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07

# A COMPUTER PROGRAM FOR THE CALCULATION OF NATURAL VENTILATION DUE TO WIND

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# A computer program for the calculation of natural ventilation due to wind

J M Bruce, The Scottish Farm Buildings Investigation Unit

## INTRODUCTION

When a building is subjected to wind, areas of positive and negative pressure are created over the external surface. If the building has openings in it, the internal pressure may also be changed. Wind-induced ventilation is the result of these pressures. In particular the air movement through each opening may be calculated from a knowledge of the pressure difference between the inside and outside pressures at the opening. Where there are many openings present in a building shell each may be subject to a different wind pressure. The time spent in manual calculation of air flows is prohibitive involving the simultaneous solution of many equations. The digital computer is an ideal tool for this type of calculation, providing accuracy and speed at low cost. Without a ready means of calculation the designer is unable to allocate time to examining the effect of changing opening size and position and wind direction.

The mathematical model for wind-induced ventilation is presented as a computer program. The model, although imperfect, will aid a quantitative appreciation of the interaction of wind and building and the resultant ventilation rate and internal velocities.

## THEORY

The flow of a fluid through an opening can be described by the following equation:

$$\Delta P = k \tfrac{1}{2} \rho V^2 \qquad \ldots 1$$

The pressure difference due to wind across an opening in a building is given by:

$$\Delta P = P_e - P_i = (C_{pe} - C_{pi}) \tfrac{1}{2} \rho V_{10}^2 \qquad \ldots 2$$

Combining Equations 1 and **2** gives:

$$V^2 = V_{10}^2 \frac{C_{pe} - C_{pi}}{k} \qquad \ldots 3$$

For a sudden expansion and negligible approach velocity k is taken as unity. Allowance is made for the vectorial character of the momentum with the result:

$$V_n = V_{10} \frac{C_{pen} - C_{pi}}{\sqrt{|C_{pen} - C_{pi}|}} \qquad \ldots 4$$

for the nth opening.

The volume flow rate through the nth opening is:

$$Q_n = A_n V_n \qquad \ldots 5$$

Assuming negligible change in air density the overall continuity constraint gives:

$$\Sigma A_n V_n = 0 \qquad \ldots 6$$

## SOLUTION

The basic problem is to find the internal pressure coefficient which gives values of $V_n$ which satisfy Equation **6**. The method adopted is to guess an initial value for the internal pressure coefficient, $C_{pi}$, calculate the corresponding set of $V_n$ values, then check to determine whether the air entering the building is approximately equal to the air leaving the building. If this is not so then the guess is modified and the calculation repeated.

Initially $C_{pi}$ is given the value $-2.0$. This ensures that a net inwards or positive flow will be calculated. $C_{pi}$ is then repeatedly incremented by $+0.2$ and the calculation carried

**NOTATION**

| | |
|---|---|
| A | area of opening |
| Cp | pressure coefficient |
| k | resistance coefficient |
| P | pressure |
| $\Delta P$ | pressure difference |
| Q | volume flow rate |
| V | velocity |
| $\rho$ | density |

**Subscripts**

| | |
|---|---|
| e | external |
| i | internal |
| n | nth |
| 10 | at 10 m height |

out until a value of $C_{pi}$ is reached which results in a change to a net outward flow. The process is repeated using a step of - 0.01 and finally with steps of + 0.0005 until a change in direction of the net flow occurs. The $C_{pi}$ currently in use is then printed out together with the calculated velocity and ventilation data. The flow chart and program listing in Fortran IV are given in the Appendices.

The surface of a building being considered may be divided into any number of parts which need not be equal. The program will currently handle up to 200 elements but this could easily be expanded. The pressure coefficient and the area of opening for each element must be specified. The open area may, of course, be zero. The wind velocity $V_{10}$ is taken as 1 m/s therefore all velocities and ventilation rates must be scaled to the wind velocity of interest.

## EXAMPLE

A complete set of pressure coefficients had previously been measured and documented for a model livestock building (1). The building is described in detail elsewhere (1, 2). The plan of the building is rectangular; the length is 35 m and the width 22 m. The eaves height is 2.2 m with sloped side walls. The roof pitch angle is 12°. The ventilation apertures in the gables are shown in Fig 1. Not shown are the 75 mm continuous eaves openings and the 150 mm continuous open ridge uncapped with no upstands. The building surface was divided into 132 elements to correspond to the pressure tapping positions on the model and the open area for each element calculated.

The computer is presented with data as follows: number of wind angles to be considered, number of elements on building, list of open areas for all elements, wind angle, pressure

**Table 1**

Sample of computer output

WIND ANGLE 30 CPI - 0.130
VENTILATION 11.22 DV - 0.012

| N | CPE | AREA | VELOCITY | VENTILATION |
|---|---|---|---|---|
| 1 | 0.26 | 0.000 | 0.625 | 0.000 |
| 2 | 0.25 | 1.290 | 0.617 | 0.796 |
| 3 | 0.20 | 0.000 | 0.575 | 0.000 |
| 4 | 0.15 | 0.000 | 0.530 | 0.000 |
| . | . | . | . | . |
| . | . | . | . | . |
| . | . | . | . | . |
| . | . | . | . | . |
| 131 | - 0.14 | 1.290 | - 0.097 | - 0.126 |
| 132 | - 0.20 | 0.000 | - 0.264 | 0.000 |

coefficients for each element corresponding to the wind angle. As many wind angles as wished can be processed.

The computer output takes the form shown in Table 1.

The output is self explanatory. The ventilation rates are given in $m^3/s$ and DV gives the magnitude and sign of the residual error in the flow balance.

Fig 2 shows the variation of the internal pressure coefficient with wind angle. Also shown on Fig 2 are the values which were calculated on an approximate basis (1). The agreement is not good and reflects the inaccuracy of the value of $C_{pi}$ derived from:

$$C_{pi} = \Sigma A^2 C_{pe} / \Sigma A^2 \quad \ldots 7$$

which was originally acknowledged as not theoretically correct.

The variation of total ventilation rate with wind direction is shown in Fig 3 for $V_{10}$ = 1 m/s.

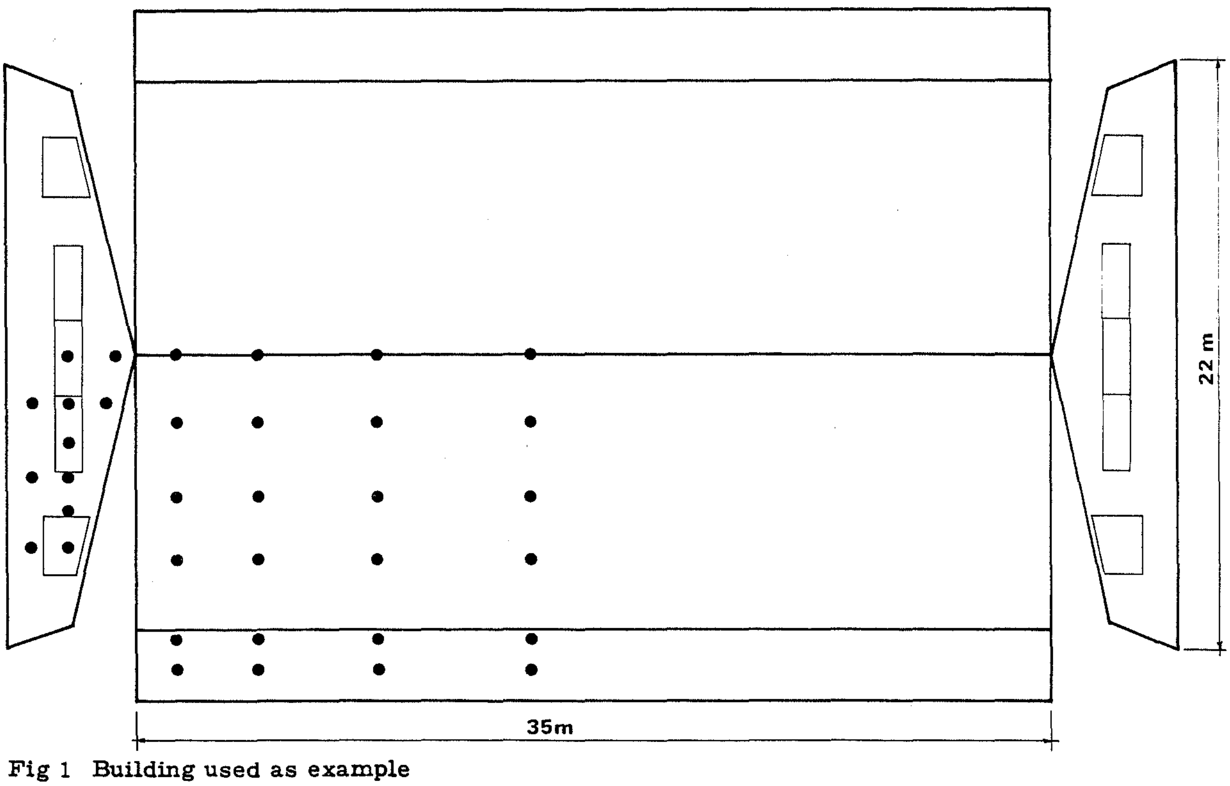



**Fig 1 Building used as example**

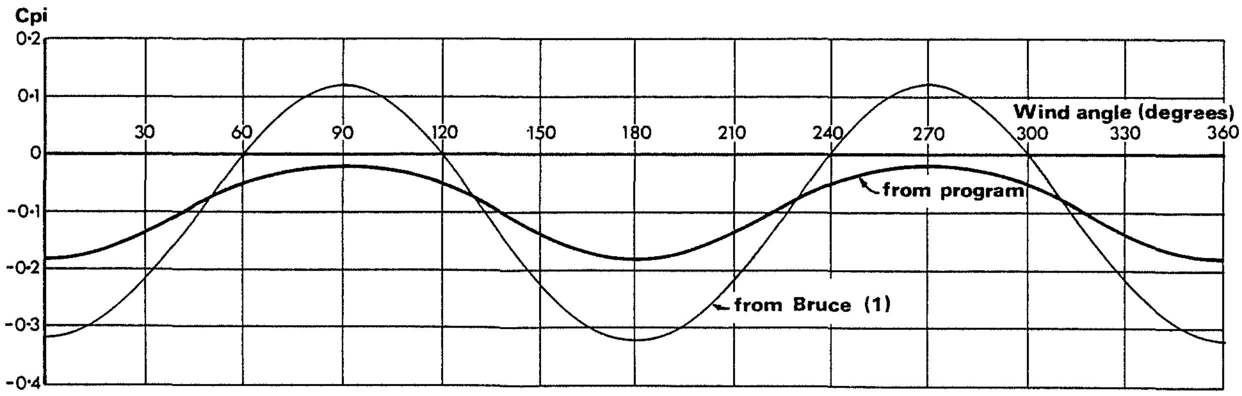



**Fig 2 Internal pressure coefficient**

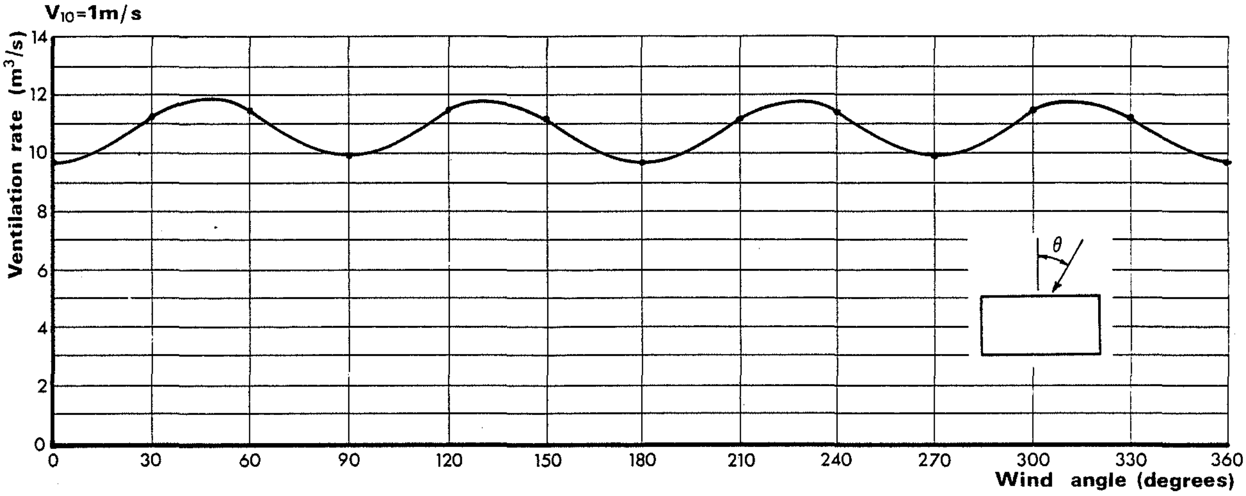



**Fig 3 Variation of ventilation rate with wind direction**

The main observation is that there is not a great deal of variation, ie the ventilation of the building is not highly dependent on the wind direction. If the average wind velocity varies with direction, which it normally does, then the ventilation rate will also vary with wind direction. A secondary point is that the frequency of change of ventilation rate with wind angle is twice the frequency of change of the internal pressure coefficient. There is no general significance attached to this.

Each opening may be looked at to decide its contribution to the ventilation system, eg it is found that the open ridge acts as an outlet along its whole length at all times.

Where no opening is present the pressure difference across the building shell is found from Equation 2. However structural aspects are not the primary consideration here and no pressure tappings were located very near the roof borders which are known to be highly loaded areas.

Only a free-standing building has been considered in this work. If there are obstructions such as trees, hedges or other buildings near enough to affect the pressure coefficient distribution, then these obstructions must also be modelled in the wind tunnel.

## LIMITATIONS

The use of the program described presupposes the existence of pressure coefficient data which would normally be obtained from wind tunnel and model work.

It is known that in turbulent flow ventilation can take place by pulses in and out of an opening. This will be unaccounted for when time-averaged pressure coefficient data are used. The assumption is made that the resistance coefficients of the openings are all unity. This limitation is imposed due to ignorance of the actual values rather than a desire for simplicity. Where the openings can be treated as sharp-edged orifices the assumption is not likely to be far wrong. Also a factor would necessarily have to be applied to the ventilation values to allow for the flow area contraction at the openings. An area coefficient of 0.6 would be suitable for a sharp-edged orifice which would be reasonable for most naturally ventilated livestock buildings.

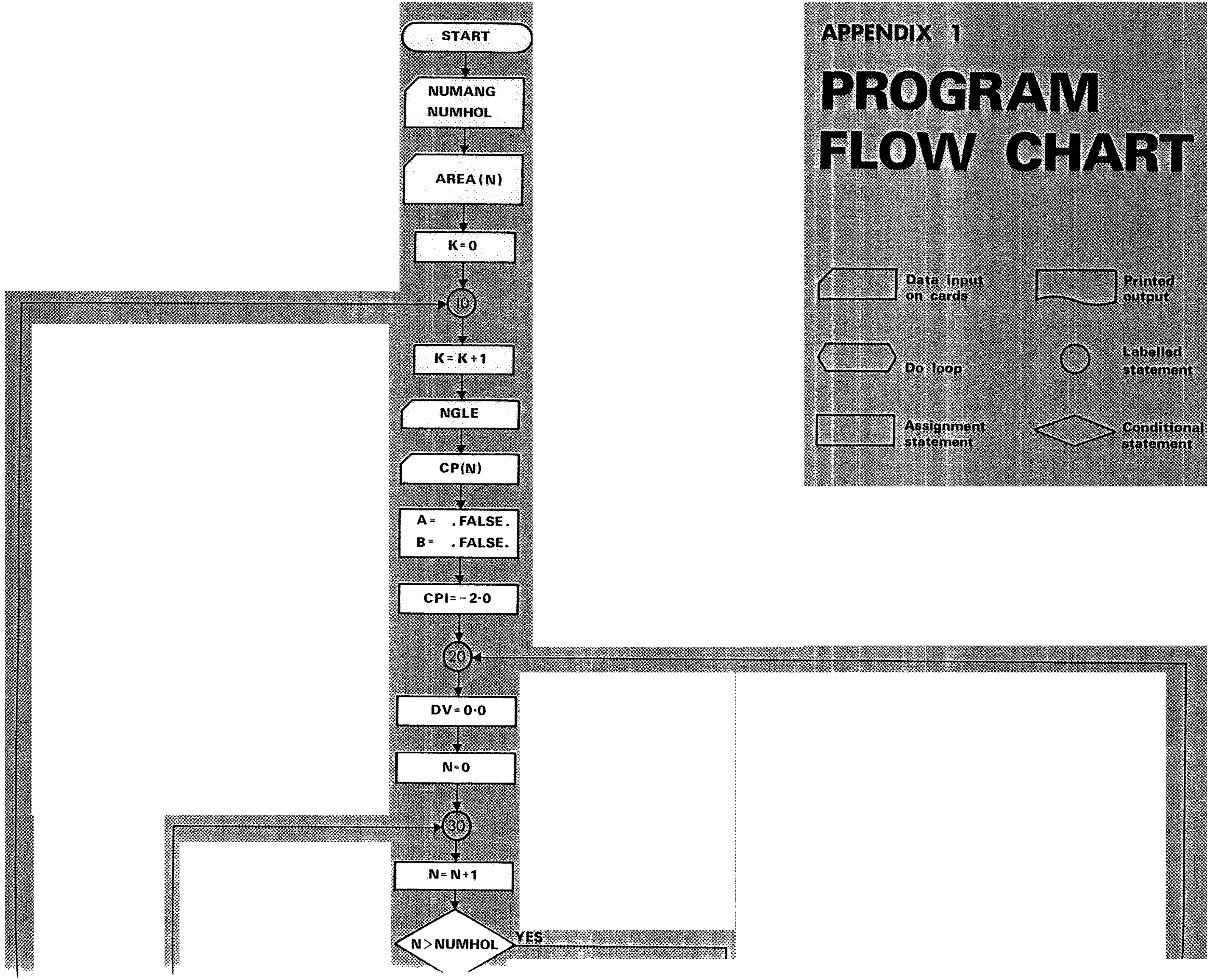
The solid model pressure coefficients are assumed to be unchanged for a building with openings. A simple analysis (1) justifies this assumption.

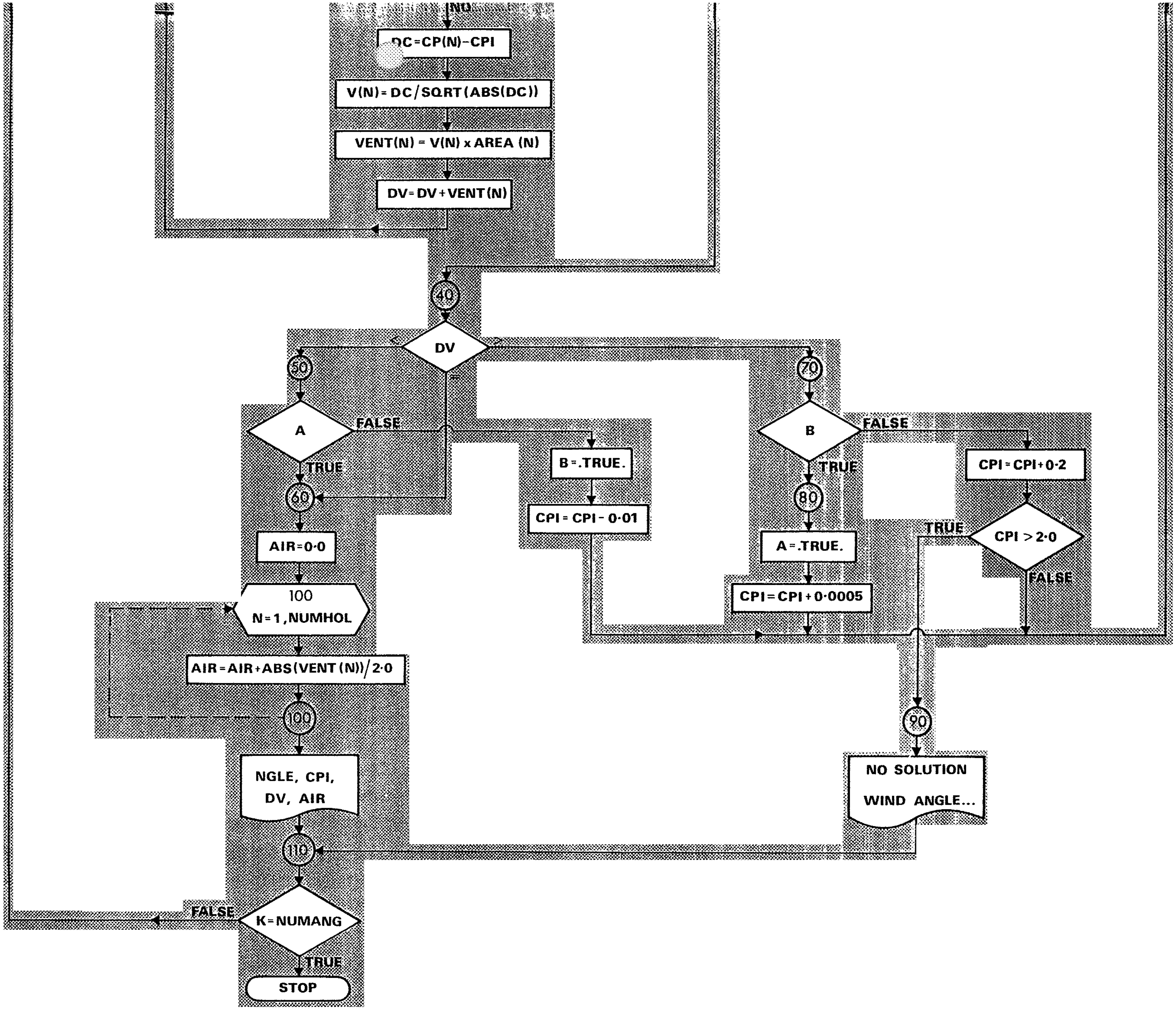
## FUTURE DEVELOPMENT AND APPLICATION

Wind effects only have been considered so far. The mathematical model could be expanded to incorporate the effects of thermal buoyancy which would be important at low wind speeds. The pressure-flow characteristics of fans could be incorporated so that wind interference could be investigated and the position of fans in the building shell optimised. In a complex

APPENDIX 1

# PROGRAM FLOW CHART




NO
DC=CP(N)−CPI
V(N)=DC/SQRT(ABS(DC))
VENT(N) = V(N) x AREA (N)
DV=DV+VENT(N)
40
DV
<
>
=
50
A
FALSE
TRUE
60
AIR=0·0
100
N=1,NUMHOL
AIR=AIR+ABS(VENT(N))/2·0
100
NGLE, CPI, DV, AIR
110
K=NUMANG
FALSE
TRUE
STOP
B=.TRUE.
CPI=CPI−0·01
70
B
FALSE
TRUE
80
A=.TRUE.
CPI=CPI+0·0005
CPI=CPI+0·2
CPI > 2·0
TRUE
FALSE
90
NO SOLUTION
WIND ANGLE...

case it would also be necessary to use measured flow resistance coefficients. The program as developed will be used to investigate the effects of perforated roofs on natural ventilation, a task otherwise prohibited by the lengthy calculations.

Air movement within a livestock building has an important effect on the thermal environment of the animals. Analysis of buildings using the program can help quantify and compare maximum air velocities. A quantitative measure of the wind sheltering effect of naturally ventilated buildings becomes possible. A simple application of this has been made (3).

**SUMMARY**

A digital computer program has been described which will, within the limitations described, calculate air velocities at the openings in a building and the ventilation rate due to wind.

**REFERENCES**

(1) BRUCE J M Wind tunnel investigation of a model livestock building SFBIU rep April 1974

(2) BRUCE J M Wind tunnel study Fm bldg prog (38) October 1974 15-17

(3) BRUCE J M Natural ventilation - its role and application in the bio-climatic system Presented at MAFF closed tech conf 'Climatic environment and livestock production' London 5-6 May 1975

# Appendices

**Appendix 1 - see centre pages**

**Appendix 2 Program Listing**

```
      PROGRAM WINDIN
      DIMENSION AREA(200),CP(200),V(200),VENT(200)
      LOGICAL A,B
      READ(5,1)NUMANG,NUMHOL
    1 FORMAT(2I6)
      READ(5,2) (AREA(N),N=1,NUMHOL)
    2 FORMAT(10F8.3)
      K=0
   10 K=K+1
      READ(5,1)NGLE
      READ(5,2) (CP(N),N=1,NUMHOL)
      A=.FALSE.
      B=.FALSE.
      CPI=-2.0
   20 DV=0.0
      N=0
   30 N=N+1
      IF(N.GT.NUMHOL) GO TO 40
      DC=CP(N)-CPI
      V(N)=DC/SQRT(ABS(DC))
      VENT(N)=V(N)*AREA(N)
      DV=DV+VENT(N)
      GO TO 30
   40 IF (DV)50,60,70
   50 IF (A) GO TO 60
      B=.TRUE.
      CPI=CPI-0.01
      GO TO 20
   70 IF (B)  GO TO 80
      CPI=CPI+0.2
      IF(CPI.GT.2.0) GO TO 90
      GO TO 20
   80 A=.TRUE.
      CPI=CPI+0.0005
      GO TO 20
   90 WRITE(6,3)NGLE
    3 FORMAT(1H0,4X,22HNO SOLUTION WIND ANGLE,I4,1X,7HDEGREES)
      GO TO 110
   60 AIR=0.0
      DO 100 N=1,NUMHOL
      AIR=AIR+ABS(VENT(N))/2.0
  100 CONTINUE
      WRITE(6,4)NGLE,CPI,AIR,DV
    4 FORMAT(1H0,10HWIND ANGLE,I4,5X,5HCPI =,F6.3,5X,11HVENTILATION,F8.2
     1,5X,2HDV,F8.3)
      WRITE(6,5)
    5 FORMAT(1H0,3X,1HN,6X,3HCPE,7X,4HAREA,7X,8HVELOCITY,7X,11HVENTILATI
     1ON)
      WRITE(6,7)
    7 FORMAT(1H )
      WRITE(6,6) (N,CP(N),AREA(N),V(N),VENT(N),N=1,NUMHOL)
    6 FORMAT(I4,F11.2,F12.3,F10.3,9X,F11.3)
  110 IF(K.EQ.NUMANG) STOP
      GO TO 10
      END
```

**NOTATION**

| | |
|---|---|
| NUMANG | number of wind angles |
| NUMHOL | number of building surface elements |
| AREA(N) | area of opening in nth element |
| NGLE | wind angle |
| CP(N) | external pressure coefficient for nth element |
| CPI | internal pressure coefficient |
| AIR | total ventilation rate |
| DV | residual error in total ventilation rate |
| N | nth element |
| V(N) | velocity for nth element |
| VENT(N) | volume flow for each element |

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