VENTILATION STRATEGIES AND MEASUREMENT TECHNIQUES

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PAPER 23

VENTILATION STRATEGIES FOR CRAWL-SPACES, ATTICS ETC.

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1. SYNOPSIS

In this paper ventilation of attics and crawl-spaces is investigated theoretically. Ventilation rates and temperatures of the spaces are calculated by means of flow balance procedures. Flow characteristics of ventilators and openings for attics and crawl-spaces are far from well known, so a laboratory investigation on pressure drops across such devices was undertaken and reported in the paper. As convective flows from the heated part of a house into a colder, ventilated space can create moisture problems this situation has been investigated extensively.

2. INTRODUCTION

Spaces connected to heated parts of a building, such as crawl-spaces, attics etc, are normally ventilated. The need for ventilation is mainly based on ambitions of moisture control. An adequate ventilation of these spaces prevents moisture problems and damages. The ventilation <u>need</u> for this purpose depends on many factors such as outer climate, heat insulation degree, moisture sources within the space itself, for example evaporation from the ground in a crawl-space, or built- in moisture in the building material, degree of moisture convection from the heated part of the buildning into the space. The ultimate ventilation need is settled by the critical level of moisture load for buildning materials within the ventilated space. This critical level is normally formulated in terms of maximum allowable relative humidity (RH) for different materials. For wood and wood-based materials this level is often claimed to be around 75% for avoiding mould growth on wood and around 80% for avoiding rot in wood. (NEVANDER & ELMARSSON, 1981). For chip-boards moisture-related movements may cause trouble for example om attic floors prepared for making dwelling room on later on. For steel and other metals, risk for corrosion may create certain critical moisture levels.

Considerations as these mentioned above lead to settlement of a minimum ventilation degree.

On the other hand, excessive ventilation of such spaces creates unnecessarily high energy losses due to transmission between the heated part of the building and the ventilated space. For example, the design philosophy of crawl-space foundation implies a certain insulation gain due to the presense of the crawl-space. This implies a maximum ventilation degree.
The desired ventilation intensity can be achieved by means of natural forces such as wind and/or temperature differences or by mechanical ventilation devices. The degree of wind-driven ventilation of these spaces is depending on several factors:

- local wind velocity
- shape of the surrounding of the building
- geometrical proportions of the building
- dimensions and design of air inlet/outlet openings and ventilators
- location of these openings and ventilators
- etc.

Estimating climate in ventilated non heated spaces belongs to the more severe problems in building physics. For a complete analysis of the problems a lot of factors have to be taken into account:

- The ventilation degree (see above)
- The air tightness behaviour of the buildning component between the space and the heated part of the buildning
- The heat exchange within the space involving transmission, convection and radiation
- Moisture sources, moisture flow and moisture capacity

The analysis is strongly simplified if average conditions are sufficient for the considerations. As a first step such an analysis may be enough as far as durability risks are concerned.
The radiative part of the heat exchange is also a difficult step in a complete heat exchange analysis. However, for modern well-insulated constructions between heated and ventilated spaces the

influence of heat radiation may be small. The long wave radiation though can cause considerable surface temperature phenomena especially on the outside of roofs on clear nights.
In this paper a method for calculating ventilation intensities in attics and crawl-spaces is presented. Furthermore an average based analysis of the climate in the spaces is carried out.

3. REFERENCE HOUSE

The calculations presented further on in the paper are all performed for a house outlined in figure 3.1.

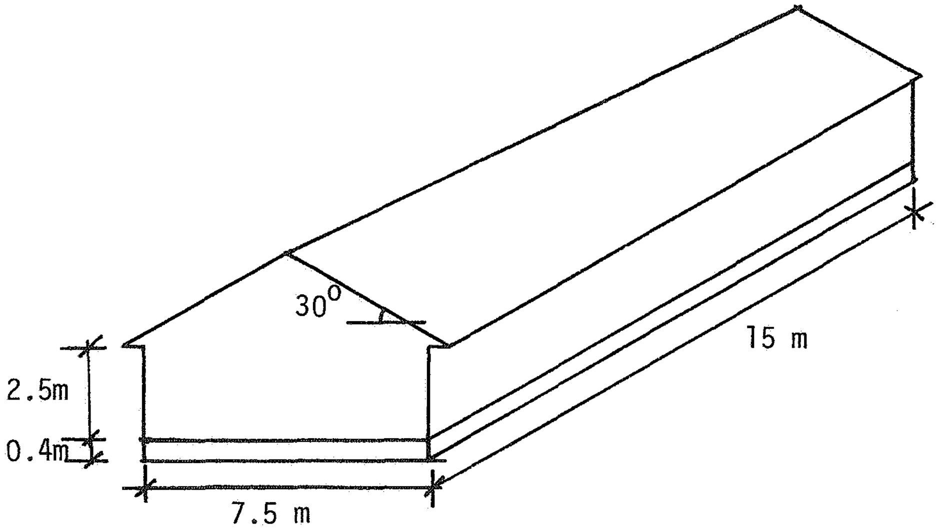

FIG. 3.1 Reference house.

For wind load considerations the house is intended to be located in a built up area. The shape factors used for the calculations figure 3.2-3.4 are mainly based on comparisons and analyses of results reported by JENSEN & FRANK, 1965; GANDEMER, 1978; LEUTHENSSER, 1970; NEWBERRY & EATON, 1974; THURESSON, 1977; GUSTEN, 1984; AIC, 1984 & SOLIMAN, 1973.

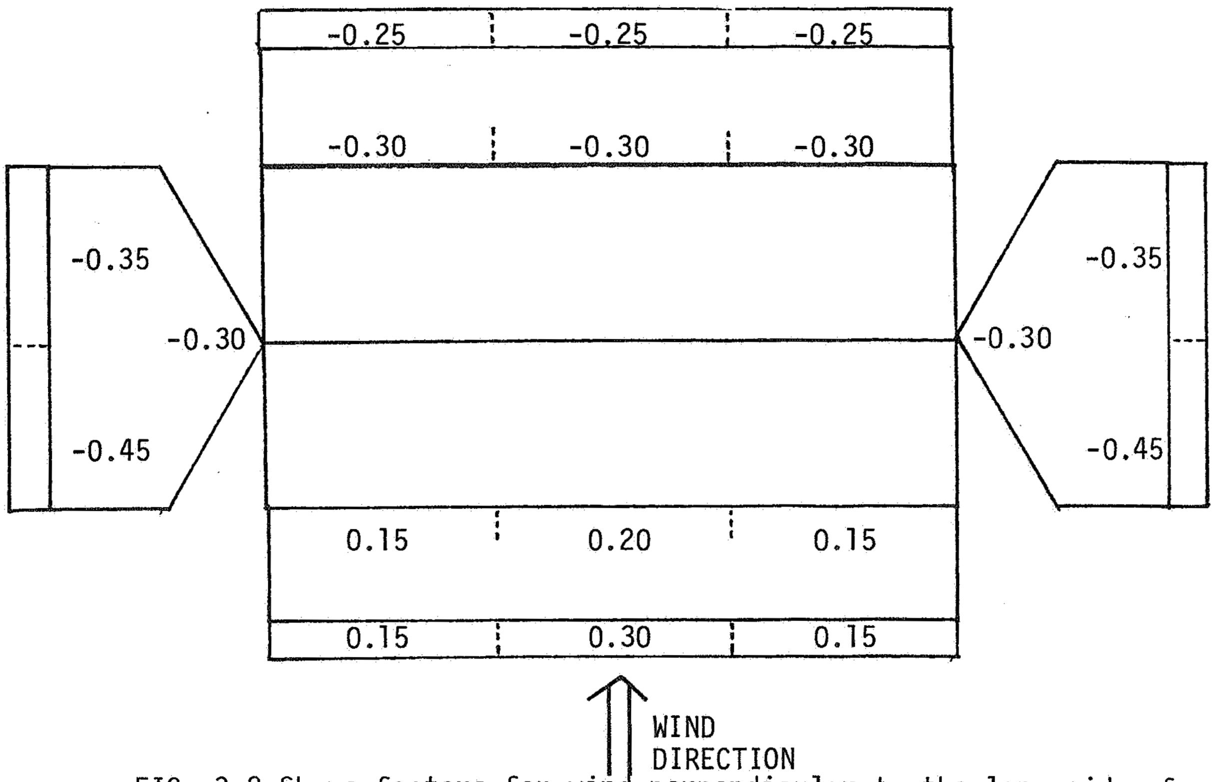

FIG. 3.2 Shape factors for wind perpendicular to the long side of the reference house.

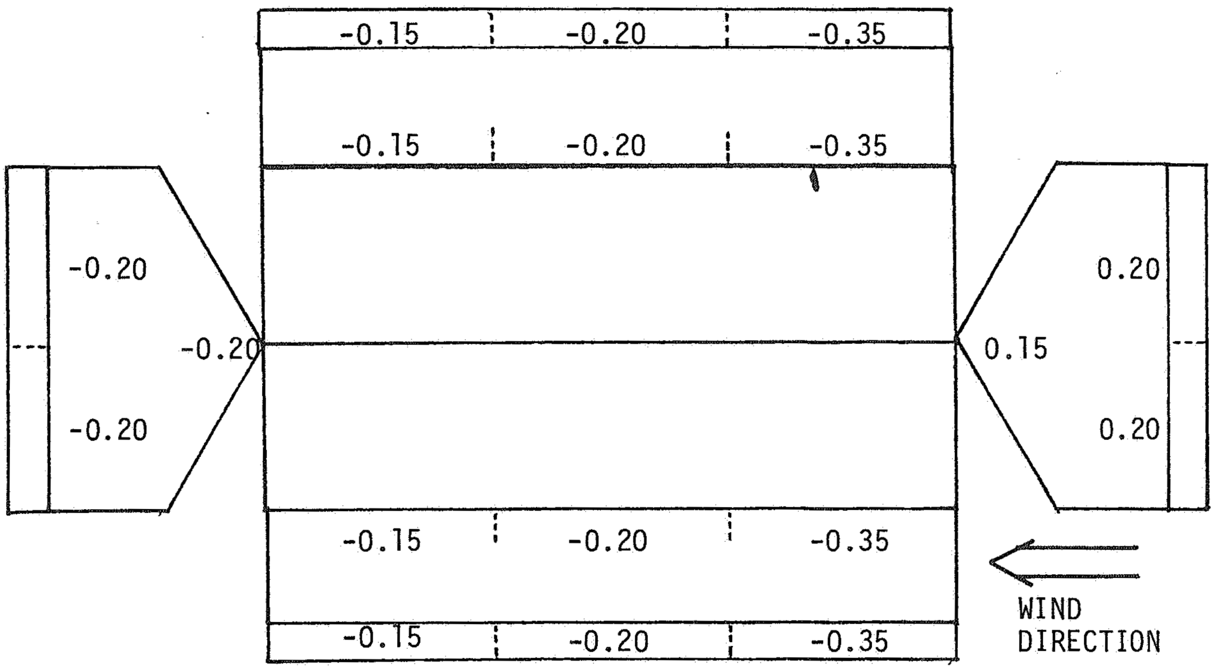

FIG. 3.3 Shape factors for wind perpendicular to gable part of the reference house.

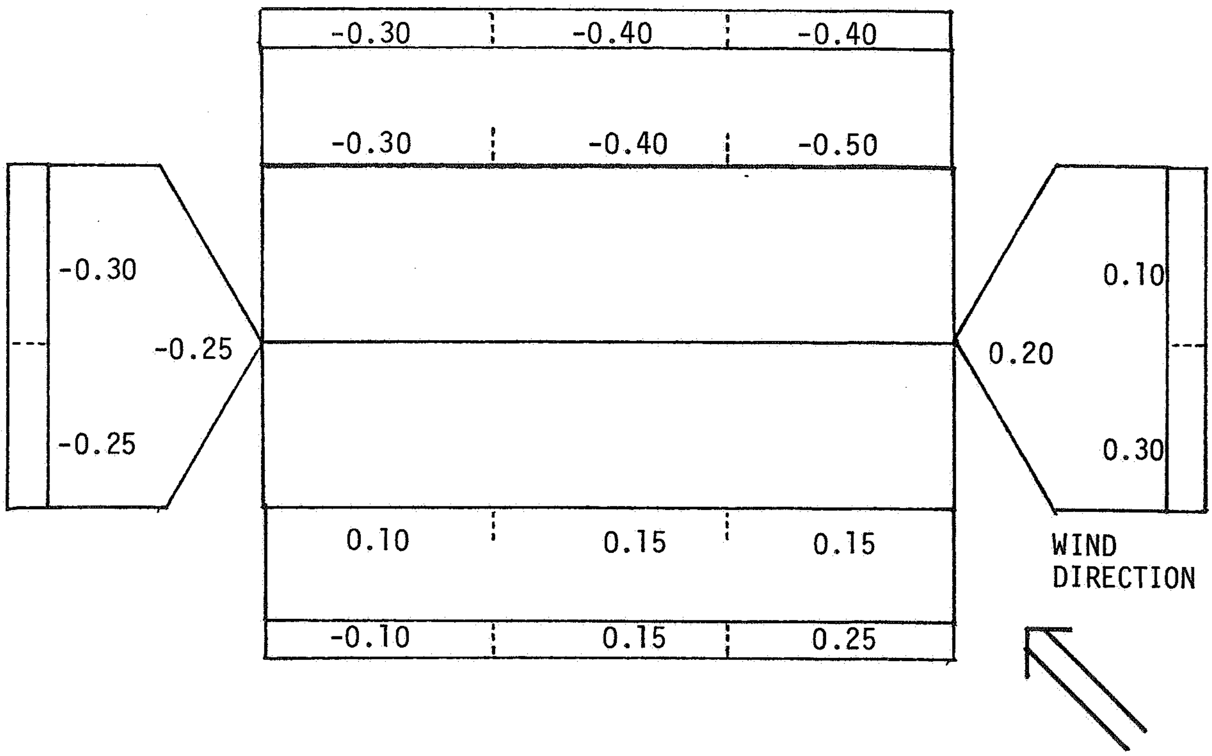

FIG. 3.4 Shape factors for wind 45^0 to longside and gable part of the reference house.

4. AIR FLOW CHARACTERISTICS OF VENTILATION OPENINGS AND VENTILATORS

In the laboratory the air flow behaviours of different ventilation openings and commercially offered ventilators were investigated. The openings and ventilators were connected to a pressurized box, airtight except for the investigated specimen. The pressure difference between the two sides of the specimen was monitored by means of an electrical micro-manometer. The air flow rate supplied to the box was monitored by means of an orifice plate and a micro-manometer. The pressure regime investigated was 0-100 Pa. The results are given in table 4.1 as pressure loss factors, ξ , originating from the well-known expression

$$\Delta p = \xi \frac{\rho \cdot u_m^2}{2}$$

where

Δp = pressure difference, Pa

ξ = pressure loss factor, -

ρ = density, kg/m^3

U_m = mean velocity i.e. q_v/A
where q_v = volume flow rate, m^3/s and A = nominal frontal area, m^2

Ventilator/opening, type	Area mm^2	Pressure loss factor, ξ
Pressed steel	125 x 125	48
"-	150 x 150	47
"-	200 x 200	45
"-	250 x 250	32
"-	65 x 250	26
Light metal	125 x 125	7,7
"-	150 x 150	6,9
"-	200 x 200	6,8
"-	250 x 250	7,1
Open hole	71 x 71	2,1
"-	150 x 150	2,3
Hole with plastic net	71 x 71	2,3
Hole with brass net	71 x 71	2,4
Hole with plastic net	150 x 150	2,9
Hole with brass net	150 x 150	2,6

TABLE 4.1 Pressure loss factors for different ventilators and openings.

5. VENTILATION RATE CALCULATION PROCEDURE

The rates of air flow into and out from the ventilated space for different flow types were calculated using the following expressions. (see for example KRONVALL, 1980):

Single resistance flow

$$|q_v| = \sqrt{\frac{|(\mu \cdot \rho \cdot u_0^2/2 - p)| \cdot 2}{\xi \cdot \rho}} \cdot A \qquad \ldots 5a$$

where

q_v = volume flow rate, m^3/s

μ = shape factor, -

u_0 = reference wind velocity, m/s

ρ = density, kg/m^3

p = pressure in the ventilated space, Pa

ξ = pressure loss factor, -

A = flow (frontal) area, m^2

Flow through building components etc.

Laminar flow:

$$q_v = (\mu \cdot \rho \cdot u_0^2/2 - p) \cdot L \cdot A \qquad \ldots 5b$$

where

L = flow coefficient, $m^3/(m^2 \cdot s \cdot Pa)$

Exponent flow:

$$|q_v| = \alpha \, |(\mu \cdot \rho \cdot u_0^2/2 - p|^{\beta} \cdot A \qquad \ldots 5c$$

where

α = flow coefficient, $m^3/(m^2 \cdot s \cdot Pa^{\beta})$

β = flow exponent, - , $0{,}5 \leq \beta \leq 1.0$

The flow expressions are written as flows into the ventilated spaces. For the flow balance calculation of the pressure differences 5 a and 5 c are given positive or negative values depending on the sign of the pressure expressions.

Summing up all the different flows into the space and putting the sum equal to 0 i.e. :

$\Sigma q_v = 0$ ...5d

makes it possible to determine the unknown variabel p (pressure inside the space). If different flow types are involved the implicite function must be treated iteratively. The calculations were performed by using the Newton-Raphson procedure and executed on a Hewlett-Packard HP 85 computer. The computer program is listed in appendix 1.

6. CALCULATION RESULTS

Some of the results of executed calculations are given in diagraph form in
figure 6.1-6.6.

6.1 ATTICS

Two main alternatives for ventilating the attic were investigated:

- slot at roof bottom of the long sides of the house, width 20, 10 and 2 mm (the last case representing non volontarily made slots).
- ventilators in the gable tops, pressed steel and light metal, dimensions 150 x 150 mm and 250 x 250 mm.

The calculations were performed for different wind directions.

Results:

A 45^o angle between wind direction and the long side of building seems to produce higher ventilation rates than that of wind perpendicular to the long sides of the house. The least effective ventilation seems to be obtained when the wind is parallel to the long sides of the house. In the case of ventilation openings in the gable tops however the situation is the opposite.

There are linear relationships between

- wind velocity and ventilation rate
- ventilation opening area and ventilation rate

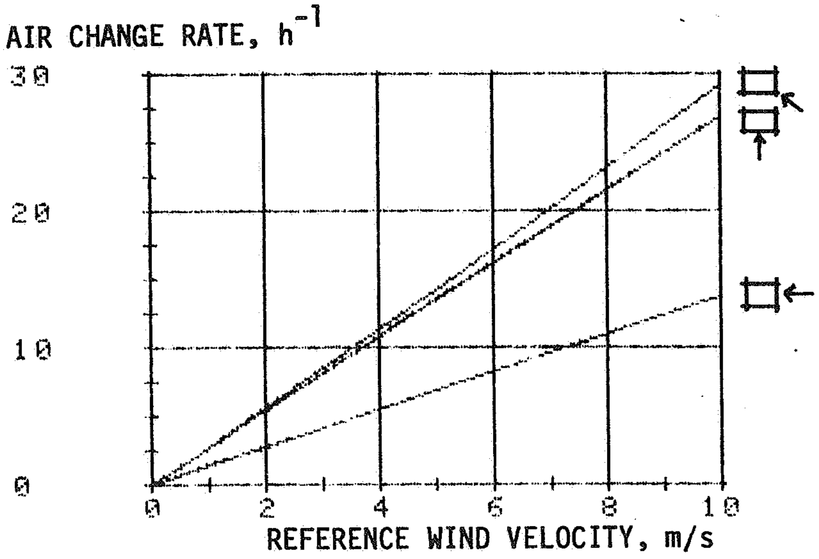

FIG. 6.1 Slot at roof bottom, width 20 mm, permeable gable tops $0.14 \cdot 10^{-3}$ $m^3/(m^2 \cdot s \cdot Pa)$

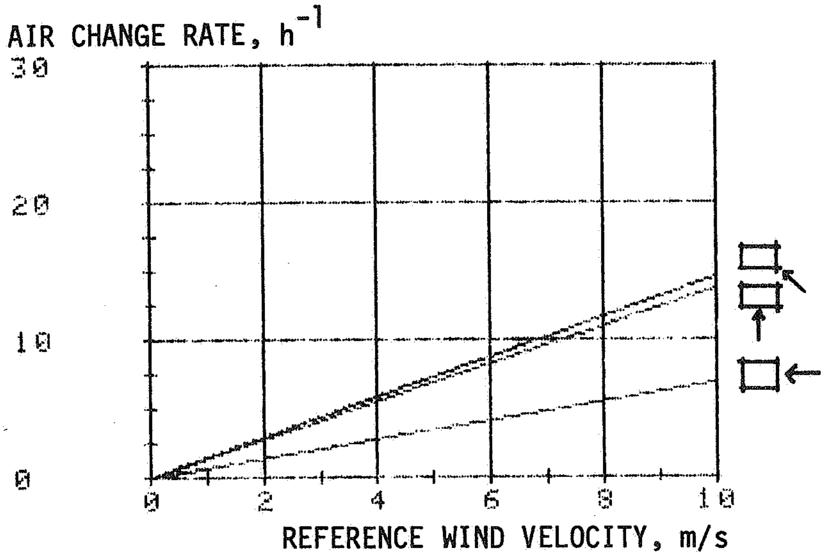

FIG. 6.2 Slot at roof bottom, width 10 mm, permeable gable tops $0.14 \cdot 10^{-3}$ $m^3/(m^2 \cdot s \cdot Pa)$

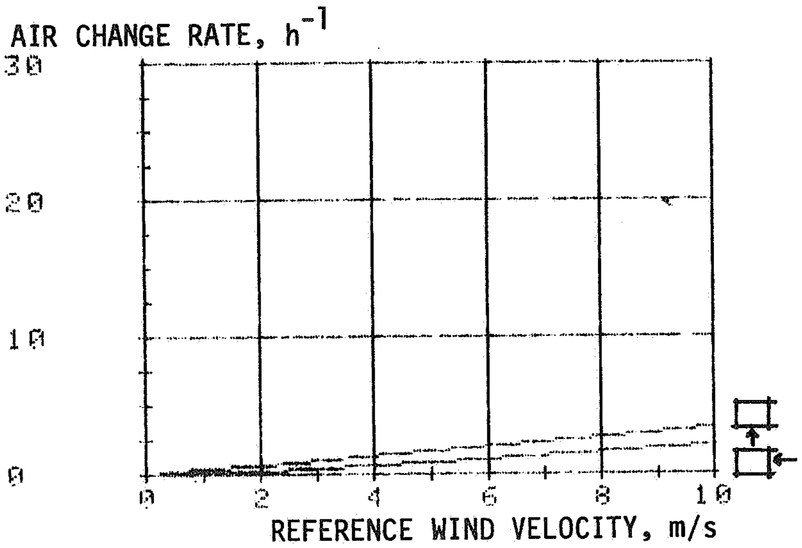

FIG. 6.3 Slot at roof bottom, width 2 mm, permeable gable tops 0.14 · 10^{-3} $m^3/(m^2 \cdot s \cdot Pa)$
1 ventilator 150 x 150 mm, pressed steel, in each gable top

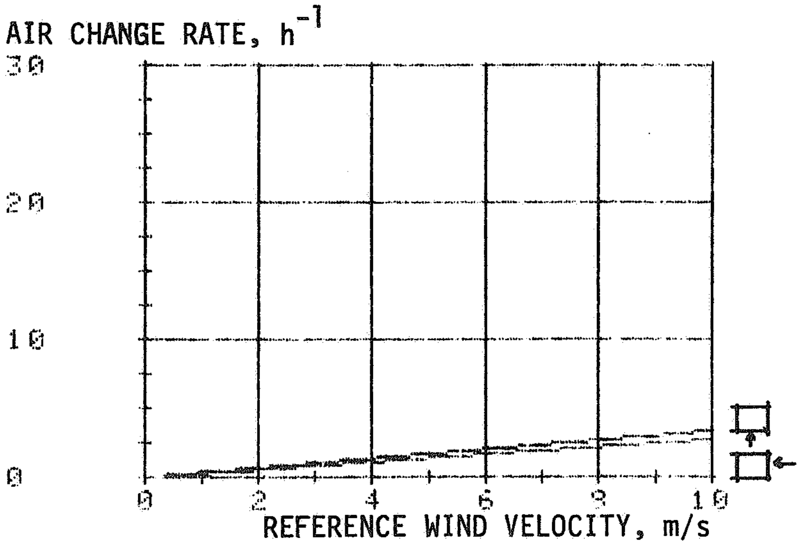

FIG. 6.4 Slot at roof bottom, width 2 mm, permeable gable tops 0.14 · 10^{-3} $m^3/(m^2 \cdot s \cdot Pa)$
1 ventilator 150 x 150 mm2, light metal, in each gable top

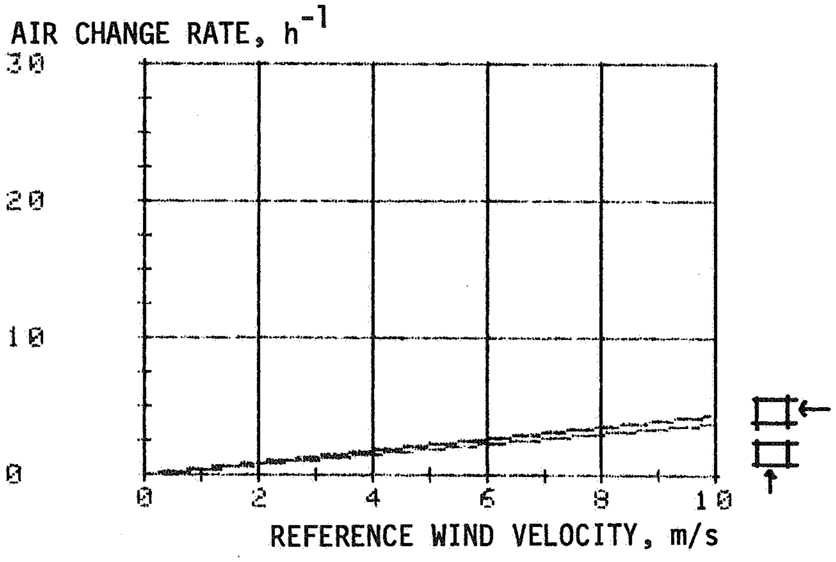

FIG. 6.5 Slot at roof bottom, width 2 mm, permeable gable tops 0.14 · 10^{-3} $m^3/(m^2 \cdot s \cdot Pa)$
1 ventilator 250 x 250 mm2, light metal, in each gable top

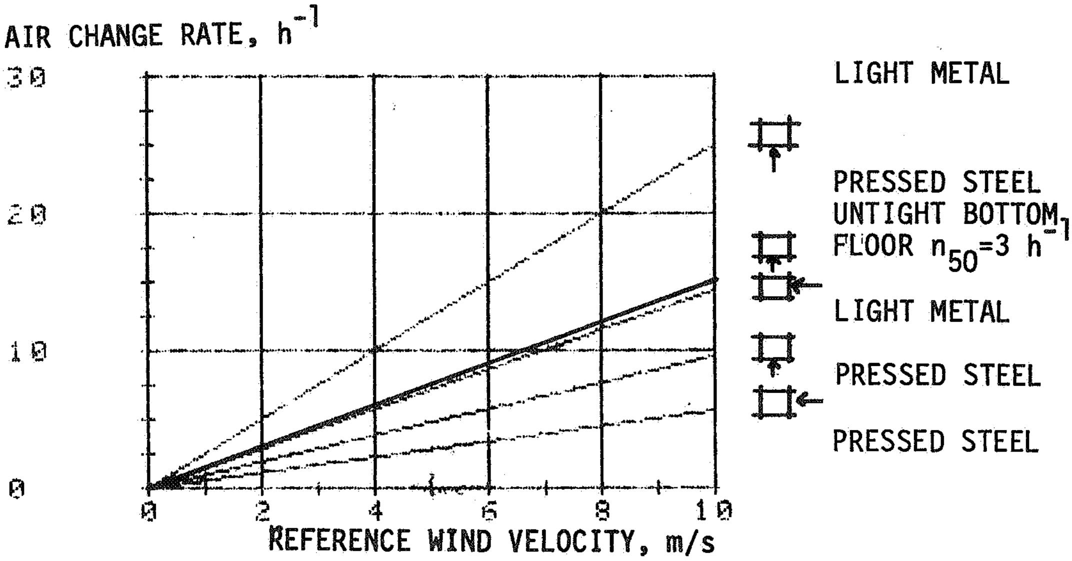

FIG. 6.6 24 ventilators 150 x 150 mm2, 9 on each long side, 3 on each gable side, pressed steel and light metal, average height of crawl-space 0,60 m

These facts are of course due to the small influence of the presumed laminar flow through the gable tops.
($L = 0{,}14 \cdot 10^{-3}\ m^3/(m^2 \cdot s \cdot Pa)$; value for wood panel according to BANKVALL, 1981.)
The most effective ventilation of the attic space seems to be obtained by means of ventilation slots at the roof bottoms of the long sides of the house.

6.2 CRAWL-SPACES

The ventilation devices chosen for the crawl-space are ventilators 150 x 150 mm, pressed steel and light metal. The number of ventilators was chosen according to recommendations in the Swedish Building Code. (0,10 m^2 open area/100 m^2 floor area, which is a recommendation for houses in tight built up areas when using wood bottom floor. For pressed steel ventilators an area reduction is prescribed, namely 22% of ventilator frontal area.)
In order to study the consequences of a leaky bottom floor, one calculation was made for a bottom floor having an air leakage of a value corresponding to 3,0 h^{-1} at 50 Pa pressure difference, evenly distributed over the house envelope area.

Results:
Apart from the linear relationship between wind velocity and ventilation rate mentioned above, the ventilation rate is strongly depending on type of ventilator used. This is of course due to the large differences between pressure loss factors for pressed steel and light metal ventilators, cf. table 4.1. When using light metal ventilators instead of pressed steel ones, both being of the same size, the ventilation rate is raised by a factor of appr. 2.5.
$(= \xi_{\text{pressed steel}} / \xi_{\text{light metal}})$.
When the untight bottom floor is added to the calculation the ventilation rate increases and the air flow through the bottom floor, directed from the crawl-space to the heated part of the house is of considerable magnitude, appr. 75% of the total ventilation flow rate !

7. HEAT BALANCE CALCULATIONS

Heat balance calculations have been conducted for a winter case with the temperature of outside air equals ± 0 ° C. Conductive and convective parts of the heat exchange have been taken into account. For the roofing a heat transmission coefficient of 1,5 $W/(m^2 \cdot K)$ was chosen.

7.1 ATTICS

Figure 7.1-7.4 illustrate the resulting air temperature in the attic space under influence of different ventilation rates (fresh air), heattransmission coeffients of the attic floor and convection flows from the heated part of the house into the attic.

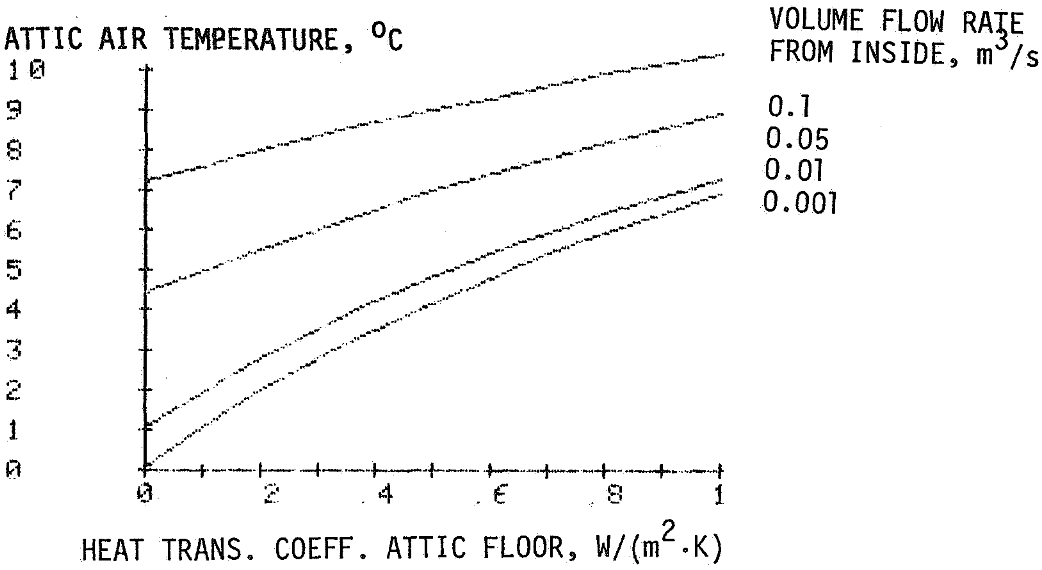

FIG. 7.1 Heat balance calculation

$n_{attic} = 0,5\ h^{-1}$

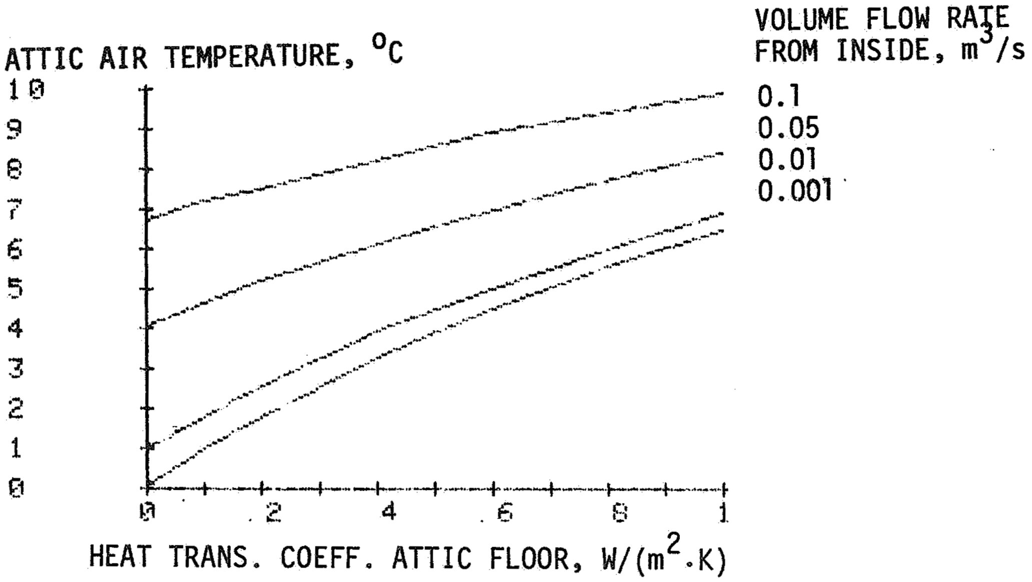

FIG. 7.2 Heat balance calculation
$n_{attic} = 1.0\ h^{-1}$

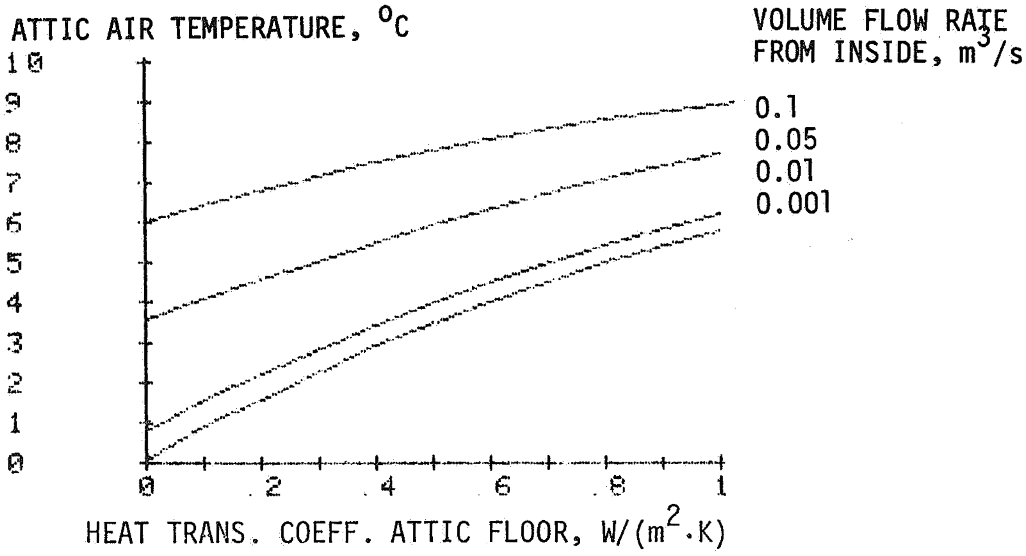

FIG. 7.3 Heat balance calculation
$n = 2.0\ h^{-1}$

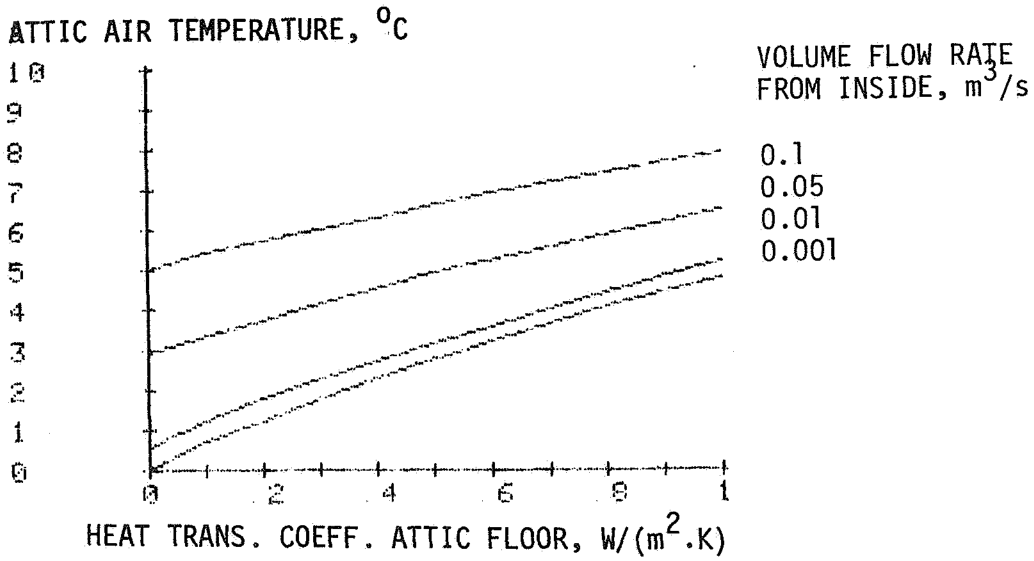

FIG. 7.4 Heat balance calculation
$n = 4{,}0\ h^{-1}$

In order to make it possible to perform proper considerations on the magnitude of the convective flow into the attic, figure 7.5 can serve as a basis. Even distribution of leaks all over the house envelope is assumed, why n_{50} describes the air tightness of the attic floor. For different pressure differences the resulting air flow into the attic can be seen. The air tightness behaviour of the attic floor can also be included in the air flow balance calculation revued in ch. 5. However, as stack effect inside the house must be considered at winter conditions the "normally" used inner shape factor, μ_i of a magnitude - 0,3, see for example NEWBERRY & EATON, 1974, must be modified for stack effect. This was made for a "typical" winter condition assuming that the pressure difference caused by stack effect inside the house was appr. + 2 Pa at ceiling height.

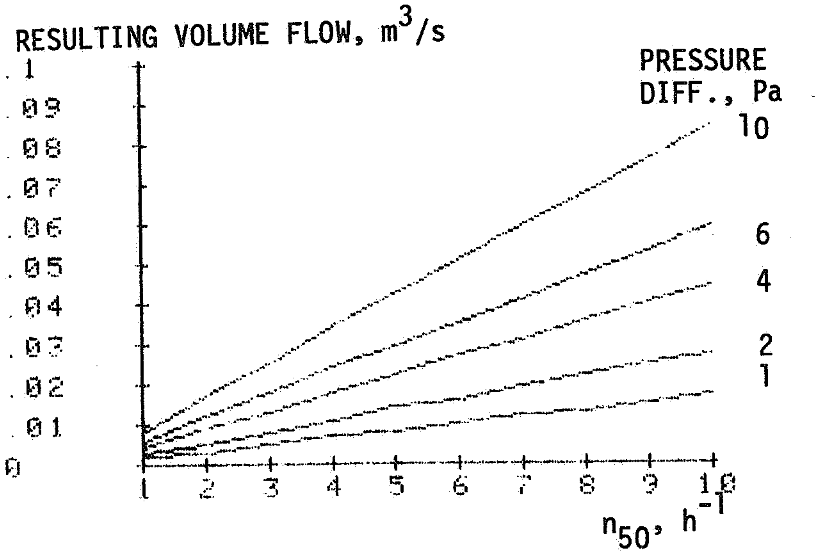

FIG. 7.5 Resulting air flow through the top floor for different n_{50} -values and pressure differences.

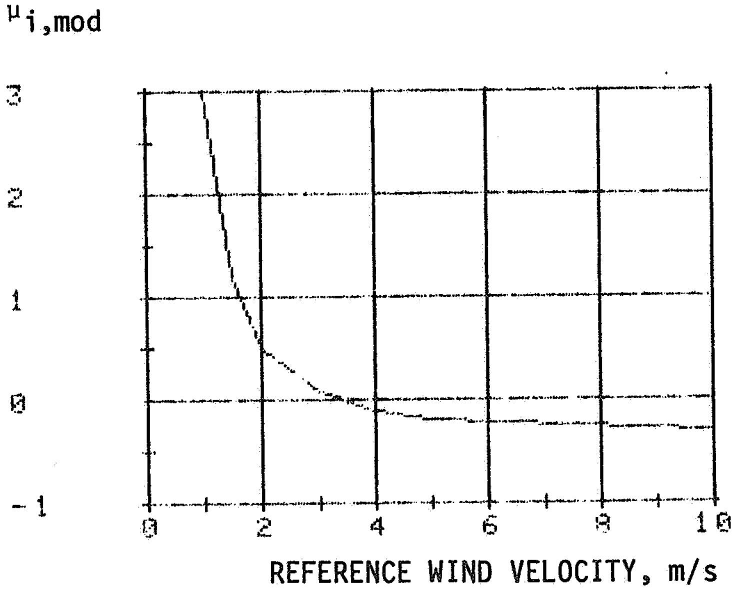

FIG. 7.6 Modified inner shape factor $\mu_{i,mod}$ for different wind velocities.

This modified shape factor, μ_i, mod, of course different for different wind velocities, is plotted in figure 7.6. Using μ_i,mod in a calculation with conditions presented in figure 6.1 (wind along the long sides of the house), the contribution to the total ventilation flow from leaking indoor air can be studied for different n_{50} - values. Figure 7.7.
The calculation was run for one wind velocity only; 2 m/s.

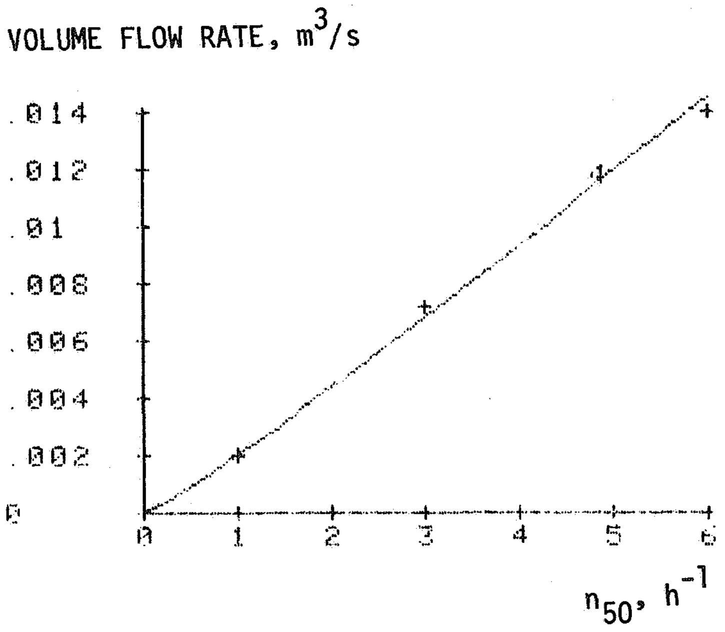

FIG. 7.7. Incoming heated air into the attic. Wind velocity 2 m/s.

In table 7.1 the resulting ventilation flows of fresh and heated air can be studied for different tightnessdegrees of the attic floor.

n_{50}	fresh air		heated air from the house	
h^{-1}	m^3/s	h^{-1}	m^3/s	h^{-1}
0	0.092	2.72	0	0
1	0.090	2.66	0.002	0.06
3	0.085	2.51	0.007	0.21
6	0.078	2.31	0.014	0.41

TABLE 7.1

7.2 CRAWL-SPACES

Meaningful heat balance calculations must be based on non-steady state calculations, mainly due to the considerable heat capacity of the ground under the crawl-space. Such calculations are not presented in this paper.

8. MOISTURE CONSIDERATIONS. ATTICS

Calculations on heat and air flow balances may serve as a basis for moisture considerations. A simple moisture damage criterion could be:

$$(RH)_{\text{attic air}} \leq (RH)_{\text{critical}} \qquad \ldots 8\text{ a}$$

The moisture content in air within a ventilated space, in this case the attic, can (under steady state conditions) be written

$$v_a = v_o + \frac{G}{nV} \qquad \ldots 8\text{ b}$$

where

v_a = moisture content in attic air, g/m^3

v_o = "- "- in outdoor air, g/m^3

G = moisture supply in or into the attic, g/h

n = ventilation rate (fresh air), h $^{-1}$

V = attic inner volume, m^3

Furthermore:

$$(RH)_a = \frac{v_a}{(v_s)_{\theta_a}} = \frac{v_o + \frac{G}{nV}}{(v_s)_{\theta_a}} \qquad \ldots 8\text{c}$$

where

RH = relative humidity, -

$(v_s)_{\theta_a}$ = moisture saturation value at $\theta = \theta_a$, g/m^3

The same outer condition of air temperature as for the heat balance calculations is chosen i.e. $\theta_o = \pm 0^oC$. Outdoor relative humidity is chosen to 80%. Since the saturation value for $\pm 0^oC$ = 4,84 g/m^3, $v_o = 0{,}8 \cdot 4{,}84 = 3{,}87$ g/m^3.
Indoor conditions are $\pm 20^oC$, RH = 45%, so the moisture content of indoor air is $0{,}45 \cdot 17{,}28 = 7{,}78$ g/m^3.

Using attic temperatures calculated by means of the heat balance procedure it is possible to calculate maximum moisture supply, G, under different conditions.

$$G_{max} = \{ (RH)_{critical} \cdot (v_s)_{\theta_a} - v_o \} \cdot nV \qquad ...8d$$

Such calculations were made for different air tightness degrees of the attic floor (i.e. the whole house tightness, even tightness distribution prescribed). Two heat transmission coefficients were chosen, 0,2 W/m^{2}K (modern, highly insulated construction) and 1,0 W/m^{2}K (older, badly insulated construction). Furthermore two levels of $(RH)_{critical}$ were chosen; 70% and 80%.

The calculation results can be studied in figure 8.1.

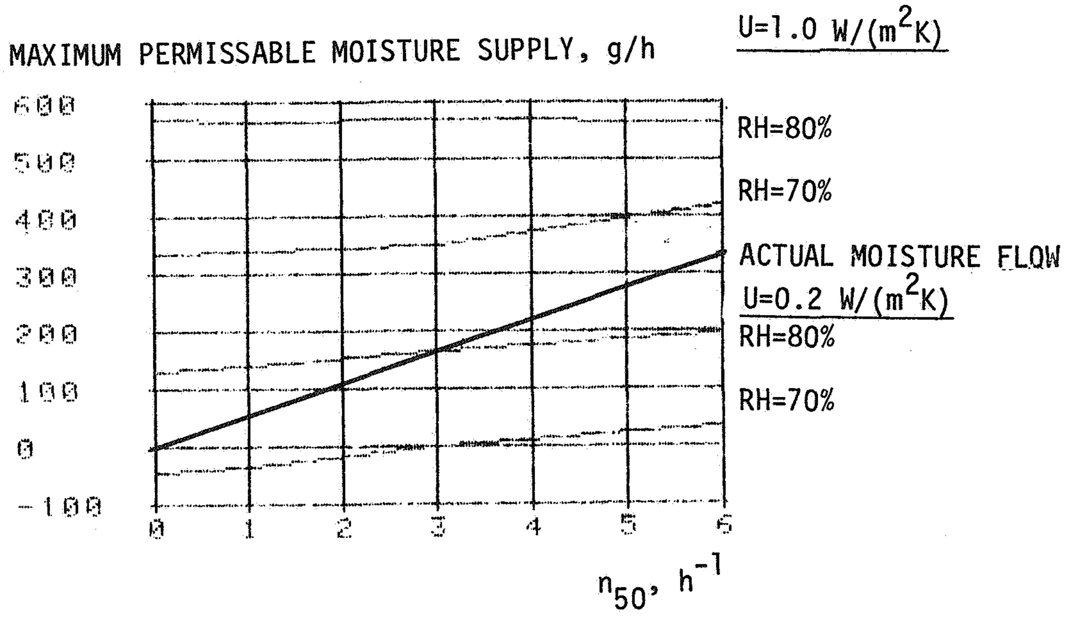

FIG. 8.1 Maximum pernissable moisture supply (g/h) to the attic for different $(RH)_{critical}$, U-value and airtightness levels for the attic floor. The line "actual moisture flow" refers to calculated moisture flow. (See below.)

The result should be compared to actual levels of moisture supply (see table 7.1 or figure 7.7). The relation between $_{50}$ and moisture supply is almost linear. The conection between air flow and moisture flow is

$$q_{\text{moisture}}\ (g/h) = q_v\ (m^3/s) \cdot 3600\ (s/h) \cdot v_{in}\ (g/m^3) \quad \ldots 8e$$

Since $q_v = 0.002 \cdot n_{50}$ (m^3/s) (Fig. 7.7)

and $v_{in} = 7.78\ g/m^3$ (see above)

$$q_{\text{moisture}} = 0.002 \cdot n_{50} \cdot 3600 \cdot 7.78\ g/h = 56.0 \cdot n_{50}\ g/h \quad \ldots 8f$$

This line i also included in figure 8.1.

If RH = 80% is chosen as a critical level, it could be seen that for n_{50} - values less than 3.0 h^{-1}, the actual moisture flow rate is below the highest permissable moisture supply rate. If the air tightness is less than so ($n_{50} \geq 3{,}0\ h^{-1}$) the critical RH-level (80%) will be exceeded. RH = 70% will not be possible to attain.

For the badly insulated attic floor case, actual moisture supply flow rate is always lower than critical flow rates.

Thus, moisture problems can be expected if a house with bad air tightness in the attic floor will be additionally insulated without any attempts made to tighten up the attic floor in connection with the additional insulation procedure.

Bad conditions can also arise if, in a new, highly insulated house, large air leaks are left in the attic floor. Such leaks may occur for example around pipes penetrating the floor if no special care is undertaken to tighten up around the pipe. Large leaks are also frequent in the connection between the attic floor and the gable wall, especially in 1½ story buildings.

8.1 CONCLUDING REMARKS

It would be strongly desirable to execute calculations similar to the presented ones for other outside climates than this single investigated one ($\pm$ 0^oC, RH = 80%.) Experience shows for example that severe moisture conditions in attic spaces are frequent at spring and autumn conditions.

In a coming research project under my direction at the Lund Institute of Technology such calculations will be performed. Also the influence of non stationary conditions and moisture capacity effects will be investigated both theoretically and in field measurements.

APPENDIX 1.

Computer program "AIRBAL" written in HP-BASIC for HP-85 for calculation of ventilation rate of ventilated spaces such as attics, crawl-spaces etc.

```
100 REM PROGRAM "AIRBAL" FOR
120 REM CALCULATING VENTILATION
140 REM INTENSITY OF CRAWL SPACE
    S
160 REM ATTICS ETC.
180 REM CREATED BY JOHNNY KRONVA
    LL
200 REM NATIONAL SWEDISH TESTING
     INSTITUTE
220 ASSIGN# 1 TO "TEST1"
240 PRINT "DENSITY OF AIR"
260 READ# 1 ; R1@ PRINT R1;"kg/m
    3"
280 PRINT "DYNAMIC VISCOSITY OF
    AIR"
300 READ# 1 ; V1@ PRINT V1;"Ns/m
    2"
320 PRINT "NUMBER OF SINGLE RESI
    STANCES"
340 READ# 1 ; N1@ PRINT N1
360 PRINT "NUMBER OF EXPONENT FL
    OWS"
380 READ# 1 ; N2@ PRINT N2
400 PRINT "NUMBER OF LAMINAR FLO
    WS"
420 READ# 1 ; N3@ PRINT N3
440 PRINT "NUMBER OF MECHANICAL
    VENTILATION DEVICES"
460 READ# 1 ; N4@ PRINT N4
480 REM
500 REM
520 PRINT "SINGLE RESISTANCE CHA
    RACTERISTICS"
540 FOR I1=1 TO N1
560 READ# 1 ; A1(I1)@ PRINT "ARE
    A";A1(I1);"m2"
580 READ# 1 ; K1(I1)@ PRINT "LOS
    S FACTOR";K1(I1)
600 READ# 1 ; M1(I1)@ PRINT "SHA
    PE FACTOR";M1(I1)
620 NEXT I1
640 PRINT "EXPONENT FLOW CHARACT
    ERISTICS"
660 FOR I2=1 TO N2
680 READ# 1 ; A2(I2)@ PRINT "ARE
    A";A2(I2);"m2"
700 READ# 1 ; W2(I2)@ PRINT "FLO
    W COEFFICIENT";W2(I2);"m3/(s
    *m2*Pa^B)"
720 READ# 1 ; B2(I2)@ PRINT "FLO
    W EXPONENT, BETA";B2(I2)
740 READ# 1 ; M2(I2)@ PRINT "SHA
    PE FACTOR";M2(I2)
760 NEXT I2
780 PRINT "LAMINAR FLOW CHARACTE
    RISTICS"
800 FOR I3=1 TO N3
820 READ# 1 ; A3(I3)@ PRINT "ARE
    A";A3(I3);"m2"
840 READ# 1 ; L3(I3)@ PRINT "FLO
    W COEFFICIENT";L3(I3);"m3/(m
    2*s*Pa)"
```

```
820 READ# 1 ; A3(I3)@ PRINT "ARE
    A";A3(I3);"m2"
840 READ# 1 ; L3(I3)@ PRINT "FLO
    W COEFFICIENT";L3(I3);"m3/(m
    2*s*Pa)"
```

```
860 READ# 1 ; M3(I3)@ PRINT "SHA
    PE FACTOR";M3(I3)
880 NEXT I3
900 PRINT "MECHANICAL VENTILATIO
    N DEVICES"
920 FOR I4=1 TO N4
940 READ# 1 ; Q4(I4)@ PRINT "AIR
     FLOW RATE";Q4(I4);"m3/s"
960 NEXT I4
980 PRINT "REFERENCE WIND VELOCI
    TY"
1000 INPUT U@ PRINT U;"m/s"
1020 PRINT "INTERNAL START PRESS
     URE"
1040 INPUT P0@ PRINT P0;"Pa"
1060 PRINT "TOLERANCE VALUE"
1080 DISP "NORMALLY 1.E-6"
1100 INPUT E@ PRINT E
1120 PRINT "MAX NUMBER OF LOOPS"
1140 INPUT N9@ PRINT N9
1160 PRINT "LIMIT DELTA P"
1180 DISP "NORMALLY .001 Pa"
1200 INPUT P9@ PRINT P9
1220 D=.00001*P0 @ P1=P0 @ N=0
1240 GOTO 1320
1260 REM
1280 N=0
1300 D=P1-P0
1320 P=P1
1340 GOSUB 1780
1360 Q6=Q
1380 IF ABS(Q6)<=E THEN 1600
1400 P=P1+D
1420 GOSUB 1790
1440 Q7=Q
1460 P2=P1-D*Q6/(Q7-Q6)
1480 IF ABS(P2-P1)<=P9 THEN 1640
1500 P0=P1
1520 P1=P2
1540 N=N+1 @ PRINT N;
1560 IF N>=N9 THEN 1680
1580 GOTO 1300
1600 PRINT "CALCULATION TERMINAT
     ED DUE TO FLOW CRITERION"
1620 GOTO 1700
1640 PRINT "CALCULATION TERMINAT
     ED DUE TO PRESSURE CRITERIO
     N"
1660 GOTO 1700
1680 PRINT "CALCULATION TERMINAT
     ED DUE TO MAX LOOP CRITERIO
     N"
1700 REM
1720 GOTO 2440
1740 REM
```

```
1760 REM
1780 REM SUBROUTINE FLOW RATE
1800 REM FLOW THROUGH SINGLE RES
     ISTANCES
1820 Q1=0
1840 FOR I1=1 TO N1
1860 Q1(I1)=SQR(ABS(M1(I1)*U^2*R
     1/2-P)*2*A1(I1)^2/K1(I1)/R1
     )
1880 IF SGN(M1(I1)*U^2*R1/2-P)>=
     0 THEN 1920
1900 Q1(I1)=-Q1(I1)
1920 Q1=Q1+Q1(I1)
1940 NEXT I1
1960 REM FLOW THROUGH EXPONENT
1980 REM FLOW COMPONENTS
2000 Q2=0
2020 FOR I2=1 TO N2
2040 Q2(I2)=W2(I2)*ABS(M2(I2)*U^
     2*R1/2-P)^B2(I2)*A2(I2)
2060 IF SGN(M2(I2)*U^2*R1/2-P))=
     0 THEN 2100
2080 Q2(I2)=-Q2(I2)
2100 Q2=Q2+Q2(I2)
2120 NEXT I2
2140 REM FLOW THROUGH LAMINAR
2160 REM FLOW COMPONENTS
2180 Q3=0
2200 FOR I3=1 TO N3
2220 Q3(I3)=(M3(I3)*U^2*R1/2-P)*
     L3(I3)*A3(I3)
2240 Q3=Q3+Q3(I3)
2260 NEXT I3
2280 REM FLOW THROUGH MECHANICAL
      1201REM VENTILATION DEVICE
     S
2300 Q4=0
2320 FOR I4=1 TO N4
2340 Q4=Q4+Q4(I4)
2360 NEXT I4
2380 REM TOTAL AIR FLOW
2400 Q=Q1+Q2+Q3+Q4
2420 RETURN
2440 PRINT @ PRINT @ PRINT
2460 PRINT "RESULT:"
2480 PRINT "INTERNAL PRESSURE (P
     a)";
2500 PRINT P2
2520 PRINT
2540 FOR J=1 TO N1
2560 PRINT "Q1(J)=";Q1(J),"m3/s"
2580 NEXT J
2600 J=0
2620 PRINT "Q1=";Q1;"m3/s"
2640 FOR J=1 TO N2
2660 PRINT "Q2(J)=";Q2(J),"m3/s"
2680 NEXT J
2700 PRINT "Q2=";Q2;"m3/s"
2720 J=0
2740 FOR J=1 TO N3
2760 PRINT "Q3(J)=";Q3(J);"m3/s"
2780 NEXT J
2800 PRINT "Q3=",Q3;"m3/s"
2820 J=0
2840 FOR J=1 TO N4
2860 PRINT "Q4(J)=";Q4(J);"m3/s"
2880 NEXT J
2900 PRINT "Q4=";Q4;"m3/s"
2920 PRINT "Q tot=";Q;"m3/s"
2940 DISP "NEW WIND VELOCITY YES
     /NO"
2960 INPUT H$
2980 IF H$="YES" THEN 980
3000 PRINT "CALCULATION FINISHED
     "
3020 END
```

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