qquad ...1.$$

The values of the total leakage coefficient, C x L, and flow exponent, n, could be unique for each opening in the building.

2.3. The input information required by the programme consisted of the following values:

(1) number of floors in the building,

(2) floor to floor height, m,

(3) number of rooms on each floor (even number),

(4) values of total leakage coefficient for exterior/room opening and room/corridor opening for each room, $m^3/hr/mm\ wg^{0.6}$.

(5) values of flow exponent for interior/room opening and room/corridor opening for each room,

(6) values of total leakage coefficient and flow exponent for each corridor/stairwell opening,

(7) wind pressure outside each opening expressed as a pressure coefficient with respect to free stream wind speed at building roof height,

(8) assumed meteorological wind speed, m/s,

(9) assumed mean internal/external temperature difference, ^{o}C.

One significant limitation of the programme is that corner rooms with windows opening onto two facades at two different external pressures are not accurately modelled. In these situations a representative external pressure should be taken. If this factor is likely to be important the flow from one window to the other could be considered separately and an estimation of the extra flow found.

2.4. The programme was designed to compute ventilation rate either for one specified set of design meteorological conditions or for an array of meteorological conditions covering the combinations of wind speed and temperature difference normally encountered. The array of meteorological values used consisted of wind speeds 0.001, 1.0, 2.0, 4,0, 6.0, 8.0 m/s and temperature differences of 0.0, 8.0, 16.0 and 24.0 ^{o}C. The design meteorological values may be any values of wind speed or temperature difference which do not occur in the array. The meteorological wind speed input was an assumed wind speed from a remote site in open country at a height of 10 m., which was then converted to the site wind speed, assuming the site to be in an urban area. This form of input may easily be altered as was done in the comparative tests, to use the site wind speed as a direct input, or to produce site wind speeds characteristic of suburban or open sites.

2.5. The output information given by the programme consisted of the following values:

(1) review of the input information used in the programme,

(2) meteorological wind speed, m/s,

(3) interior/exterior temperature difference, ^{o}F,

(4) total infiltration rate for the building, m^3/hr (total of all air flow rates entering the building through external openings).

(5) average room ventilation rate, m^3/hr,

(6) standard deviation of room ventilation rates, m^3/hr,

(7) for each room:

pressure differences acting across the external and internal ventilation openings, expressed in mm.wg. and as pressure coefficient values,

flow rate and direction of flow, m^3/hr

(8) flow rate and direction of flow from the stairwell to the corridor at each floor level, m^3/hr,

(9) pressures in the stairwell and each internal corridor, mm.wg.

The sign convention used for air flow rates and pressure differences in the programme was:

All flows towards the central corridor on that floor level, from any other part of the floor, are taken to be positive.

All pressure differences which would act to cause positive flow rates are taken to be positive.

3. PROGRAMME DESCRIPTION

3.1. The programme was written in Fortran 1900 language for use on the Sheffield University I.C.L. 1907 computer. The programme works on the basis of making successive approximations of the ventilation rates occuring throughout the building until the estimated rates are within the required accuracy limits. The approximation techniques used in the programme are illustrated by the flow charts shown in Figure 1. These are discussed in more detail in the following section and related to the appropriate steps in the full programme. A print-out of the full programme is given in Appendix A1. In the following paragraphs figures in parentheses refer to line numbers of the programme shown in Appendix A1.

3.2. The analysis is carried out in three main consecutive steps in the programme. These are shown in Figure 1. Initially the external pressures outside each of the external openings, caused by wind pressure alone, are found. Each floor is analysed separately, considering it to be isolated from the rest of the building. The pattern of ventilation for the floor is found, and also the absolute pressure on the corridor of each floor. A flow diagram of this section may be seen in Figure 1(a). The detailed operations are noted below:

(1) Each floor is considered in turn, (74, 152).

(2) The convergency rate figure is set to one, (75).

(3) Initial internal pressures are set up (76 - 85):

the corridor pressure is set to the average of all the external pressures acting outside that floor,

the room pressures are set to half the difference between the corridor pressure and the appropriate external pressure.

(4) The accuracy limits are set up, (86-7):

the current values of two pressure differences are set to L1M1, L1M2; at the end of the cycle the current values are compared with L1M1, L1M2. If the pressure difference values have changed by more than 1/1000 of their value during the cycle L1M1 and L1M2 are set to the new current values and the cycle repeated.

(5) The ventilation rates are calculated through all openings on the floor and are balanced, (88-104):

for each room in turn the flow rates in and out are equated, each being set at the average of the two flow rates,

for the corridor, the net flow is found and the room/corridor flow rates altered proportionally so that the net flow is made zero.

the balance of air flow through each room is checked and if necessary adjusted,

the balance of air flow into the corridor is checked and if necessary adjusted.

(6) The pressure differences are re-calculated and balanced, (105-134):

they are correlated with the values of the external pressures and altered so that they are in agreement with these values.

(7) The number of cycles carried out is checked. If this is over 50 the analysis is stopped, the number of cycles and current values being written out, (135-6, 141-2).

(8) The relevant pressure differences are checked against L1M1, L1M2 and if not sufficiently accurate the approximation cycle is repeated, (137-140).

(9) The variable values used to calculate the combined ventilation rates are set up (143-151).

3.3. In the second section of the analysis the stack effect, assumed to be acting alone, is considered. A neutral zone height is found such that the net flow from all corridors to the stairwell is zero. The corridors are assumed to be at zero pressure relative to each other from forces other than stack effect. The stack pressures found by this analysis are added to all relevant wind induced pressures found in the initial analysis step. Figure 1(b) shows a flow diagram for this section and the detailed steps are again noted below:

(1) Assume an initial neutral zone height of half of the building height, and calculate the pressures due to stack effect, (157-160).

(2) Calculate the net flow into the corridor from each stairwell (161-5).

(3) If the net flow into the stairwell is zero add the relevant stack pressures to each level of the building assuming the current value of neutral zone height (166, 189-195).

(4) If the net flow into the stairwell is positive, decrease the neutral zone height progressively, in steps of 1/500 building height, until the net flow becomes zero or negative, (166-177, 189-195)

if the net flow becomes zero assume the current neutral zone height value,

if the net flow becomes negative assume a value half way between the current value and the value used in the previous cycle,

add the relevant stack pressures to each level of the building.

(5) If the net flow into the stairwell is negative increase the neutral zone height progressively, in steps of 1/500 building height, until the net flow becomes zero or positive, (166, 178-195):

if the net flow becomes zero assume the current neutral zone height value,

if the net flow becomes positive assume a value half way between the current value and the value used in the previous cycle,

add the relevant stack pressures to each level of the building.

3.4. The combined ventilation rates, assuming both wind and stack effect to be acting simultaneously, are calculated in the third section of the programme. Each floor is analysed again, this time with the presence of the stairwell, at the appropriate pressure taken into account. Flow rates are balanced until the net flow into each central corridor from the rooms on the floor and the stairwell is again zero. These results are taken to represent the final estimated ventilation pattern for the building. Once again a flow diagram is given, (see in Figure 1(c)) and the detailed steps noted below:

(1) Each floor is considered in turn (200, 256)

(2) The pressure difference between the relevant corridor and the stairwell is calculated (201, 202).

(3) The increment value is set, (203):

the ventilation pattern is found by a series of approximations, altering the corridor pressure by increments; the incremental values are made progressively smaller and the accuracy limits are assumed to be met when the incremental values become equal to preset limiting values.

(4) The stairwell to corridor pressure difference is decreased by a factor of one increment, (204-5):

as the flow pattern for each floor was prevously balanced, the introduction of the stairwell at a different pressure will cause the corridor pressure to be altered, the corridor pressure becoming nearer in value to the stairwell pressure.

(5) All pressure differences on the floor are re-calculated, (206-219):

this procedure is carried out by a series of approximations; the pressures cannot be simply altered in proportion due to the different possible flow exponent values of the openings.

(6) The flow rates are calculated for these new pressure differences, the flow for each room balanced, and the pressure differences re-calculated from the balanced flows (220-239).

(7) The net flow into the central corridor is calculated, (240-250):

if the net flow is positive and the stairwell to corridor pressure difference is positive or if the net flow is negative and the stairwell to corridor pressure difference is negative then the corridor pressure has not been altered sufficiently to balance the total flow on the floor; the stairwell to corridor pressure difference is reduced further, if these conditons are not met then the corridor pressure has been compensated at least enough and the accuracy check is made.

(8) The value of the increment is checked, (251-254):

if this is larger than the preset limiting value then the value of the increment is reduced by a factor of ten, the corridor pressure reset to its previous value and the calculation repeated from step 4,

if the incremental value is sufficiently small the analysis is stopped.

3.5. Summary ventilation rate values are calculated from the final calculated detailed ventilation rates (257-274). and the results are printed (275-306). The values of temperature difference and wind speed assumed in the input are cycled in turn, and in that order, if this type of analysis is required (308-327). Each time the temperature difference is changed the second and third steps are repeated. Only when the wind speed is changed is the first step repeated in addition.

3.6. One further approximation is made in the programme which has not been discussed. The stairwell pressure in the final analysis is set to the mean wind-induced corridor pressure and the flow rates into and out of the stairwell are not balanced by the programme. However the stack pressures are calculated from the estimated neutral zone height so that the stack induced ventilation through the staircase would be balanced (paragraph 3.5.). As these ventilation forces are likely to produce the major part of the vertical air movement it was decided that the added accuracy which might be achieved in balancing the stairwell air flow system would not justify the increase in computing time required.

Figure 1. Flow chart for building ventilation prediction program, BT5VENT4.

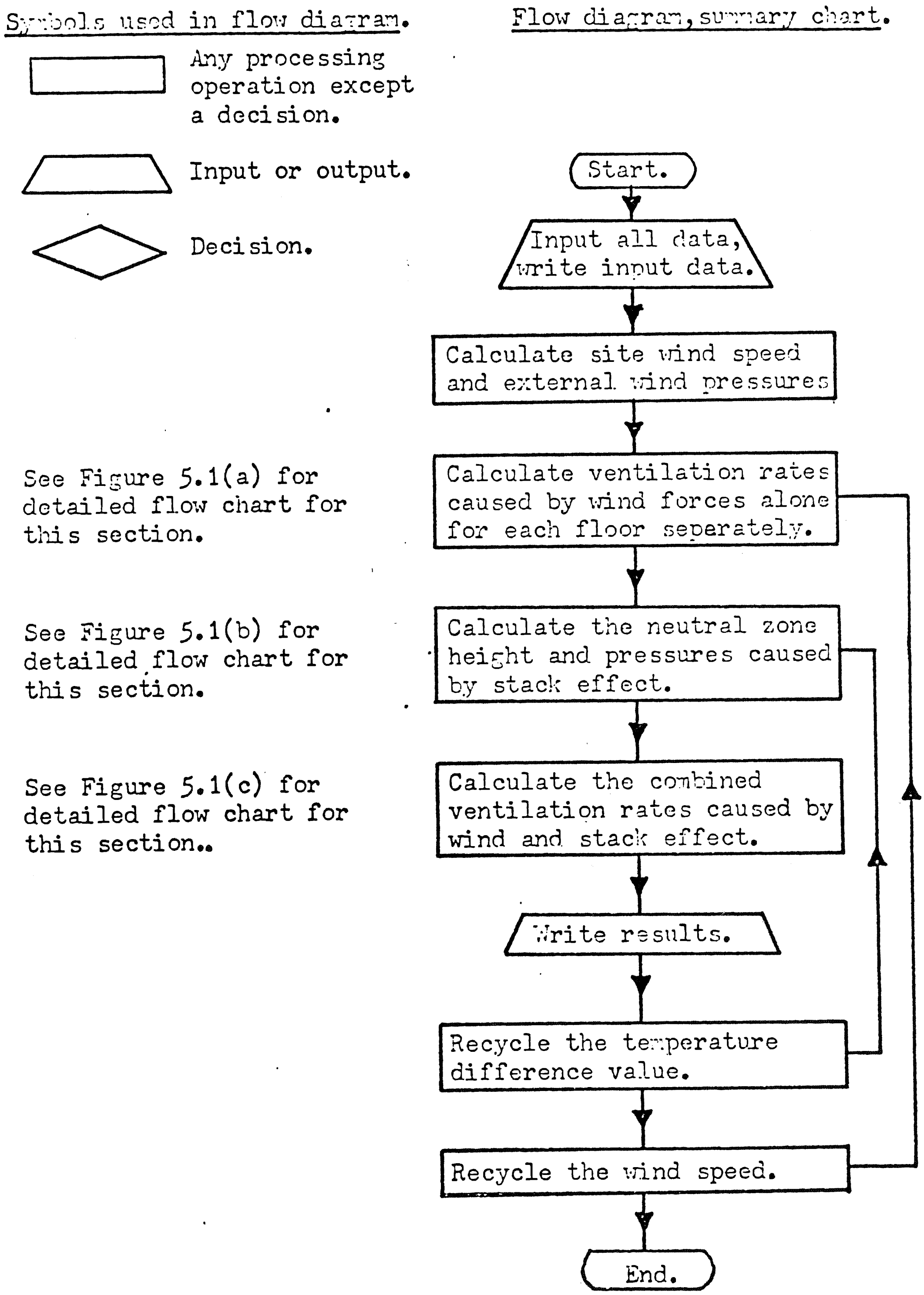


Figure 1(a). Calculation of ventilation rates due to wind alone, floors considered in isolation.

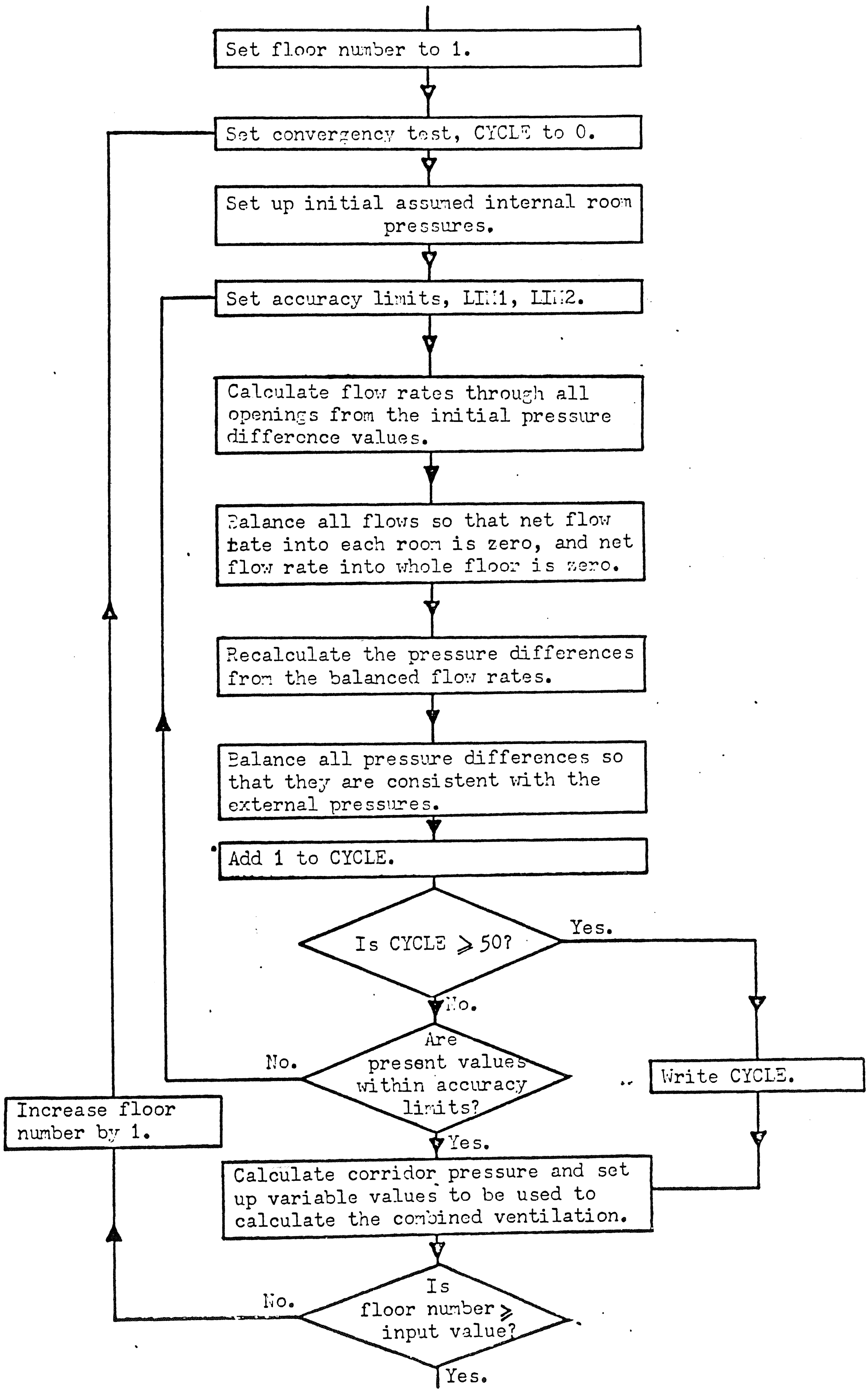


Figure 1(b). Calculation of neutral zone height.

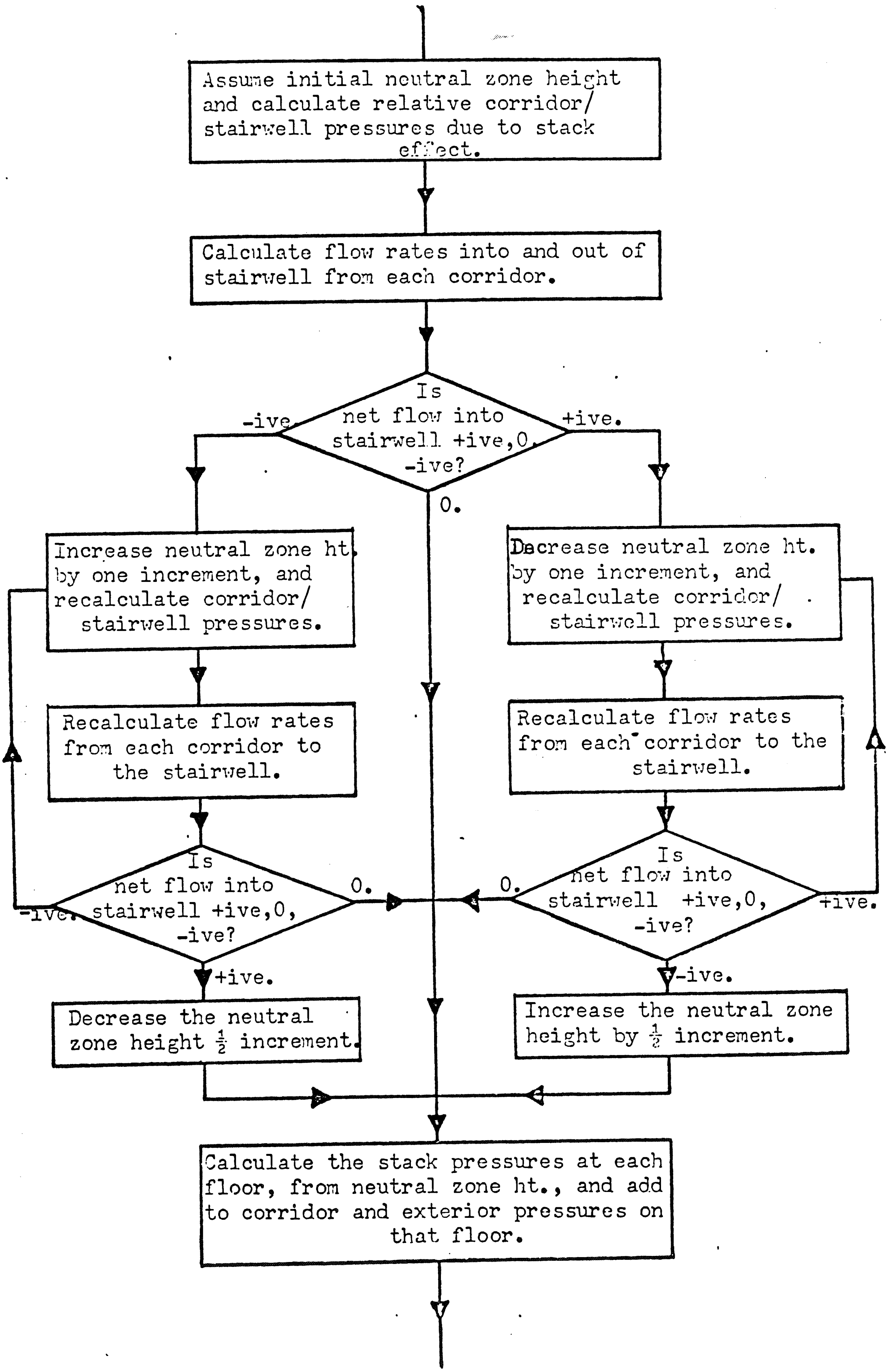


Figure .1(c). Calculation of combined ventilation rates.

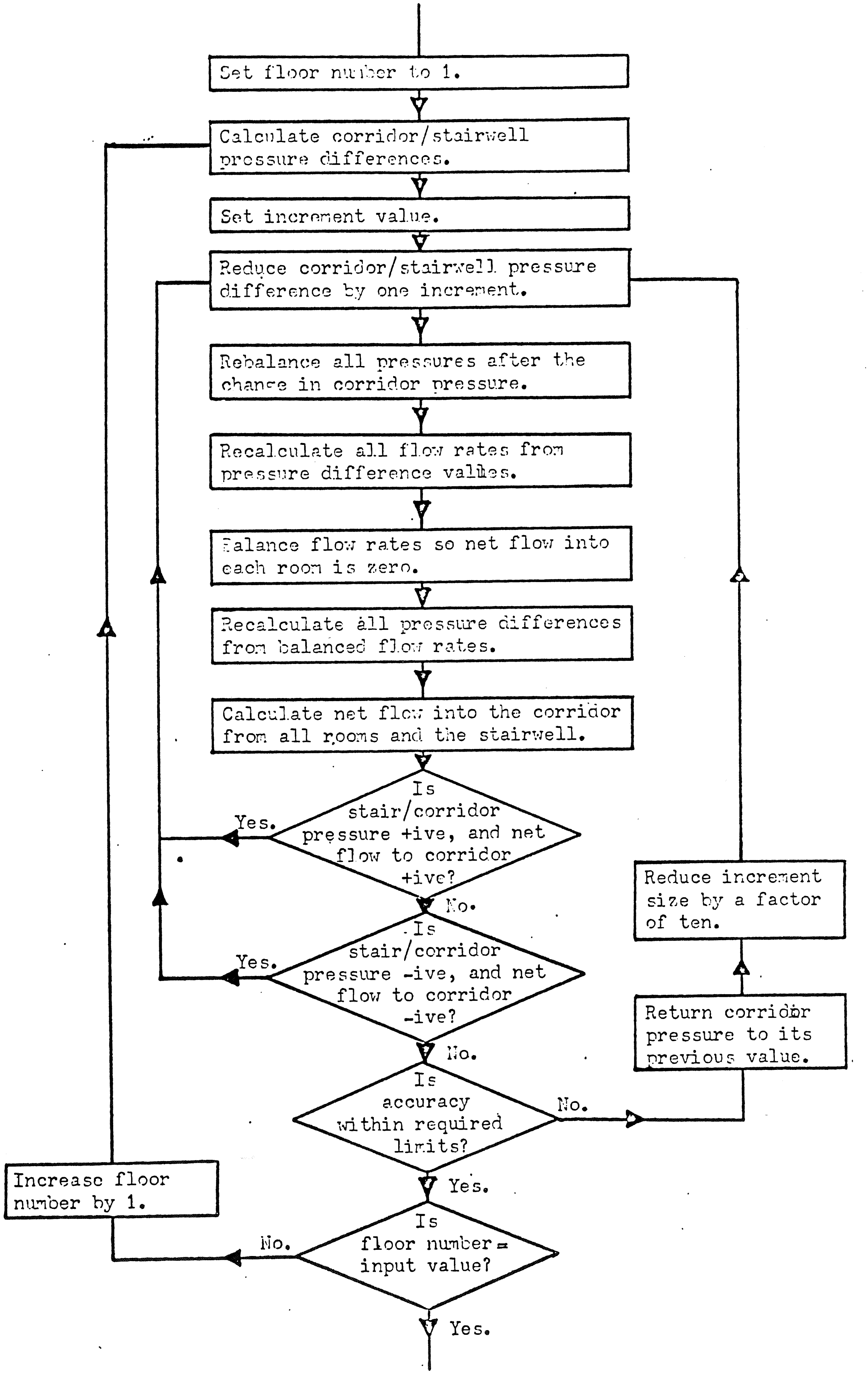
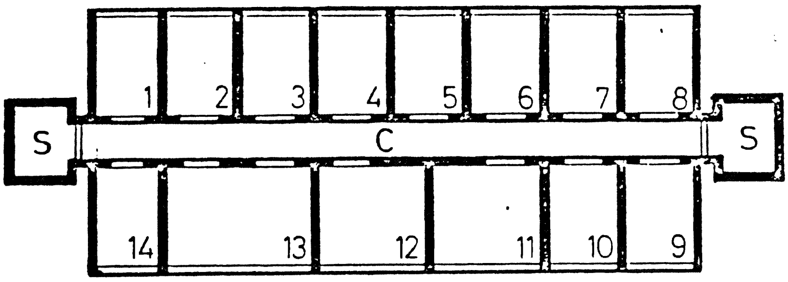


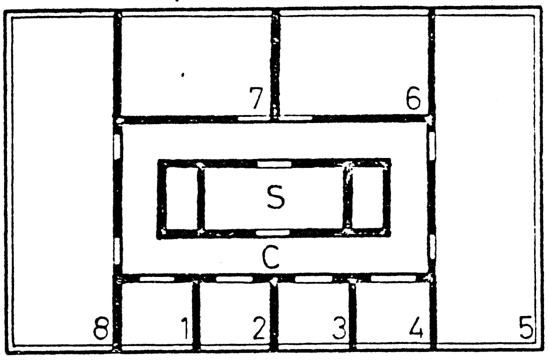
Figure 2. Typical plan forms suitable for analysis by BT5VENT4

S Stairwell
C Corridor

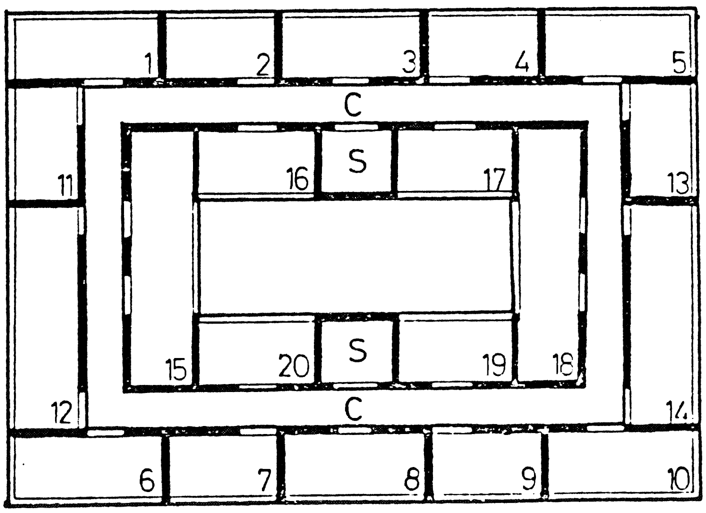
Slab block:



Uniformly glazed building:



Courtyard building:



Appendix A1 — A print-out of the Digital Analogue Programme Developed to Determine Building Ventilation Rates

The following are the major abbreviations used in the programme:

N(J)	Number of rooms on floor J
M	Room number
K	Number of floors in building
J	Floor number
FLTOFL	Floor to floor height, m
HT	Building height, m
WINDMET	Meteorological wind speed, m/s, at 10 m height in open country
WIND	Site wind speed, at building roof height, m/s
TDIFF	Interior/exterior temperature difference, ^{o}C
SP	Pressures generated by stack effect, mm.wg./m/^{o}C
VE(J,M) or VEI(J,M)	Volumetric flow rate through the external opening in room M, floor J, m^3/hr
PDE(J,M) or PDEI(J,M)	Pressure difference acting across the external opening in room M, floor J, mm.wg
PCOEFEE(J,M)	Pressure difference acting across the external opening in room M, floor J, expressed as a pressure coefficient
CLI(J,M)	Total leakage coefficient for the external opening in room M, floor J, $m^3/hr/mm.wg^{1/n}$
ZI(J,M)	Reciprocal of the flow exponent for the external opening in room M, floor J
PE(J,M)	External pressure outside room M, floor J, caused by the wind speed, mm.wg
CE(J,M)	External pressure outside room M, floor J, caused by the wind, expressed as a pressure coefficient

	relative to the free stream wind speed at the building roof height
VC(J,M) or VCI(J,M)	Volumetric flow rate through the internal opening in room M, floor J, m^3/hr
PDC(J,M) or PDCI(J,M)	Pressure difference acting across the internal opening in room M, floor J, m^3/hr
PCOEFFC(J,M)	Pressure difference acting across the internal opening in room M, floor J, expressed as a pressure coefficient
CL2(J,M)	Total leakage coefficient for the internal opening in room M, floor J, $m^3/hr/mm.wg^{1/n}$
Z2(J,M)	Reciproval of the flow exponent for the internal opening in room M, floor J
VSTAIR(J)	Volumetric flow rate through the corridor/stairwell opening, floor J, m^3/hr
PSTAIR(J)	Pressure difference in the stairwell, mm.wg
CLS(J)	Total leakage coefficient for the corridor/stairwell opening, $m^3/hr/mm.wg^{1/n}$
ZS(J)	Reciprocal of flow exponent for the corridor/ stairwell opening, floor J.
PDCS(J)	Pressure difference acting across the corridor/ stairwell opening, floor J, mm.wg
PC(J)	Corridor pressure, floor J, mm.wg
ZTOTVENT	Sum of ventilation rates for all rooms, m^3/hr
ZINFILT	Sum of ventilation rates for all rooms where the flow direction is into the building, m^3/hr
ZAVVENT	Average room ventilation rate, m^3/hr
ZSTDEV	Standard deviation of all room ventilation rates, m^3/hr

Appendix A1 Digital analogue programme to determine natural ventilation in buildings.

Line. Column.

```
                    10        20        30        40        50        60        70        80

JOB BT5VENT4, 1807BT5C, BILSBORROW
FORTRAN 1, CR0(BT5VENT4PROG),CR0(BT5VENT4DATA),500,5000
****
DOCUMENT BT5VENT4PROG
      PROGRAM(BT5V1807BT5C)
      INPUT 1=CR0
      OUTPUT 2=LP0
      END

      MASTER VENTPLOT4
C  THE PROGRAM COMPUTES VENTILATION RATES AND PRESSURES BASED ON THE
C  EQUATION FOR FLOW THROUGH AN ORIFICE     V=CL * ((PD) ** 1/Z)
C  EITHER FOR AN ARRAY OF CLIMATIC  VARIABLES OF VALUEI
C  WIND SPEED     0.001 1.0 2.0 4.0 6.0 8.0    TEMP DIFF    0.0 8.0 16.0 24.0
C  WHERE INITIAL VALUES SHOULD BE 0.001 M/S. AND 8.0 DC.
C  OR FOR ANY SPECIFIC CASE WHERE THE VALUES OF THE VARIABLES ARE NOT
C  ANY OF THOSE OCCURRING IN THE CLIMATIC ARRAY
C
C     INDEPENDENT FLOOR BY FLOOR ANALYSIS GIVING PC(J)
C
C     N(J) IS NO. OF ROOMS ON FLOOR J        M IS ROOM NUMBER
C     K IS NO. OF FLOORS                     J IS FLOOR NUMBER
C     VE OR VE1 IS VOLUME FLOW CMH. FROM EXTERIOR TO ROOM M
C     VC OR VC1 IS VOLUME FLOW CMH. FROM ROOM M TO  CORRIDOR
C     VSTAIR IS VOLUME FLOW RATE CMH. FROM STAIR TO CORRIDOR
C     PE IS EXTERNAL PRESSURE MM.WG. OUTSIDE ROOM M
C     CE IS PRESSURE COEFFICIENT OUTSIDE ROOM M
C     PDE OR PDE1 IS PRESSURE DIFFERENCE MM.WG. FROM EXTERIOR TO ROOM M
C     PCOEFFE IS PRESSURE DIFFERENCE FROM OUTSIDE TO ROOM M
C     IN PRESSURE COEFFICIENT FORM
C     PDC OR PDC1 IS PRESSURE DIFFERENCE MM.WG. FROM ROOM M TO CORRIDOR
C     PCOEFFC IS PRESSURE DIFFERENCE ROOM M TO CORRIDOR
C     IN PRESSURE COEFFICIENT FORM
C     PC IS PRESSURE IN CORRIDOR MMWG.
C     PSTAIR OR PSTAIR1 IS PRESSURE IN STAIRWELL MMWG.
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Appendix A1 Digital analogue programme to determine natural ventilation in buildings.

Line. Column.

10 20 30 40 50 60 70 80

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C     PDCS OR PDCS1 IS PRESSURE DIFFERENCE MMWG. BETWEEN CORRIDOR AND STAIR
      DIMENSION VE(10,20),PDE(10,20),PDC(10,20),VC(10,20),PF(10,20)
      DIMENSION VE1(10.20),PDE1(10,20),PDC1(10,20),VC1(10.20),CF(10,20)
      DIMENSION Z1(10,20),CL1(10,20),Z2(10,20),CL2(10,20),PC(10).N(10)
      DIMENSION PSTAIR(10),VSTAIR(10),CLS(10),ZS(10),PDCS(10)
      DIMENSION PSTAIR1(10),PDCS1(10),PCOEFFE(10,20).PCOEFFC(10,20)
      READ(1,101)K
      READ(1,104)FLTOFL
      HT=FLTOFL*K
 101  FORMAT(I2)
      DO 40 J=1,K
      READ(1,101)N(J)
      DO 41 M=1,N(J)
      READ(1,102)CL1(J,M),CL2(J,M),Z1(J,M),Z2(J,M)
 102  FORMAT(4F0.0)
 41   CONTINUE
      READ(1,103)CLS(J),ZS(J)
 40   CONTINUE
      READ(1,104)((CE(J,M),M=1,N(J)),J=1,K)
 104  FORMAT(200F0.0)
      READ(1,103)WINDMET,TDIFF
 103  FORMAT(2F0.0)
      DO 44 J=1,K
      WRITE(2,105)J,CLS(J),ZS(J)
      WRITE(2,106)
      DO 45 M=1,N(J)
 45   WRITE(2,107)CE(J,M),CL1(J,M),CL2(J,M),Z1(J,M),Z2(J,M)
 44   CONTINUE
 105  FORMAT(1H0,10HFLOOR NO.=,I2,10X,4HCLS=,F6.1.5X,3HZS=,F5.2)
 106  FORMAT(20X,2HPE,10X,3HCL1,10X,3HCL2,10X,2HZ1,10X,2HZ2)
 107  FORMAT(20X,F4.2,6X,F7.1,6X.F7.1,8X.F4.2,8X,F4.2)
      WIND=WINDMET*1.62*((HT/500.0)**0.33)
      PCTOT=0.0
      DO 46 J=1,K
      DO 47 M=1,N(J)
 47   PE(J,M)=CE(J,M)*0.0624*WIND*WIND
```

Appendix A1 Digital analogue programme to determine natural ventilation in buildings.

Line. Column.

```
        10        20        30        40        50        60        70        80
 46   CONTINUE
      DO 29 J=1,K
      CYCLE=1.0
      PETOT=0.0
      DO 18 M=1,N(J)
 18   PETOT=PETOT+PE(J,M)
      PEAVG=PETOT/N(J)
      DO 27 M=1,N(J)
      PDE(J,M)=(PE(J,M)-PEAVG)/2.0
      PDC(J,M)=(PE(J,M)-PEAVG)/2.0
      IF(PDE(J,M).EQ.0.0)PDE(J,M)=0.01
      IF(PDC(J,M).EQ.0.0)PDC(J,M)=0.01
 27   CONTINUE
 17   ALIM1=PDE(J,1)
      ALIM2=PDE(J,N(J))
      DO 11 M=1,N(J)
      IF(PDE(J,M).GE.0.0)VE(J,M)=CL1(J,M)*(PDE(J,M)**(1/Z1(J,M)))
      IF(PDE(J,M).LT.0.0)VE(J,M)=-CL1(J,M)*
     1          ((ABS(PDE(J,M)))**(1/Z1(J,M)))
      IF(PDC(J,M).GE.0.0)VC(J,M)=CL2(J,M)*(PDC(J,M)**(1/Z2(J,M)))
 11   IF(PDC(J,M).LT.0.0)VC(J,M)=-CL2(J,M)*
     1          ((ABS(PDC(J,M)))**(1/Z2(J,M)))
 20   DO 12 M=1,N(J)
      VE(J,M)=(VE(J,M)+VC(J,M))/2.0
 12   VC(J,M)=VE(J,M)
      H=0.0
      DO 23 M=1,N(J)
 23   H=H+VC(J,M)
      DO 19 M=1,N(J)
 19   VC(J,M)=VC(J,M)-H/N(J)
      IF(ABS(ABS(VC(J,1))-ABS(VE(J,1))).GT.
     1          (ABS(VC(J,1)/10000.0)))GO TO 20
      DO 13 M=1,N(J)
      IF(VE(J,M).GE.0.0)PDE(J,M)=(VE(J,M)/CL1(J,M))**Z1(J,M)
      IF(VE(J,M).LT.0.0)PDE(J,M)=-(((ABS(VE(J,M)))/CL1(J,M))**Z1(J,M))
      IF(VC(J,M).GE.0.0)PDC(J,M)=(VC(J,M)/CL2(J,M))**Z2(J,M)
```

Appendix A1 Digital analogue programme to determine natural ventilation in buildings.

```
13    IF(VC(J,M).LT.0.0)PDC(J,M)=-(((ABS(VC(J,M)))/C12(J,M))**Z2(J,M))
      DO 14 M=1,N(J)/2
      F1=PDE(J,M)+PDC(J,M)-PDC(J,N(J)/2+M)-PDE(J,N(J)/2+M)
      F2=PE(J,M)-PE(J,N(J)/2+M)
      IF(F1.EQ.0.0)F1=F1+0.001
      IF(PE(J,M)-PE(J,N(J)/2+M))21,22,21
22    PDE(J,M)=PDE(J,M)-F1*PDE(J,M)/((PDE(J,M)+PDC(J,M))*2.0)
      PDC(J,M)=PDC(J,M)-F1*PDC(J,M)/((PDE(J,M)+PDC(J,M))*2.0)
      PDC(J,N(J)/2+M)=PDC(J,N(J)/2+M)+F1*PDC(J,N(J)/2+M)/
     1          ((PDE(J,N(J)/2+M)+PDC(J,N(J)/2+M))*2.0)
      PDE(J,N(J)/2+M)=PDE(J,N(J)/2+M)+F1*PDE(J,N(J)/2+M)/
     1          ((PDE(J,N(J)/2+M)+PDC(J,N(J)/2+M))*2.0)
      GO TO 24
21    F=F2/F1
      PDE(J,M)=PDE(J,M)*F
      PDC(J,M)=PDC(J,M)*F
      PDC(J,N(J)/2+M)=PDC(J,N(J)/2+M)*F
      PDE(J,N(J)/2+M)=PDE(J,N(J)/2+M)*F
24    CONTINUE
14    CONTINUE
      DO 15 M=1,N(J)-1
      G=(PE(J,M)-PDE(J,M)-PDC(J,M)-PE(J,M+1)+PDE(J,M+1)+PDC(J,M+1))/2.0
      PDE(J,M)=PDE(J,M)+G*PDE(J,M)/(PDE(J,M)+PDC(J,M))
      PDC(J,M)=PDC(J,M)+G*PDC(J,M)/(PDE(J,M)+PDC(J,M))
      PDC(J,M+1)=PDC(J,M+1)-G*PDC(J,M+1)/(PDC(J,M+1)+PDE(J,M+1))
15    PDE(J,M+1)=PDE(J,M+1)-G*PDE(J,M+1)/(PDC(J,M+1)+PDE(J,M+1))
      CYCLE=CYCLE+1.0
      IF(CYCLE.GT.50.5)GO TO 31
      IF(ABS(ALIM1-PDE(J,1)).LT.ABS(PDE(J,1)/1000.0))GO TO 16
      GO TO 17
16    IF(ABS(ALIM2-PDE(J,N(J))).LT.ABS(PDE(J,N(J))/1000.0))GO TO 28
      GO TO 17
31    WRITE(2,108)
108   FORMAT(1H1,30HCURRENT VALUES AFTER 50 CYCLES)
28    PC(J)=((PE(J,1)-PDE(J,1)-PDC(J,1))+(PE(J,N(J))
     1         -PDE(J,N(J))-PDC(J,N(J))))/2.0
```

Appendix A1 Digital analogue programme to determine natural ventilation in buildings.

Line. Column.

```
      PCTOT=PCTOT+PC(J)
      PCAVG=PCTOT/K
      DO 30 M=1,N(J)
      VE1(J,M)=VE(J,M)
      PDE1(J,M)=PDE(J,M)
      PDC1(J,M)=PDC(J,M)
   30 VC1(J,M)=VC(J,M)
   29 CONTINUE
C
C
C     CALCULATION OF NFUTRAL ZONE HEIGHT
C
  218 ZN=HT/2.0
      SP=0.0044*TDIFF
      DO211 J=1,K
  211 PSTAIR(J)=-(ZN-((J-1)*FLTOFL)-1.0)*SP
      VSTOT=0.0
      DO 212 J=1,K
      IF(PSTAIR(J).GE.0.0)VSTAIR(J)=CLS(J)*(PSTAIR(J)**(1/ZS(J)))
      IF(PSTAIR(J).LT.0.0)VSTAIR(J)=-CLS(J)*(ABS(PSTAIR(J))**(1/ZS(J)))
  212 VSTOT=VSTOT+VSTAIR(J)
      IF(VSTOT)240,299,242
  240 ZN=ZN-(HT/500.0)
      DO 213 J=1,K
  213 PSTAIR(J)=-(ZN-((J-1)*FLTOFL)-1.0)*SP
      VSTOT=0.0
      DO 214 J=1,K
      IF(PSTAIR(J).GE.0.0)VSTAIR(J)=CLS(J)*(PSTAIR(J)**(1/ZS(J)))
      IF(PSTAIR(J).LT.0.0)VSTAIR(J)=-CLS(J)*(ABS(PSTAIR(J))**(1/ZS(J)))
  214 VSTOT=VSTOT+VSTAIR(J)
      IF(VSTOT)240,299,243
  243 ZN=ZN+(HT/1000.0)
      GO TO 299
  242 ZN=ZN+(HT/500.0)
      DO 215 J=1,K
  215 PSTAIR(J)=-(ZN-((J-1)*FLTOFL)-1.0)*SP
```

Appendix A1 Digital analogue programme to determine natural ventilation in buildings.

Line. Column.

```
         10        20        30        40        50        60        70        80
      VSTOT=0.0
      DO 216 J=1,K
      IF(PSTAIR(J).GE.0.0)VSTAIR(J)=CLS(J)*(PSTAIR(J)**(1/ZS(J)))
      IF(PSTAIR(J).LT.0.0)VSTAIR(J)=-CLS(J)*(ABS(PSTAIR(J))**(1/ZS(J)))
  216 VSTOT=VSTOT+VSTAIR(J)
      IF(VSTOT)244,299,242
  244 ZN=ZN-(HT/1000.0)
      GO TO 299
  299 DO 217 J=1,K
      PC(J)=PC(J)+(ZN-((J-1)*FLTOFL)-1.0)*SP
  217 PSTAIR(J)=PCAVG
      DO 220 J=1,K
      DO 219 M=1,N(J)
  219 PE(J,M)=PE(J,M)+(ZN-((J-1)*FLTOFL)-1.0)*SP
  220 CONTINUE
C
C
C     CALCULATION OF COMBINED VENTILATION
C
      DO 320 J=1,K
      PSTAIR1(J)=PSTAIR(J)
      PDCS(J)=PSTAIR1(J)-PC(J)
      DENOM=10.0
  399 PC(J)=PC(J)+PDCS(J)/DENOM
      PDCS1(J)=PSTAIR1(J)-PC(J)
      DO 321 M=1,N(J)
      PDE1(J,M)=(PDE(J,M)/(PDE(J,M)+PDC(J,M)))*(PE(J,M)-PC(J))
      RATIO=PDE1(J,M)/PDE(J,M)
      IF(RATIO.LT.0.0)GO TO 340
      PDC1(J,M)=PDC(J,M)*(RATIO**(Z2(J,M)/Z1(J,M)))
      GO TO 338
  340 PDC1(J,M)=-(PDC(J,M)*((ABS(RATIO))**(Z2(J,M)/Z1(J,M))))
  338 PDE1(J,M)=(PDE1(J,M)/(PDE1(J,M)+PDC1(J,M)))*(PE(J,M)-PC(J))
      RATIO=PDE1(J,M)/PDE(J,M)
      IF(RATIO.LT.0.0)GO TO 341
      PDC1(J,M)=PDC(J,M)*(RATIO**(Z2(J,M)/Z1(J,M)))
```

Appendix A1 Digital analogue programme to determine natural ventilation in buildings.

```
Line.  Column.
                10        20        30        40        50        60        70        80
      GO TO 342
  341 PDC1(J,M)=-(PDC(J,M)*((ABS(RATIO))**(Z2(J,M)/Z1(J,M))))
  342 CONTINUE
      IF(PDE1(J,M).GE.0.0)GO TO 322
      VE1(J,M)=-CL1(J,M)*((ABS(PDE1(J,M)))**(1/Z1(J,M)))
      GO TO 323
  322 VE1(J,M)=CL1(J,M)*(PDE1(J,M)**(1/Z1(J,M)))
  323 IF(PDC1(J,M).GE.0.0)GO TO 324
      VC1(J,M)=-CL2(J,M)*((ABS(PDC1(J,M)))**(1/Z2(J,M)))
      GO TO 325
  324 VC1(J,M)=CL2(J,M)*(PDC1(J,M)**(1/Z2(J,M)))
  325 VE1(J,M)=(VE1(J,M)+VC1(J,M))/2.0
  321 VC1(J,M)=VE1(J,M)
      DO 326 M=1,N(J)
      IF (VE1(J,M).GE.0.0)GO TO 327
      PDE1(J,M)=-(((ABS(VE1(J,M)))/CL1(J,M))**Z1(J,M))
      GO TO 328
  327 PDE1(J,M)=(VE1(J,M)/CL1(J,M))**Z1(J,M)
  328 IF(VC1(J,M).GE.0.0)GO TO 329
      PDC1(J,M)=-(((ABS(VC1(J,M)))/CL2(J,M))**Z2(J,M))
      GO TO 326
  329 PDC1(J,M)=(VC1(J,M)/CL2(J,M))**Z2(J,M)
  326 CONTINUE
      WTOT=0.0
      DO 330 M=1,N(J)
  330 WTOT=WTOT+VE1(J,M)
      IF(PDCS1(J).GE.0.0)GO TO 331
      VSTAIR(J)=-CLS(J)*((ABS(PDCS1(J)))**(1/ZS(J)))
      GO TO 332
  331 VSTAIR(J)=CLS(J)*(PDCS1(J)**(1/ZS(J)))
  332 CONTINUE
      WTOT=WTOT+VSTAIR(J)
      IF(PDCS(J).GE.0.0.AND.WTOT.GE.0.0)GO TO 399
      IF(PDCS(J).LT.0.0.AND.WTOT.LT.0.0)GO TO 399
      PC(J)=PC(J)-PDCS(J)/DENOM
      IF(DENOM.GE.999.0)GO TO 398
```

Line. Column.

```
       DENOM=DENOM*10.0
       GO TO 399
  398  PC(J)=PC(J)+PDCS(J)/DENOM
  320  CONTINUE
       VELHEAD=0.0624*WIND*WIND
       ZINFILT=0.0
       ZNOROOM=0.0
       ZTOTVENT2=0.0
       ZTOTVENT=0.0
       ZAVVENT=0.0
       DO 336 J=1,K
       DO 335 M=1,N(J)
       PCOEFFE(J,M)=PDE1(J,M)/VELHEAD
       IF(ABS(PCOEFFE(J,M)).GE.10.0)PCOEFFE(J,M)=0.0
       PCOEFFC(J,M)=PDC1(J,M)/VELHEAD
       IF(ABS(PCOEFFC(J,M)).GE.10.0)PCOEFFC(J,M)=0.0
       ZTOTVENT2=ZTOTVENT2+(VE1(J,M)**2)
       ZTOTVENT=ZTOTVENT+ABS(VE1(J,M))
  335  IF(VE1(J,M).GT.0.0)ZINFILT=ZINFILT+VE1(J,M)
  336  ZNOROOM=ZNOROOM+N(J)
       ZAVVENT=ZTOTVENT/ZNOROOM
       ZSTDEV=SQRT((ZTOTVENT2/ZNOROOM)-(ZAVVENT*ZAVVENT))
C
C
C      PRINTOUT OF RESULTS
C
       WRITE(2,301)WINDMET,TDIFF
       WRITE(2,302)ZINFILT
       WRITE(2,303)ZAVVENT
       WRITE(2,304)ZSTDEV
       DO 310 J=1,K
       WRITE(2,305)
       DO 311 M=1,N(J)-1,2
       M1=M+1
  311  WRITE(2,306)J,M,VE1(J,M),PCOEFFE(J,M),PDE1(J,M),PDC1(J,M)
      1 J,MM,VE1(J,MM),PCOEFFE(J,MM),PDE1(J,MM),PDC1(J,MM)
```

Appendix A1 Digital analogue programme to determine natural ventilation in buildings.

Line. Column.

```
         10        20        30        40        50        60        70        80
||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||
  310 CONTINUE
      WRITE(2,307)
      DO 339 J=1,K
  339 WRITE(2,308)J,VSTAIR(J),PSTAIR(J),PC(J)
  301 FORMAT(1H1,22HRESULTS FOR WIND SPEED,F5.2,
     1     29HM/S.  TEMPERATURE DIFFERENCE,F5.2,3HDC.)
  302 FORMAT(1H0,29HTOTAL INFILTRATION RATE, CMH.,21X,F8.2)
  303 FORMAT(1H0,35HAVERAGE ROOM VENTILATION RATE, CMH.,15X,F8.2)
  304 FORMAT(1H0,46HSTANDARD DEVN. OF ROOM VENTILATION RATES, CMH.,
     1           4X,F8.2)
  305 FORMAT(1H0,10HFLOOR ROOM,5X,7HVE(CMH),5X,7HPDE(CP.,5X,3HMM),5X,
     1 7HPDC(MM),9X,10HFLOOR ROOM,5X,7HVE(CMH),5X,7HPDE(CP.,5X,3HMM),
     2 5X,7HPDC(MM))
  306 FORMAT(I4,3X,I2,5X,F8.2,5X,F5.2,3X,F7.3,5X,F7.3,9X,I4,3X,I2,5X,
     1           F8.2,5X,F5.2,3X,F7.3,5X,F7.3)
  307 FORMAT(1H0,5HFLOOR,10X,6HVSTAIR,6X,6HPSTAIR,12X,9HPCORRIDOR)
  308 FORMAT(I4,10X,F8.2,4X,F7.3,13X,F7.3)
C
C
C     RECYCLING OF WIND AND TEMPERATURE VALUES
C
      TDIFF1=1000.0
      IF(TDIFF.EQ.0.0)TDIFF1=8.0
      IF(TDIFF.EQ.8.0)TDIFF1=16.0
      IF(TDIFF.EQ.16.0)TDIFF1=24.0
      IF(TDIFF.EQ.24.0)GO TO 337
      TDIFF=TDIFF1
      IF(TDIFF.EQ.8.0.OR.TDIFF.EQ.16.0.OR.TDIFF.EQ.24.0)GO TO 218
      WIND1=1000.0
  337 TDIFF=0.0
      IF(WINDMET.EQ.0.001)WIND1=1.00
      IF(WINDMET.EQ.1.00)WIND1=2.00
      IF(WINDMET.EQ.2.00)WIND1=4.00
      IF(WINDMET.EQ.4.00)WIND1=6.00
      IF(WINDMET.EQ.6.0)WIND1=8.00
      IF(WINDMET.EQ.8.00)GO TO 400
||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||
```

Appendix A1 Digital analogue programme to determine natural ventilation in buildings.

Line. Column.

```
         10        20        30        40        50        60        70        80
      WINDMET=WIND1
      IF(WINDMET.EQ.1.00.OR.WINDMET.EQ.2 00.OR.WINDMET.EQ.4.00)GO TO 44
      IF(WINDMET.EQ.6.00.OR.WINDMET.EQ.8 00)GO TO 44
 400  STOP
      END
      FINISH
****
```