TESTING OF HOUSES FOR AIR LEAKAGE USING A PRESSURE METHOD

JOHNNY KRONVALL

INTRODUCTION

During the last few years in Sweden there has been a great desire to find methods for air leakage testing of houses. Investigations from the early sixties (1) showed rather high air change rates in Swedish houses. These results and the general conversion of energy policy in Sweden since the oil crises of 1974 indicated that there exists a great energy-saving potential in reducing the air leakage of buildings.

In Supplement No. 1 to SBN 1975 (Swedish Building Code 1975) limitations of air leakage of buildings are stated. These regulations partly concern building components, such as outer-walls, roofs, floors, windows and doors, and partly whole houses. The content of these rules is briefly discussed in Appendix 1.

The actuality of this matter stimulated us to begin work on a research program in 1975. Until now the work has resulted in an examination paper (2) and a literature list (3). The latter consists of some hundred titles on air leakage of buildings. They are assorted both after the name of the author and the content of the reference.

Earlier, air tightness of buildings was almost always monitored with tracer gas technique (4, 5, 6). However, this method is afflicted with some troublesome disadvantages.

- o The monitoring procedure takes quite a lot of time and trained personal are required.
- o Every measurement with tracer gas technique is unique for the weather at this very occation (temperature and wind).
- o The test equipment is rather expensive.

Testing of air tightness of buildings using a pressure method has been done only to a very small extent. Some experiments have been carried out in Canada (7, 8, 9, 10), Great Britain (11) and Denmark (12). The method used at the Lund Institute of Technology shows a certain similarity to the British variant.

The demands of a routine test of air tightness of buildings are

- o The testing procedure should be fast and easy-operated.
- o The result of the test should be unambiguous.
- o The test result should preferably give an estimate of the natural ventilation of the house.

TEST EQUIPMENT

By installing a powerful fan in an opening on the envelope of the house it is possible to build up static pressure inside the house. Tests have been done with both positive and negative

---

J. Kronvall is Research Scientist at the Division of Building Technology, Lund Institute of Technology, Lund, Sweden.

pressure difference acting on the envelope of the house. This is easily done by turning the fan equipment and to operate in the opposite direction. The test equipment arranged for evacuating air from the inside of a house is shown in Fig. 1.

In ordinary houses and flats it has turned out to be suitable to change the outer door for a wood fibre board plate of the same size as the door with a hole to which the fan is attached. It is possible to vary the capacity of the fan. In this case an electric "variac" of a special fan design is used. The maximum capacity of the fan used should not be less than 1-1,5 m^3/s at a pressure rise of 50-100 Pa according to experiences from normally air-tight Swedish houses. For very tight or leaky houses the capacity may be different from the value above. The air-flow through the fan is measured with some air-flow measurement device, such as an orifice plate. The device should be calibrated for the capacity range of the fan.

TEST RESULTS

The data that are primarily obtained by the test are the pressure difference over the house and the resulting air leakage. This latter can for a certain pressure-difference

- be used as it is (m^3/h)
- be related to the volume of the house (h^{-1})
- be related to the inner area of the house envelope ($m^3/m^2 \cdot h$)

The inner area of the house is here defined as the area that separates the inner of the house from the ambient air (ground excluded).

The results indicate that the last way of expressing the air-tightness ($m^3/m^2 \cdot h$) can be related to the natural ventilation monitored with a tracer-gas technique under some specified weather situations. Further, the unit $m^3/m^2 \cdot h$ is very familiar when speaking of pressure tests of building components.

Apart from the way of expressing the result the test determines some kind of air permeability characteristic of the house. Measurements made with the pressure method were carried out until August, 1977.

The natural ventilation of most of the houses was monitored too. All ventilation - chimney and fireplace openings - have been sealed by tape during the tests. Tracer gas technique (N_2O) was used to measure the natural ventilation.

The results of the measurements are summarized in Table 1 and Fig. 2. The locations of air leakage paths have for some of the objects been discovered using the thermography method (infrared camera). During the thermography procedure a negative pressure inside the building caused by the testfan has been applicated. The resulting leakage of cold air from the outside to the inside of the structure will give rise to cooled paths that easily can be discovered by the infrared camera. Fig. 3 shows such paths of air leakage in wooden houses.

Hitherto it has been observed that in wooden houses the connections of outer-wall / ceiling, outer-wall / floor, joints between prefabricated elements and interstices around windows and doors often are leaky points. The velocity of the air near the orifice of such leakages has been monitored. These velocities are plotted in the thermographic pictures, Fig. 3.

Further investigations using thermography to detect typical air leakage points in different types of houses will probably follow.

DISCUSSION

At present it seems as though the pressure method of testing whole houses for air leakage could be applied to:

- air leakage testing of newly produced houses as a matter of routine (Appendix 1).
- studies on the influence of different air-tightening measures.

In the future it will perhaps be possible to make estimations of the natural ventilation of buildings too. To make such a relationship reliable many measurements on different types of houses with both methods must be made and reasonable corrections for the wind- and temperature influence of the tracer-gas measurements must be found. Just by plotting the actual ventilation against the specific air leakage at 50 Pa from the measurements a promising result is obtained (Fig. 4).

One weather restriction must be pointed out. It is probably rather useless to make measurements in heavy and/or gusty wind. Fig. 5 shows that for a certain parallelepipedic house (15x7,5 x 3 m^3) a wind velocity of appr. 5 m/s will produce an average pressure difference of 5 Pa. This is a value obtained using static wind loads and simplified load distribution models and does not really correspond to reality. Cf. (13) in which the dynamic characteristics of air infiltration are discussed. 5 Pa is 10% of the suggested Swedish standard pressure level of 50 Pa. (See Appendix 1). So, if the influence of wind load on the average pressure difference on the building should be limited to 10%, the wind velocity when monitoring with the pressure method should be not greater than approximately 5 m/s.

SUMMARY

A method of testing whole houses for air leakage by use of a pressure method is described. The main advantage of the method compared to the commonly used tracer gas technique is that the test equipment is inexpensive, easy to handle and because of that well adapted for routine tests. Besides the test method produces results that are reproductive to a reasonable degree. Pressure is applicated to the house tested by a powerful fan. As the ventilation openings of the house are closed during the test, the air-flow through the fan is equivalent to the leakage through the building envelope. Thus the pressure level and the resulting air leakage give an air leakage characteristic of the house. Leak-detecting by means of thermography has been carried out and it will perhaps be possible to estimate the natural ventilation of a house using the result of a pressure test. A brief extract from the new directions for air-tightness of houses according to the Swedish Building Code (SBN 1975) is given.

Appendix 1

DIRECTIONS FOR AIR TIGHTNESS ACCORDING TO THE SWEDISH BUILDING CODE (SBN 1975).

Air Tightness of Building Components

(Prescribed by law)

Maximum air leakage ($m^3/m^2 \cdot h$)

Component	Pressure difference Pa	Number of floors 1 - 2	3 - 8	> 8
Outer wall	50	0.4	0.2	0.2
Window and door	50	1.7	1.7	1.7
	300	5.6	5.6	5.6
	500	-	-	7.9
Roof and floor structure	50	0.2	0.1	0.1

Table No. 33:3, SBN 1975

Air Tightness of Building (Pressure Method)

(Recommended by law)

Maximum air leakage at a pressure difference of 50 Pa diveded with the volume of the house ($m^3/m^2 \cdot h$)

Detached houses & Row houses	3.0
Apartment houses ≤ 2 floors	2.0
- " - ≥ 3 floors	1.0

REFERENCES

1. Elmroth, A & Höglund, I.
   Analysis of factors affecting the extent of air leakage of one family houses. (Analys av ofrivillig ventilation i småhus) In Swedish. English summary. The Royal Institute of Technology, Institute of Building Technology, Meddelande No. 70, Stockholm, Sweden, 1970.
2. Hildingson, O & Holmgren, S.
   Air tightness of buildings. Investigation and development of measuring methods. (Byggnaders lufttäthet) In Swedish. Lund Institute of Technology, Div. of Building Technology. X4:76, Lund, Sweden, 1976.
3. Kronvall, J.
   Air leakage of buildings. A literature list. Lund Institute of Technology, Div. of Building Technology, Report 77, Lund, Sweden, 1976.
4. Dick, JB.
   Ventilation research in occupied houses. IHVE, vol. 19, oct 1951, p. 306 - 326.
5. Ahlström, K E & Wennberg, M.
   Some methods for measurement of ventilation rates in locals. (Några metoder för mätningar av luftomsättningar i lokaler) In Swedish. (The Royal Institute of Technology, Inst. of heating and ventilation) Tekn. medd. No. 18, p. 16 - 22, Stockholm, Sweden, 1973.
6. Hitchin, E R & Wilson, C B.
   A review of experimental techniques for the investigation of natural ventilation in buildings. Building Science Vol. 2, p. 59 - 82, Oxford, 1967.
7. Tamura, G T.
   Measurement of air leakage characteristics of house enclosures. ASHRAE Transactions Vol. 81, Part 1, p. 202 - 211, 1975.
8. Tamura, G T.
   Pressure differences caused by wind on two tall buildings. ASHRAE Transactions No. 2085, 1968.
9. Stricker, S.
   Measurements of air-tightness of houses. ASHRAE Transactions Vol. 81, Part 1, p. 148 - 167, 1975.
10. Shaw, C Y et al.
    Air leakage measurements of the exterior walls of buildings. ASHRAE Transactions No. 2280, 1973.
11. Mc Intyre, I S & Newman, C J.
    The testing of whole houses for air leakage. Building Research Establishment. Note 21/75. Princes Risborough Laboratory 1975.
12. Collet, P F & al.
    The natural ventilation of dwellings. (Boligers luftskifte), In Danish, Teknologisk Institut, Tåsterup, Denmark, 1976.
13. Hill, J E & Kusuda, T.
    Dynamic characteristics of air infiltration. ASHRAE Transactions No. 2337, 1975.

ACKNOWLEDGEMENT

The research project is sponsored by the Swedish Council for Building Research and the work is carried out at the Department of Building Technology, Lund Institute of Technology. The original idea of the work arise from professor L E Nevander, the head and supervisor of the department. I wish to express my gratitude to his great wealth of ideas which he gladly shares with his staff. The Swedish National Authority for Testing, Inspection and Metrology is acknowledged for the rent of the IR-camera on favourable conditions. Miss Mona Hammar typed the text and drew the figures and I owe her a certain dept of gratitude for her great complaisance.

TABLE 1

Object number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Year of erection	1976	1975	1969	1969	1969	1976	1976	1965	1976	1976	1976	1974	1977	1977	1976
Number of storeys	11/2	1	11/2	11/2	1	11/2	11/2	1	1	1	2	2	1	1	11/2
Row house = R Det. house= D	D	D	D	D	R	D	D	D	D	D	D	D	D	D	D
Built on site = S Prefabricated = P Small element = s Volume -"- = v	Pv	Pv	Ps	Ps	Pv	Pv	S	S	Ps	Ps	S	S	Ps	Ps	Pv
Crawl-space basement = C Floor slab on ground = F	C	C	C	C	F	F	F	C	F	F	C	F	F	F	F
Windows open outwards = o inwards = i	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
Volume, m^3	374	288	418	418	122	215	215	300	285	285	393	548	218	214	457
Area of building envelope, m^2	312	353	369	369	126	190	190	380	349	349	346	244	345	180	338
Volume / Area	1.2	0.8	1.1	1.1	1.0	1.1	1.1	0.8	0.8	0.8	1.1	2.2		1.2	1.4
Natural ventilation, h^{-1}	0.20	0.16	0.29	0.39	0.18	0.07	0.10	0.34	0.06	0.03	0.06	-	0.06	0.15	0.33
Air leakage at Δp=50 Pa, m^3/h															
At positive pressure diff.	1930	1730	1770	-	800	740	740	3190	940	660	490	850	1050	-	2106
At negative -"-	1594	-	-	-	-	-	-	-	-	-	-	-	-	485	-
$\frac{\text{Air leakage at 50 Pa}}{\text{Volume}}$, m^3/m^3h															
At positive pressure diff.	5.2	5.9	4.2	-	6.6	3.5	3.5	10.6	3.4	2.4	1.2	1.6	4.8	-	4.8
At negative pressure diff.	4.3	-	-	-	-	-	-	-	-	-	-	-	-	2.3	-
$\frac{\text{Air leakage at 50 Pa}}{\text{Area of building envelope}}$, m^3/m^2h															
At positive pressure diff.	6.2	4.9	4.8	-	6.4	3.9	3.9	8.4	2.7	1.9	1.4	3.5	3.0	-	6.5
At negative pressure diff.	5.1	-	-	-	-	-	-	-	-	-	-	-	-	2.7	-
Wind velocity, m/s	7	6	5	7	8	9	6	7	4	4	<2	<2	4	4	2
Outside temperature, °C	+1	+5	+10	+9	+10	+18	+14	+9	+19	+18	+9	+14	+4	+6	+4

Object number	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Year of erection	1977	1977	1977	1976	1977	1977	1977	1977	1977	1977	1977	1977	1975	1977
Number of storeys	11/2	11/2	1	1	11/2	11/2	11/2	11/2	11/2	11/2	11/2	1	11/2	11/2
Row house = R Det. house= D	D	D	D	D	D	D	D	D	D	R	R	D	D	D
Built on site = S Prefabricated = P Small element = s Volume -"- = v	S	S	S	Ps	Ps	S	S	Ps	S	Ps	Ps	S	Ps	Ps
Crawl-space basement = C Floor slab on ground = F	F	F	F	C	F	F	F	F	F	C	C	F	F	F
Windows open outwards = o inwards = i	O	O	O	O	I	O	O	O	I	O	O	O	I	O
Volume, m^3	497	345	214	252	409	378	378	276	347	238	238	327	366	431
Area of building envelope, m^2	308	243	181	313	286	281	281	201	251	228	228	255	262	273
Volume / Area	1.6	1.4	1.2	0.8	1.4	1.4	1.4	1.4	1.4	1.0	1.0	1.3	1.4	1.6
Natural ventilation, h^{-1}	0.15	0.22	0.09	0.19	0.4.	0.20	0.12	0.22	0.10	0.41	0.17	0.12	0.20	0.03
Air leakage at Δp=50 Pa, m^3/h														
At positive pressure diff.	1421	1350	583	709	2810	1859	1740	1160	938	2180	1440	670	1585	912
At negative -"-	1511	1269	598	690	2115	1675	1524	1239	919	2180	1220	680	1446	910
$\frac{\text{Air leakage at 50 Pa}}{\text{Volume}}$, m^3/m^3h														
At positive pressure diff.	2.9	3.9	2.7	2.8	6.9	4.9	4.6	4.2	2.7	9.2	6.1	2.1	4.3	2.1
At negative pressure diff.	3.0	3.7	2.8	2.7	5.2	4.4	4.0	4.5	2.6	9.2	5.1	2.1	4.0	2.1
$\frac{\text{Air leakage at 50 Pa}}{\text{Area of building envelope}}$, m^3/m^2h														
At positive pressure diff.	4.6	5.6	3.2	2.3	9.8	6.6	6.2	5.8	3.7	9.6	6.8	2.6	6.0	3.3
At negative pressure diff.	4.9	5.2	3.3	2.2	9.6	6.0	5.4	4.5	3.7	9.6	5.7	2.7	5.5	3.3
Wind velocity, m/s	2	4	2	6	5	2	2	4	3	2	6	2	2	5
Outside temperature, °C	+2	+1	+7	+2	+6	+8	+10	+10	+11	+12	+19	+14	+18	+18

Positive pressure difference = Higher pressure inside the house than outside.

Negative pressure difference = Lower pressure inside the house than outside.

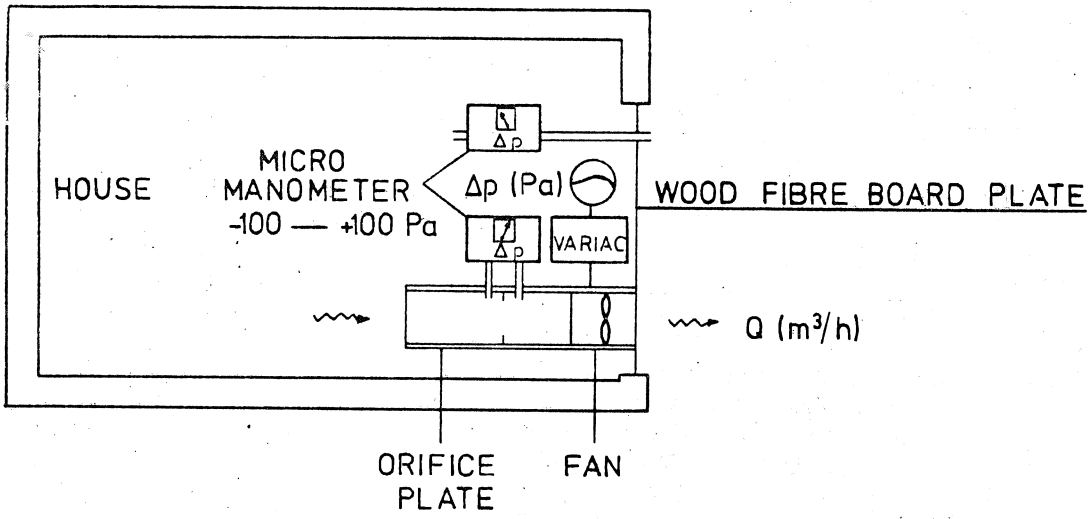

Fig. 1 The "pressure method" test equipment

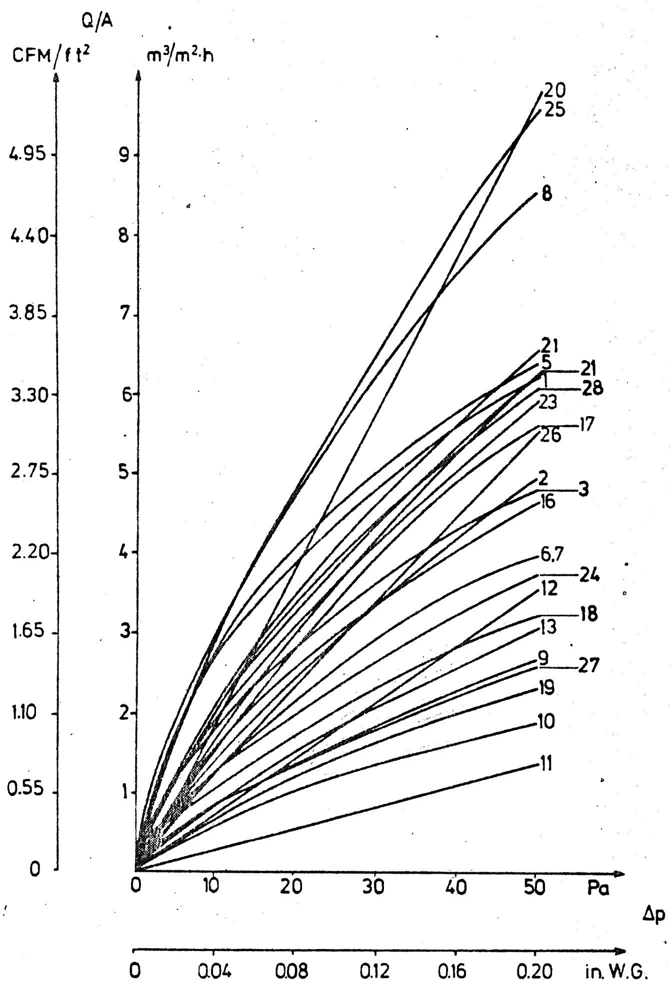

Fig. 2 Results of measurements, positive pressure difference

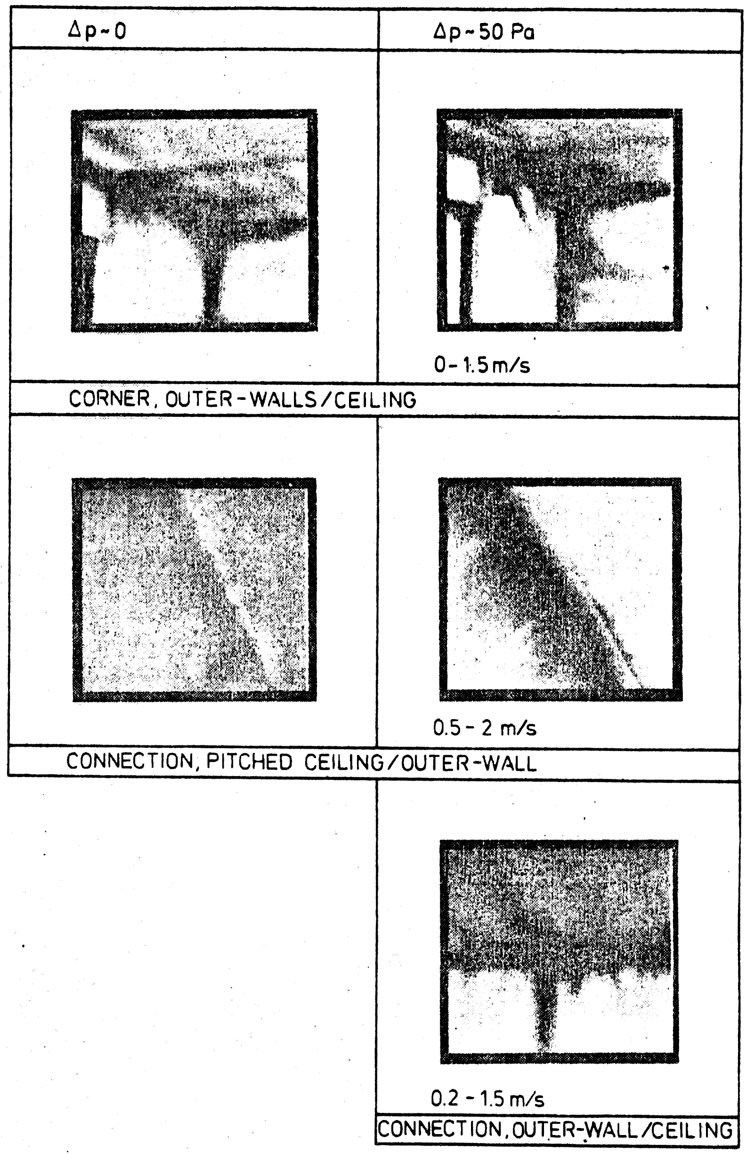

Fig. 3 Thermographs

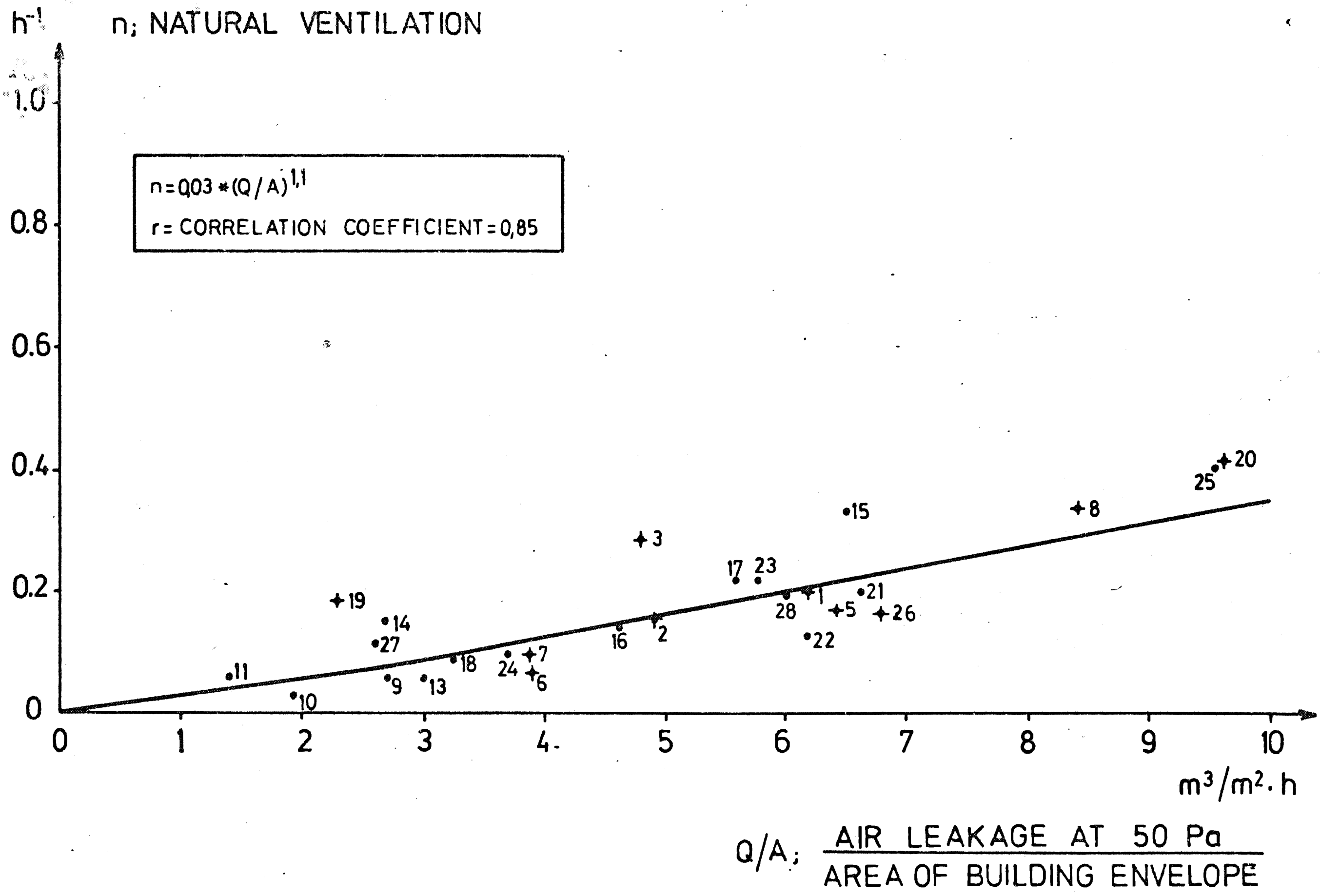

Fig. 4 Plotting of natural ventilation against specific air leakage. Measurements at wind speed ≥ 5 m/s are marked with +. The line refers to curve-fitting of the •-marked points with the "least-square method."

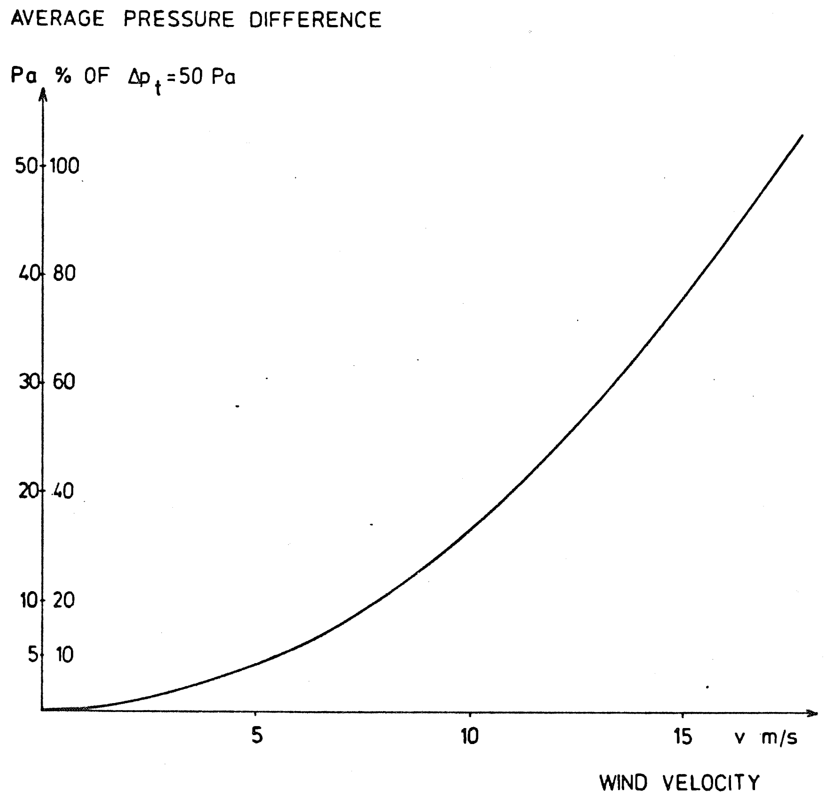

Fig. 5 Influence of wind

DISCUSSION

GERALD D. HARTFORD, JR., Black & Veatch Consulting Engineers, Kansas City, MO: How long has the maximum amount of air leakage in houses been a part of, or included in, the Swedish Building Code and what was that value?

J. KRONVALL: The values given in Appendix 1 have been included in the Swedish Building Code (SBN 1975) since the beginning of 1977.

G.D. HARTFORD, JR.: Do local contractors, who build houses in Sweden, find it necessary to make a special effort to achieve the air leakage limits which are dictated by local code? In other words, are the local contractors having to update their building standards to achieve dictated standards?

J. KRONVALL: According to our experiences there is no need for an extreme updating of the building standards to achieve these air leakage limits.

GEORGE T. TAMURA, National Research Council, Division of Building Research, Ottawa, Ontario, Canada: The recommendation of the Swedish Building Code gives a limit on the maximum leakage value. In view of the fact that outdoor air is required for combustion in fossil fuel-fired heating appliance and for control of condensation and indoor air contaminants, is there a recommended limit for the minimum leakage value?

J. KRONVALL: Yes there is. The chapter of air quality in the Building Code states that the aim should be to have an air change rate of 0.5 h^{-1} in homes. However, the general philosophy is that the house itself should be very airtight and it should be possible to control the ventilation rate through the ventilation system to achieve this air quality.

G.T. TAMURA: For a given house, would pressure tests conducted at wind velocities under 5 m/s and various outside temperatures give the same leakage values?

J. KRONVALL: The leakage values would not be exactly the same but would be within a reasonably close interval. Figures of the size of this interval are not yet available but we are conducting tests and are still working with this question.

HOWARD D. ROSS, Department of Energy, Washington, DC: What was the variance in pressurization and evacuation tests on the same house? Are there air leakage diodes?

J. KRONVALL: As apparent in Table 1, there is no general trend of pressurization giving higher leakage values than evacuation or vice versa. Air leakage diodes may exist; for example, windows and doors, depending on the opening direction and vapor barrier (plastic folium) in the ceiling under the insulating material. This could rise when pressurizing and thus make the ceiling less airtight than if the vapor barrier is close to the solid material under it.

H.D. ROSS: Did you account for external shielding effects in trying to correlate natural air infiltration and results of air leakage tests?

J. KRONVALL: This has not been done in this study but further investigations are going to be conducted.