INTERNATIONAL ENERGY AGENCY
energy conservation in buildings and
community systems programme

5th AIC Conference

The implementation and effectiveness of air infiltration standards in buildings

Supplement to Proceedings

Air Infiltration Centre
Old Bracknell Lane West, Bracknell,
Berkshire, Great Britain, RG12 4AH

This report is part of the work of the IEA Energy Conservation in Buildings & Community Systems Programme.

Annex V Air Infiltration Centre

Document AIC-PROC-5-S-84
ISBN 0 946075 17 4

Distribution: Unrestricted.

Participants in this task:

Belgium, Canada, Denmark, Finland, Netherlands, New Zealand, Norway, Sweden, Switzerland, United Kingdom and United States of America.

Additional copies of this report may be obtained from:

The Air Infiltration Centre,
Old Bracknell Lane West, Bracknell,
Berkshire, RG12 4AH, England.

5th AIC Conference

The implementation and effectiveness of air infiltration standards in buildings

(held at Harrah's Hotel
Reno, Nevada, USA
1 – 4 October 1984)

Supplement to Proceedings

CONTENTS (i)

PREFACE

International Energy Agency

In order to strengthen cooperation in the vital area of energy policy, an Agreement on an International Energy Program was formulated among a number of industrialised countries in November 1974. The International Energy Agency (IEA) was established as an autonomous body within the Organisation for Economic Cooperation and Development (OECD) to administer that agreement. Twenty-one countries are currently members of the IEA, with the Commission of the European Communities participating under a special arrangement.

As one element of the International Energy Program, the Participants undertake cooperative activities in energy research, development, and demonstration. A number of new and improved energy technologies which have the potential of making significant contributions to our energy needs were identified for collaborative efforts. The IEA Committee on Energy Research and Development (CRD), assisted by a small Secretariat staff, coordinates the energy research, development, and demonstration programme.

Energy Conservation in Buildings and Community Systems

The International Energy Agency sponsors research and development in a number of areas related to energy. In one of these areas, energy conservation in buildings, the IEA is sponsoring various exercises to predict more accurately the energy use of buildings, including comparison of existing computer programs, building monitoring, comparison of calculation methods, etc. The difference and similarities among these comparisons have told us much about the state of the art in building analysis and have led to further IEA sponsored research.

Annex V Air Infiltration Centre

The IEA Executive Committee (Building and Community Systems) has highlighted areas where the level of knowledge is unsatisfactory and there was unanimous agreement that infiltration was the area about which least was known. An infiltration group was formed drawing experts from most progressive countries, their long term aim to encourage joint international research and to increase the world pool of knowledge on infiltration and ventilation. Much valuable but sporadic and uncoordinated research was already taking place and after some initial ground-work the experts group recommended to their executive the formation of an Air Infiltration Centre. This recommendation was accepted and proposals for its establishment were invited internationally.

The aims of the Centre are the standardisation of techniques, the validation of models, the catalogue and transfer of information, and the encouragement of research. It is intended to be a review body for current world research, to ensure full dissemination of this research and based on a knowledge of work already done to give direction and a firm basis for future research in the Participating Countries.

The Participants in this task are Belgium, Canada, Denmark, Finland, Netherlands, New Zealand, Norway, Sweden, Switzerland, United Kingdom and the United States.

INTRODUCTION

This document is a supplement to the AIC's 5th Conference Proceedings AIC-PROC-5-84. It contains two additional papers presented at the Conference, together with a discussion record based on written questions and answers prepared by conference participants and authors, and a report on the final discussion period. Amendments to papers published in AIC-PROC-5-84 are also included in this Supplement.

THE IMPLEMENTATION AND EFFECTIVENESS OF AIR INFILTRATION STANDARDS IN BUILDINGS

5th AIC Conference, October 1-4 1984, Reno, Nevada, USA

PAPER S.1

THE ROLE OF AIR INFILTRATION IN ENERGY CONSERVATION

JOHN P. MILLHONE

Director, Office of Building Energy Research and Development
U.S. Department of Energy
Room GF-231, 1000 Independence Ave., S.W.
Washington, D.C. 20585

THE ROLE OF AIR INFILTRATION IN ENERGY CONSERVATION

1. INTRODUCTION

The importance of the subject you will be discussing during the next few days can be dramatized by the kind of mathematics that gets attention here in Reno.

The United States spends about $500 billion dollars on energy. Buildings consume about 36% of this energy. Of this share, roughly half is used to heat and cool buildings. And one-third of this energy is used to condition infiltration and ventilation air. As a result, a reduction of infiltration and ventilation rates by a mere 1% would reduce annual U.S. energy costs by about 300 million dollars.

We're playing for high stakes here.

In my remarks, I'll describe how we're trying to save this energy. Infiltration and ventilation activities are an important part of the comprehensive energy conservation research policy of the U.S. Department of Energy. The starting point for this policy is an analysis of how energy is used in the nation's buildings. This begins with an examination of the buildings themselves.

2. U.S. BUILDING ENERGY USE

The United States has more than 81 million occupied residential buildings; 69% owner-occupied, 31% occupied by renters. Single-family residences constitute 69% of these residences; multi-family, 25%; and mobile homes, 6%.

The U.S. commercial building sector makes up 44.6 billion square feet of floor space. This is divided among different building types, the major ones being: office, 18.4%; retail, 17.2%; warehouse, 13.6%; education, 13.1%; and assembly, 11.3%.

We then consider how these buildings use energy. The residential sector uses 16 quads; the commercial sector, 10 quads (1 quad equals 10^{15} Btu). The primary uses in the residential sector are: space heating (47.7%), water heating (14.4%), and refrigerators and freezers (13.2%). The primary uses in the commercial sector are: space heating (44%), lighting (22.5%), air conditioning (21.1%), and water heating (10.1%).

This shows us where the Btu's are. But it's also useful to look at what has been happening to this energy consumption. Here, there's good news and there's bad news. Let's dispense with the

bad news first. Although progress has been made, the U.S. energy use is higher per capita than that of other IEA countries and we have a great deal more to do to use our energy efficiently.

The good news is that the United States has made enormous progress in controlling its once ravenous appetite for energy. Last year we used 45 fewer quads of energy than we would have if the pre-1972 trends had continued. A portion of this amount --19 quads--is due to a lower gross national product. The larger amount--26 quads--is due to energy conservation, defined as an increased level of energy efficiency. Twenty-six quads is a staggering amount--as much oil as all the other IEA nations use in a year...or as much as the power generated by 870 1000MW electrical plants.

The energy consumption in residential and commercial buildings contributed to this record. This energy use remained fairly stable during the past decade. It started the decade at 24.1 quads, rose slowly to peak at 26.1 quads in 1978, and has since declined to 25.5 quads in 1983. If it had continued at its pre-1972 trend, it would have passed 42 quads.

During this period, there have been some interesting shifts in the sources of energy. Natural gas use changed little. Petroleum use declined rapidly, almost by one-half. Electricity use increased significantly, rising from less than 50% to more than 60% of the energy used in buildings. (This is measuring electricity in terms of the Btu's of the generating fuels.)

The past trends are interesting, but it also is important to try to peer into the energy uses in the future. The energy end-use projections show some shifts by the year 2000.

Table 1 Energy End-Use Projections*
Residential and Commercial Buildings

	Residential Percentage		Commercial Percentage	
	1983	2000	1983	2000
Space Heating	45.0	41.3	39.8	34.7
Space Cooling	7.0	12.7	20.9	32.5
Lighting	7.5	5.7	27.4	20.2
Water Heating	14.2	17.0	2.0	2.7
Other	26.3	23.3	9.9	9.8
	100%	100%	100%	100%

* Year 2000 projections from Energy End-Use Model, Oak Ridge National Laboratory

The end-use projections show that space heating and cooling--the uses affected by infiltration and ventilation--are expected to be even more important in the year 2000 than they are today. Their share of residential energy use will increase from 52% to 54%. Their share of commercial energy use will increase even more,

from 60.7% to 67.2%. The reason for these increases is the increased energy use for space cooling, which is expected to more than offset a decline in the energy required for space heating.

I'm afraid that the numbers have been coming about as fast as they do at the green felt tables that some of us visited last night, but they make an important point. The R&D that you do on the infiltration and ventilation of buildings is extremely important to your countries and ours and they will be even more important in the future.

Next I would like to turn to DOE's strategy for conducting this research.

3. U.S. POLICY APPROACH

The clearest and most comprehensive statement of the U.S. conservation policy is contained in the latest National Energy Policy Plan submitted to Congress by DOE. Energy conservation is singled out for special emphasis in this latest plan, reflecting the personal interest of Secretary Donald P. Hodel.

The plan identifies three areas of energy programs and actions that are particularly important: conservation, research and development, and energy security.

The goal of the U.S. policy is to foster an adequate supply of energy at reasonable costs. Implicit in this goal is a balanced and mixed energy resource system--one which relies upon a number of energy resources, including fossil fuels, solar and other renewables, and energy conservation.

"Energy conservation," the policy states, "ought to be viewed by policymakers, producers, and consumers as a significantly important energy resource. That is, energy conservation should be seen as a set of actions that individuals and businesses can take that are cost-effective alternatives to new supply development. Energy conservation actions are often cheaper and easier to undertake, and they often make good business sense. It need not be viewed as an altruistic activity or as a sacrifice."[1]

Expanding on this theme, the policy states: "Conservation has shown itself to be a unique, economic, and highly flexible energy resource applicable to all energy technologies and fuel types. It is not limited by geography or indigenous natural resources, and it may offer significant environmental advantages. No other energy resource can be tailored to individual needs or employed in increments as effectively as conservation, and each additional increment results in immediate energy savings, thus promptly reducing costs and offering return on capital investment. In short, conservation actions in response to changing market incentives have a degree of flexibility unequaled by any other

energy resource option, and they will continue to be an important component of our energy resource choices made by consumers and businesses."

In the conservation area, the broad objectives of this national plan are put in place through the "Energy Conservation Multi-Year Plan, FY 1986-FY 1990." The plan assesses the R&D needs in each of the end-use sectors: buildings, transportation, industry, and systems research--a cross-cutting sector that includes energy storage, electric energy systems and basic energy conversion and utilization technologies.

In the plan, first priority is given to implementing the statutory responsibilities contained in U.S. laws. These include the development of guidelines and standards for the energy-efficiency of new residential and commercial buildings. The standards are to be voluntary for the private sector and mandatory for new Federal buildings.

The plan then then disaggregates each of the end use sectors into specific research areas. The building sector includes 38 research technologies. Examples are wall systems, infiltration and ventilation, and condensing combustion systems. Then the relative priority of these research areas are ranked according to seven major criteria. These criteria are:

o Contribution to the energy-related objectives in the national plan;

o Contribution to maintaining or enhancing U.S. leadership in technology and international trade;

o Contribution to national defense;

o Other societal benefits, including economic, environmental, scientific, health and safety;

o Federal costs, and the degree of private-sector cost sharing;

o The degree of risk associated with the cost of project failure, as compared to the net present value of anticipated benefits; and, importantly,

o The appropriateness of Federal involvement.

Each of the 38 building technologies is given a score, based upon its perceived contribution to these objectives.

In this priority setting, infiltration and ventilation research is ranked 21st, which may appear inconsistent with the importance I attributed it earlier. The explanation is that infiltration and ventilation research is also intertwined into other research activities. For example, pollution characterization, mitigation and control is ranked 7th.

The first priority is given to commercial building systems integration, which involves an analysis of how energy-efficient components can be integrated to optimize their peformance in real buildings. A similar activity involving residential buildings is ranked 8th. Research on the retrofit of existing buildings is ranked 5th. Fenestration materials, components, systems and performance is ranked 12th. Performance simulation through computer models is ranked 16th. Home energy rating systems is ranked 18th. Advanced concepts for commercial building HVAC systems is ranked 26th. Diagnostics is ranked 27th. Energy management control systems is ranked 29th. Field monitoring and monitoring is ranked 30th. Construction quality is ranked 33rd. As you can see, all of these research activities depend heavily on infiltration and ventilation research. I believe this pattern is important and want to return to it in my concluding remarks, but first I want to tell you about DOE's current activities.

4. CURRENT DOE ACTIVITIES

The lead laboratory for infiltration, ventilation, and indoor air quality research for DOE is the Lawrence Berkeley Laboratory in Berkeley, California. Current research efforts at LBL include the development of measurement techniques and models for infiltration, air leakage, and ventilation in buildings. A companion effort is devoted to identifying important indoor pollutants and characterizing the dependence of indoor pollutant concentrations on building factors related to energy use. Specific examples of current research objectives include:

- Development of techniques to understand indoor radon concentrations and building entry mechanisms;
- Development of energy-efficient techniques to control excess pollutant concentrations in buildings;
- Design efforts for a national indoor air quality survey;
- Development of new methods for measuring whole-house air leakage;
- Development of a multizone infiltration model; and
- Determination of the energy effects of natural ventilation and comfort requirements.

The Department also supports work at the Brookhaven National Laboratory on Long Island, New York; at the National Bureau of Standards at Gaithersburg, Maryland; and at Princeton University at Princeton, New Jersey.

At Brookhaven, research is being funded to apply the use of perflurocarbon tracers (PFT) to perform multizone air flow measurements in both mechanically and naturally ventilated buildings. The concentrations measured using this relatively

inexpensive passive sampling technique allow the determination of both air infiltration and exfiltration rates from each building zone and the air exchange rates among zones.

At the National Bureau of Standards, DOE is funding the development of test methods for evaluating the movement of air into and within large commercial buildings. The objectives of this research include determinating ventilation efficiencies in commercial buildings and their impact on building energy costs and indoor air quality.

At Princeton, the DOE-funded research is devoted, in part, to studying the relationship between pressurization testing for air leakage and tracer gas measurements of infiltration and the accuracy of models based upon these measurements to predict retrofit energy savings in single- and multi-family residences. This work includes the development of a constant concentration tracer gas device to measure multizone natural ventilation, which will be used in multi-chamber experiments.

5. FUTURE DIRECTION OF DOE ACTIVITIES

As we look into the future, I anticipate a continuing major emphasis on infiltration and ventilation R&D, although there probably will be some changes in focus for the U.S. program. These changes include:

- The attention will be less on infiltration and ventilation, if those areas are interpreted narrowly, and more on closely related subjects such as "whole" building performance, distribution losses in heating, ventilation and air conditioning (HVAC) systems, indoor air quality, and air movement within buildings.

- There will be a shift of emphasis from air movement in single-family residences to air movement in multi-family high-rise and mid-rise apartments, and commercial buildings.

- There will be a shift of emphasis from how to save heating energy in cold climates to how to save cooling energy in warm climates, with implications for related infiltration and ventilation research.

- There will be more emphasis on the retrofit of existing buildings and less on the design and construction of new buildings. This will have implications on infiltration and ventilation research, although there will be continuing support for the development of guidelines and manuals for new building designs.

- The research will involve the use of multiple tracer gases to increase our understanding of more complex air movement questions, such as infiltration and interzone air movements under dynamic weather and HVAC operating conditions.

- Increased attention will be given to technology transfer, which will require that research results are interpreted into handbooks and guidelines that practicing architects and engineers can use in the design and operation of real buildings.

6. CONCLUSION

These future directions suggest we are entering into a new phase of building energy research activities. In the past, we have focused on the energy features of the components of buildings--walls, fenestration, roofs, HVAC systems. Because of its generic nature, much of the research on infiltration and ventilation has escaped this segmented approach. During the past 10 years, we have made great advances in understanding how building components perform, although much work remains to be done.

Now that this component work is well engaged, the next phase of research needs to focus on a range of integrative studies that will show how this new knowledge can be used to design, build, and operate energy-miserly buildings that offer healthy, productive, and attractive environments for their occupants. The challenge to you researchers in the infiltration and ventilation fields will be to recast your research plans into the priorities of this next phase of building research.

REFERENCES

1. "Energy Conservation Multi-Year Plan, FY 1986-FY 1990"
U.S. DOE, Office of Conservation
Washington, D.C., July 1984

2. "The National Energy Policy Plan"
U.S. DOE
Washington, D.C., October 1983

ABSTRACT

This survey describes how external walls and joints are constructed in practice. The paper gives you an opportunity to compare how successful the implementation of airtightness has been in Sweden in comparison with the results presented in the report D2:1983 "Air infiltration control ..." by A Elmroth and P Levin.

The survey covers the majority of all Swedish prefabricated single family houses constructed in 1984. All big prefabrication companies are included in the survey.

The following issues are presented:
- Wall sections
- Sealing systems
- Measured airtightness and method
- Number of houses measured
- Distribution between different heating and ventilation systems
- The demand from the customers to measure the value of airtightness

The conclusions are that:
- the majority of the houses has an airtightness of 2-2,7 ach/h
- the airtightness is easy to decrease to less than 1,0 ach/h
- it is recommended to control 5-10 % of the production of each housetype
- airtithtness is easy to control with the exhaust fan
- only the big customers carry out control

1. INTRODUCTION

In Sweden 1/3 of all dwellings are prefabricated houses. These are single-family dwellings built as detached houses and constructed of timber.

The companies have during the last 4 years developed well insulated and airtight houses with a low demand of heat power.

Three different types of element are used in house production: small elements (L < 2,5 m) 20 %; large elements (L 5-11 m) 60% and volume elements 20%.

The main part of the population in Sweden lives under the condition of 4 100 degree days.

2. METHOD

14 companies participated in the survey. They represent 2/3 of the total production (12 000 houses) of prefabricated houses in Sweden today. A questionnaire was sent to each company. The answers were collected by telephone and drawings were sent in to the author.

Test results were received from each company. The tests were carried out by consultants or official test institutes.

3. RESULTS

3.1 Thermal insulation

Prefabricated houses in Sweden have better insulation than required in the Swedish Building Code.

Table 1 House production and different k-values

Number of companies	Houses/ year	k-value wall	roof	window
1	200	0.23	0.20	1.9
2	1 000	0.23	0.15-0.16	1.9
2	1 200	0.24	0.14	1.9
3	1 100	0.21	0.13	1.9
1	400	0.21	0.20	1.9
1	1 200	0.15	0.13	1.5
1	450	0.20	0.15	1.9
1	600	0.19	0.12	1.9
2	1 300	0.17	0.11	1.9
1	100	0.13	0.09	1.5
Swedish Building Code		0.25-0.30	0.17-0.20	2.0
Swedish Building Code Electric resistance heating		0.17	0.12	2.0

The conclusion to be drawn from this is that the k-value and the insulation in the prefabricated houses are 15% better than required in the Building Code. The trend still shows a reduction of the k-value to very thick insulation.

3.2 Heating and ventilation systems

With very tight and well insulated houses the demand for a good designed ventilation system increases. With the introduction of thick insulation and heat recovery systems the power required for heating the house has decreased. To save oil for heating, Sweden has turned to electricity. In order to save both energy and electricity Sweden has developed systems with heat pumps connected to exhaust air producing hot tap water and heating the supply air or heating the water in a hydronic system.

Table 2 Heating systems in prefabricated single family houses in Sweden

Direct electric resistance heating	20 %
Air heated	60 %
Electric boiler, hydronic system	5 %
District heating, hydronic system	5 %
Wood boiler, hydronic system	5 %
Misc.	5 %

Table 3 Ventilation systems and heat recovery systems in prefabricated single family houses in Sweden

Mechanical exhaust ventilation	22 %
Mechanical exhaust ventilation - heat pump - hot tap water	9 %
Mechanical exhaust ventilation - heat pump - hot tap water - heating supply air	52 %
Mechanical exhaust ventilation - heat pump - hot tap water - preheating hydronic system	10 %
Mechanical supply and exhaust air-heat exchanger	7 %

This investigation showed that natural ventilation has totally vanished from the market. Not a single house was reported.

3.3 Airtightness

All companies included in the survey had carried out some kind of measuring with a view of convincing themselves that the end product (the house) and its detail solutions came up to standard.

One company considered that this result could be achieved by measuring a couple of exterior walls. Furthermore the detail solutions give the impression of being extremely good. Five companies have controlled that the various types of houses function with a satisfactory degree of tightness. Three companies control every year a selection of houses at various building sites in Sweden with a view of checking that the erecting is properly done. Four companies carry out routine test of various types of houses all over the country. Finally, there is one company that is measuring all their houses and guarantees the tightness of these houses.

Table 4 Measured houses. Value of airtightness

	Company	Production houses/year	Measured since -82	Measured/ year	Value ach/h 50 Pa
Checked some housetypes and/ or elements	6	3 100	60		2
Checking sometimes	3	2 500	110	30	2.5
Good quality control	4	1 700	780	170	2.0-2.5
Guarantee	1	300	450	300	0.7
	14	7 600	1 400	500	
The Swedish Building Code					3.0

All houses were measured with the blower-door method except houses with provided guarantee. All these houses are measured by means of the exhaust fan. People from the company measure the air tightness and some of the results are then checked by the Swedish Testing Institute. All other measurements have been carried out by consultants.

Companies marked with "good quality control" usually have professional customers measuring 10-20 % of the houses. Sometimes also thermography tests are being carried out.

The differences in ach/h are not high between 1-storey houses and $1\frac{1}{2}$ storey houses. Usually the airtightness is between 1/10-2/10 ach/h lower in 1-storey houses.

3.4 Sealing

The results from the 14 companies participating in the survey have been compared in order to discover if there is a solution that will give a significantly better airtightness.

The following tables and figures give an idea of how the Swedish houses are constructed.

Table 5 Wind barrier

Material	Number of companies	Houses/year %
Particleboard	1	3
Asphalt impregnated board	5	51
Gypsum board	1	8
Fibre board	1	4
Paper	4	34

Table 6 The place for vapour barrier

Vapour barrier	Number of companies	Houses/year %
Behind inner sheet. Wall	11	80
Behind inner sheet. Ceiling	13	96
50 mm in insulation. Wall	2	16
50 mm in insulation. Ceiling	-	-
Secret	1	4

Table 7 Ceiling joints

	Houses/year %	Airtightness ach/h
Vapour barrier clamped	38	no
Vapour barrier overlapping + tape	55	significant
No overlapping	3	differences
Secret	4	-

Table 8 Element joints

	Houses/year %	Airtightness ach/h
Glass fibre in plastic film	26	2-3
EPDM rubber strip	63	2-3
EPDM rubber strip + polyethylene film	5	2
EPDM rubber strip + mastic	2	-
Secret	4	0.7

Table 9 Window joints

	Houses/year %	Airtightness ach/h
Mineral wool	32	2.3-2.7
Mineral wool + mastic	18	
Mineral wool + EPDM-rubber	20	2.0-2.5
EPDM-rubber	18	2.2-3.0
Glass fibre in plastic film	5	2.0
Glued construction + foam strip	3	2.0
Secret	4	0.7

4. CONCLUSIONS

Most of the prefabricated single family houses in Sweden seem to have an airtightness of 2-2.7 ach/h. With good control and constructions it is easy to get less than 1.0 ach/h. With all the constructions presented in this paper it is possible that the companies can get an even better airtightness than shown above. It is very important that the houses are submitted to a control. It seems to be enough to control 5-10 % of the production. But then it is important to have a proper distribution between different house types and different locations in the country. The last depending on the construction workers skill.

Only one company used the fan in the house for measuring the airtightness. All the other used the blower-door method.

It is easier to get a wide-spread control if the fan in the house is used for measuring. This method is also possible because all the houses are equipped with at least one fan.

5. ACKNOWLEDGEMENTS

The author wishes to thank the following companies:

Anebyhus, Aneby; Begushus, Korsberga; Eksjöhus, Eksjö; Elementhus, Mockfjärd; Faluhus. Falun; Gullringshus, Gullringen; Götenehus, Götene; Hedlundshus, Furudal; Hjältevadshus, Hjältevad; LB-hus, Bromölla; Modulent, Hässleholm; Myresjöhus, Vetlanda; Nässjöhus, Nässjö; Ådalshus, Kramfors.

6. REFERENCES

ELMROTH, A. and LEVIN, P.
"Air Infiltration Control in Housing. A guide to International Practice".
Swedish Council for Building Research D2:1983, ISBN 91-540-3853-7.

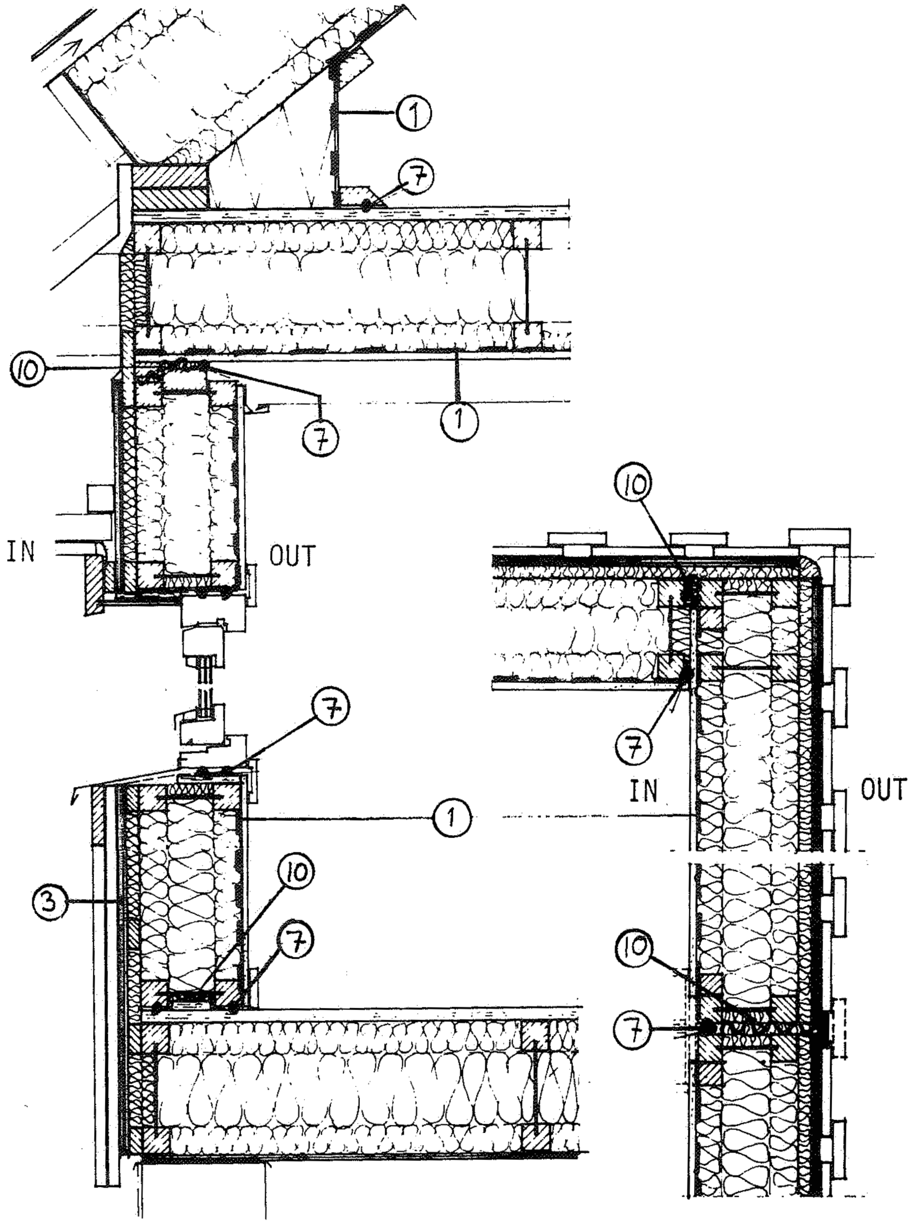


Figure 1. Volume element. Wall section and outer corner

1. Vapour barrier
2. Particle board, glued construction
3. Asphalt impregnated board
4. Gypsum board
5. Paper
6. Glassfibre in plastic film
7. EPDM rubber strip
8. Foam strip
9. Mastic
10. Mineral wool packing
11. Tape

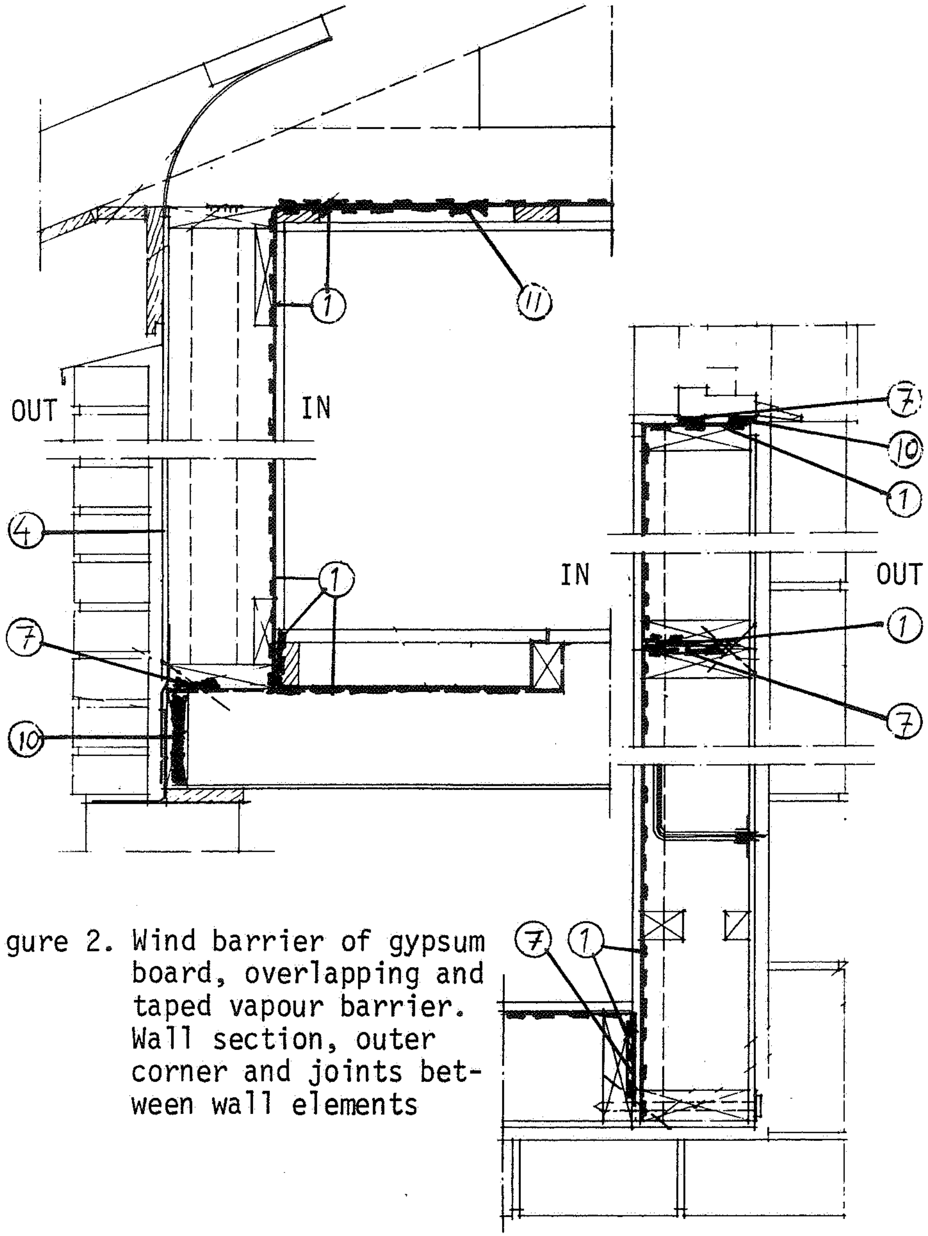


Figure 2. Wind barrier of gypsum board, overlapping and taped vapour barrier. Wall section, outer corner and joints between wall elements

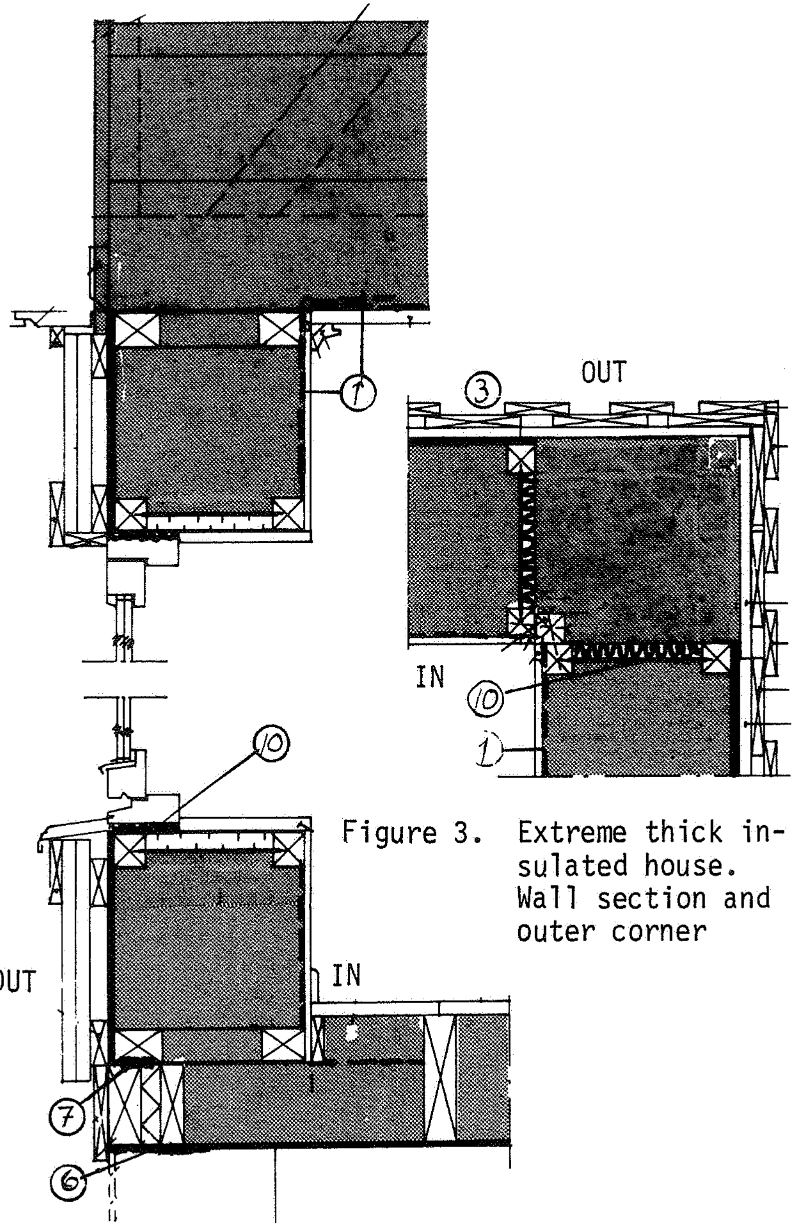


Figure 3. Extreme thick insulated house. Wall section and outer corner

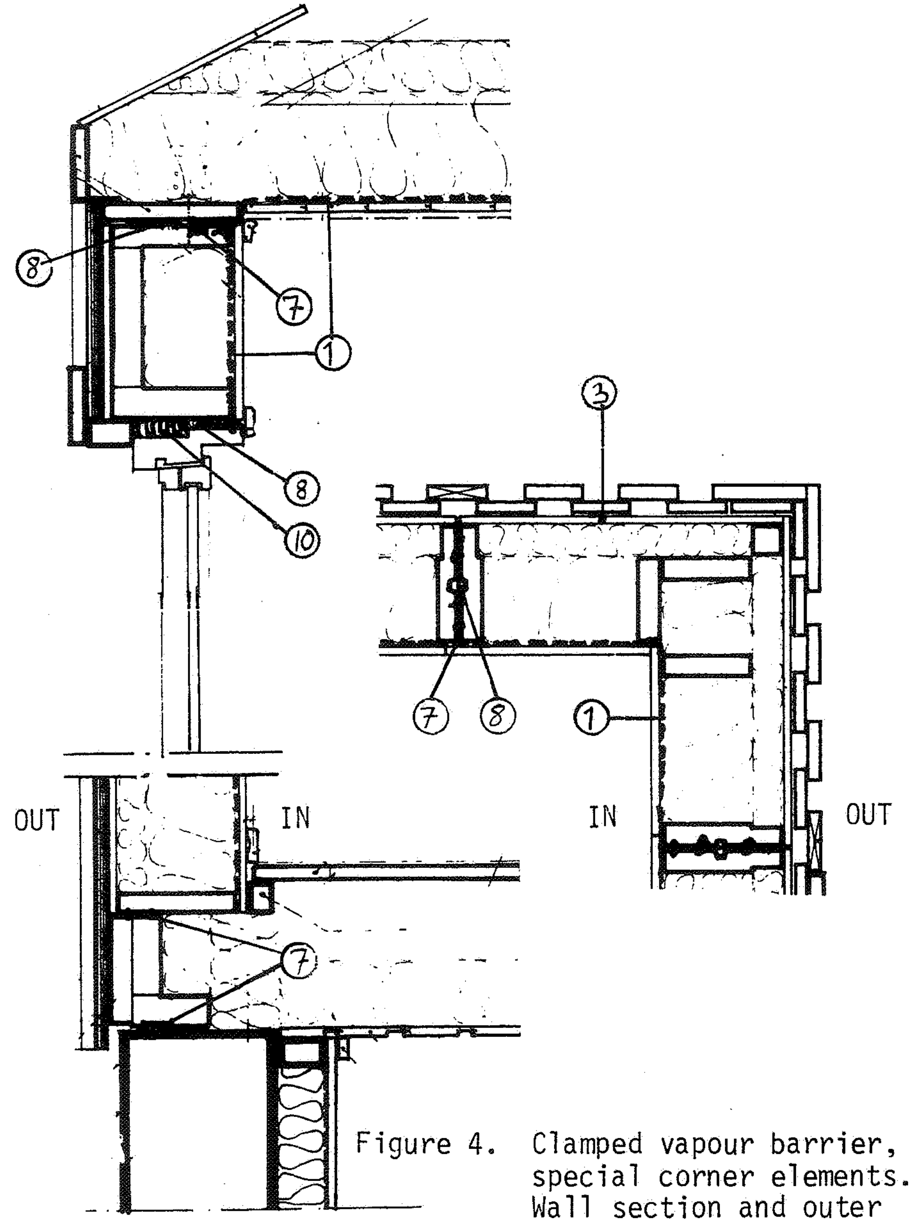


Figure 4. Clamped vapour barrier, special corner elements. Wall section and outer corner

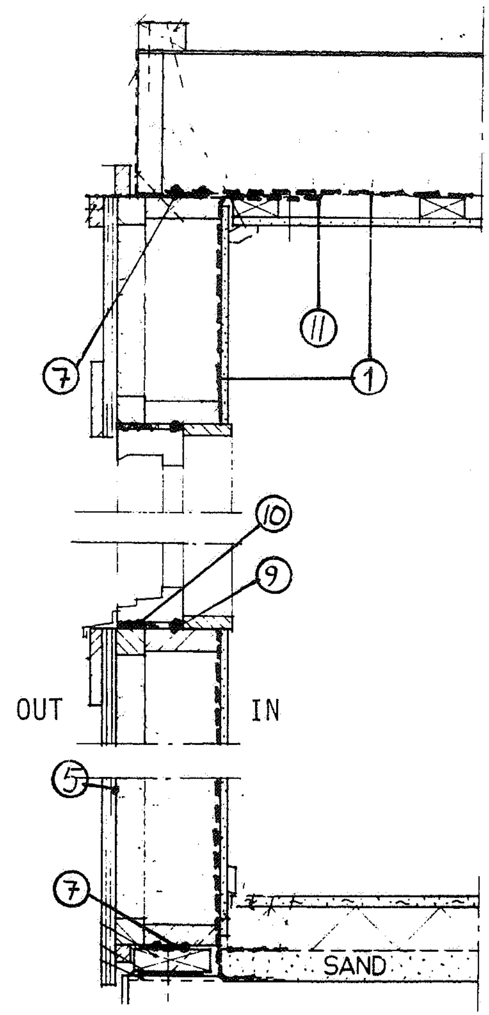


Figure 5. Wind barrier of paper, overlapping and taped vapour barrier. Wall section

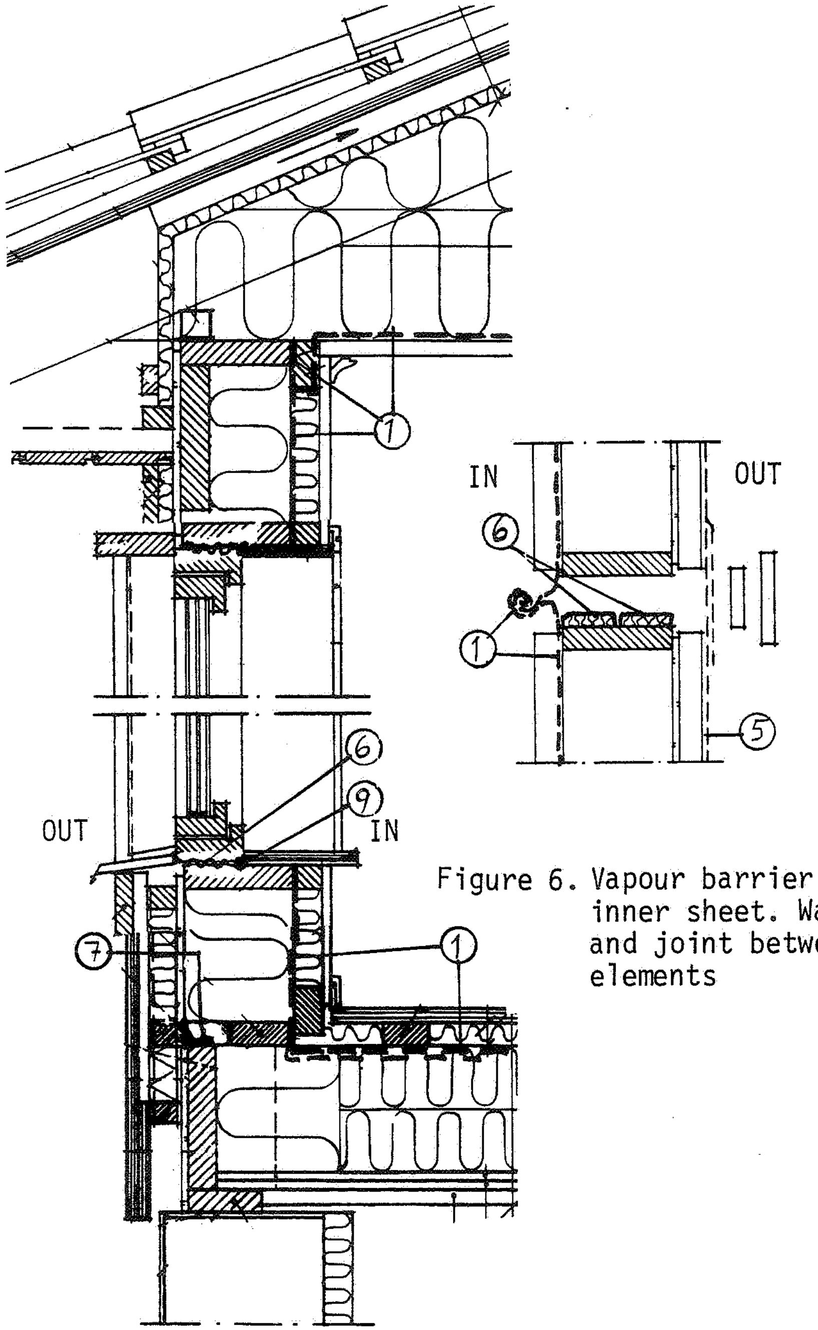


Figure 6. Vapour barrier 50 mm behind inner sheet. Wall section and joint between wall elements

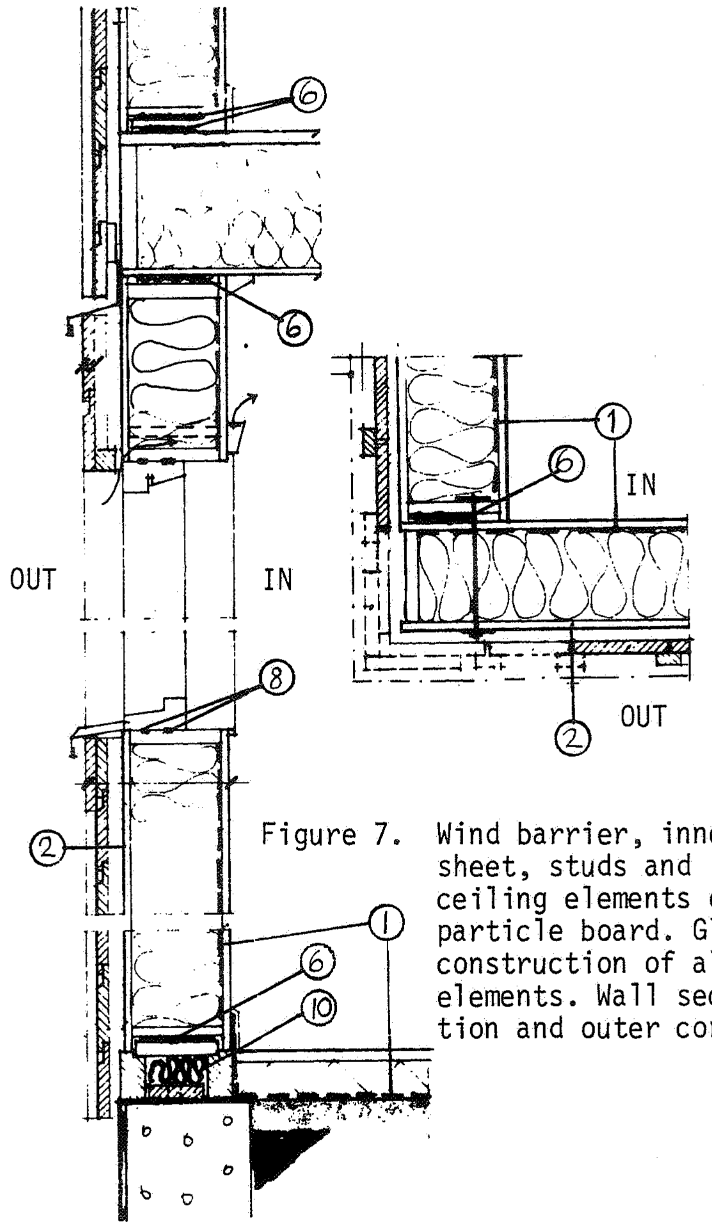
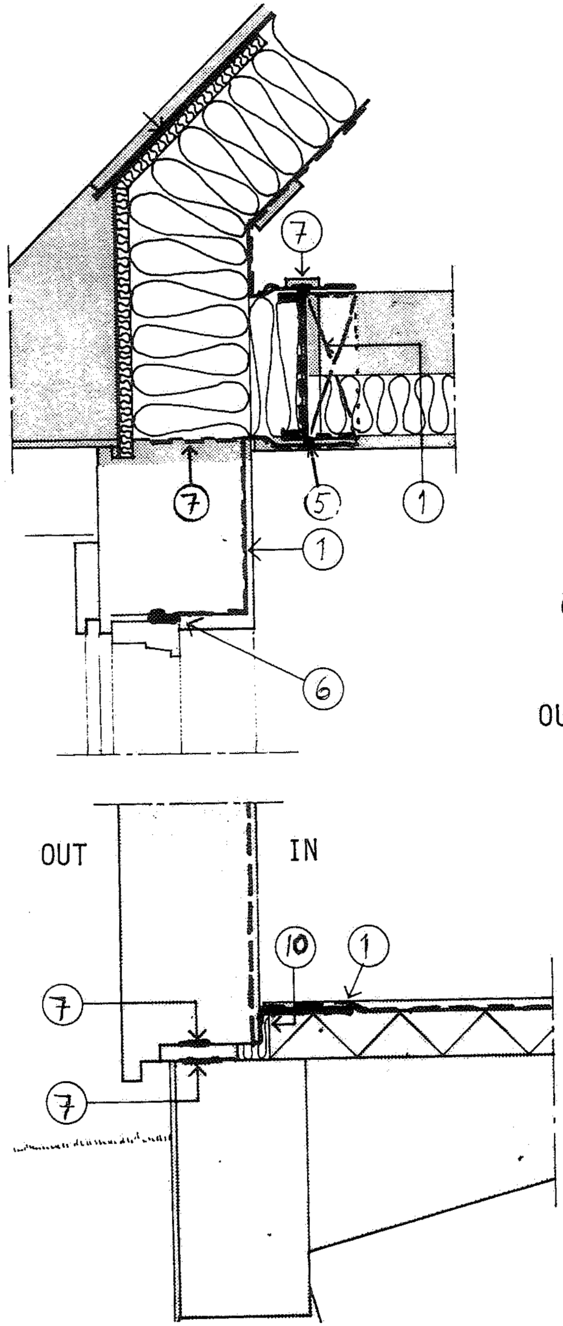


Figure 7. Wind barrier, inner sheet, studs and ceiling elements of particle board. Glued construction of all elements. Wall section and outer corner



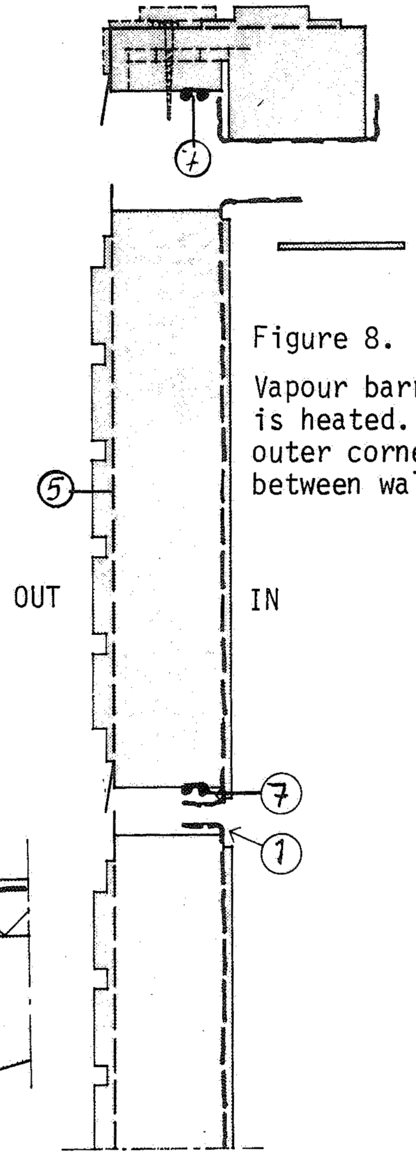


Figure 8.

Vapour barrier if attice is heated. Wall section, outer corner and joints between wall elements

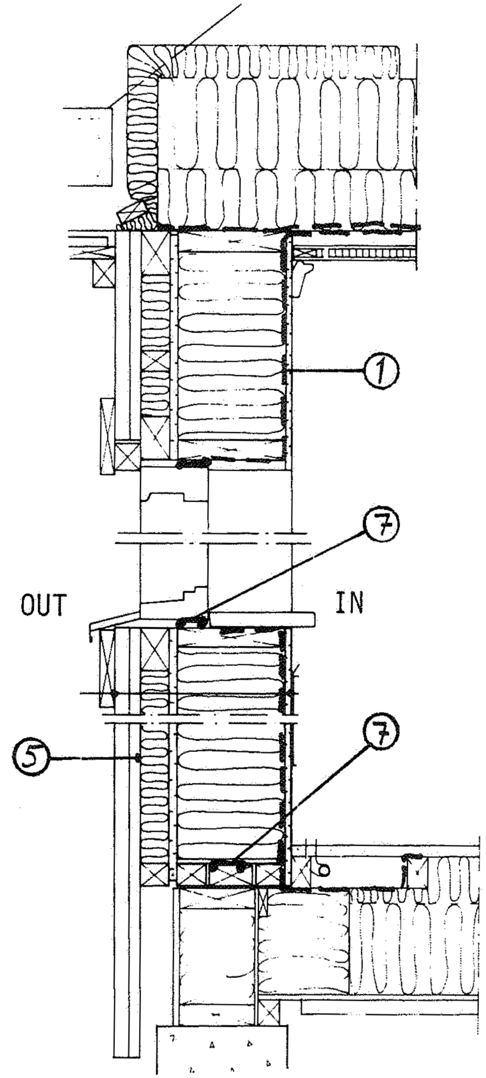


Figure 9. Floor element with installation zone. Wall section

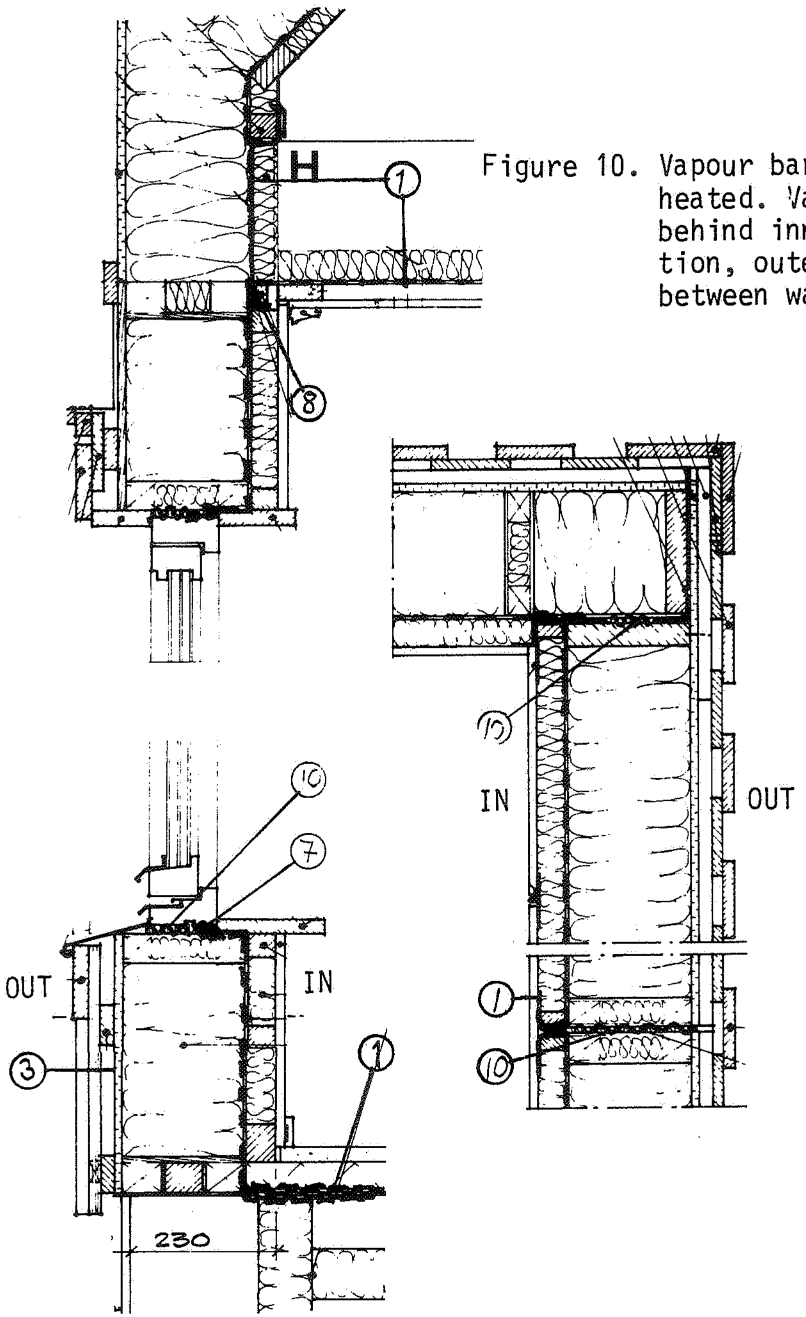


Figure 10. Vapour barrier if attice is heated. Vapour barrier 50 mm behind inner sheet. Wall section, outer corner and joint between walls

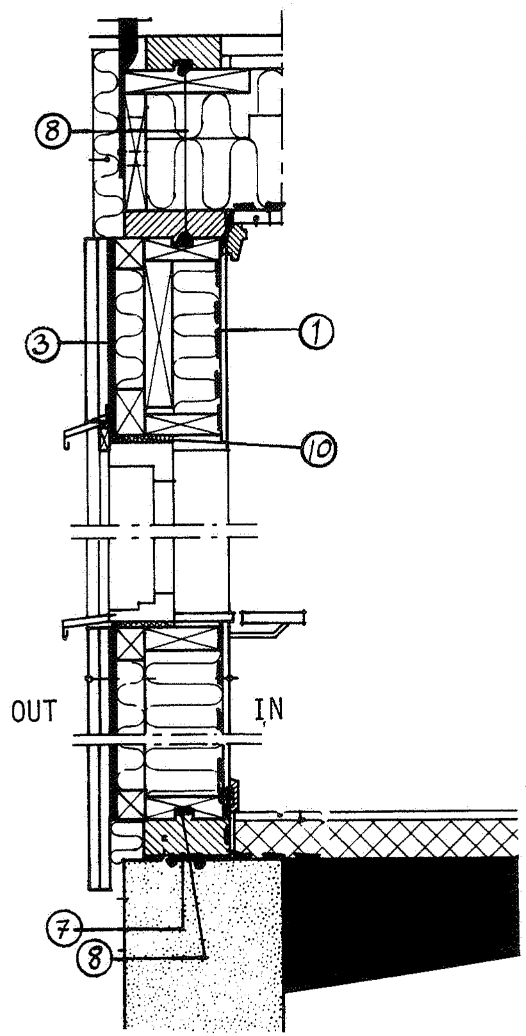


Figure 11. Vapour barrier clamped. Wall section

THE IMPLEMENTATION AND EFFECTIVENESS OF AIR INFILTRATION STANDARDS IN BUILDINGS

5th AIC Conference, October 1-4 1984, Reno, Nevada, USA

PAPER S.3

PHILOSOPHY AND BACKGROUND OF THE DUTCH STANDARD FOR AIR TIGHTNESS OF DWELLINGS

W.F. DE GIDS

Institute for Environmental Hygiene-TNO
PO Box 214
2600 AE Delft
Netherlands

Publication No.926 of the TNO Research Institute for Environmental Hygiene, PO Box 214, 2600 AE Delft, Netherlands.

SUMMARY

This paper discusses the situation in the Netherlands with respect to air tightness of dwellings and reflects discussions about this in the Dutch Standard Committee on Air Tightness of Buildings.
Results of measurements and calculations are given and the considerations of different groups in the discussion are included.
Finally an attempt is made to produce a model for the prediction of

- air flow rates
- infiltration losses
- seasonal gas consumption

on the basis of air leakage measurements.

Keywords:

air leakage, air tightness, infiltration, ventilation, standards, modeling

1. INTRODUCTION

This report can be seen as a reflection of the discussions in the Dutch Committee on Air Tightness of Buildings.
Other publications [1], [2] and [3] bring forward that measurements of air leakage by pressurization or depressurization of the building will not always simply correlate to the air infiltration.
This is a problem any standard committee on air tightness of buildings will have to deal with.
In most countries standards or proposed standards have the aim to save energy by making buildings more air tight.
The last few years we have also realized that indoor air quality problems may occur due to our endeavour to make buildings more air tight.
There will be probably two standards in the Netherlands

- one treating the measurement method
- one treating the requirements for buildings.

In the standard "Measurement method for the air leakage of buildings", which will be published soon, it is stated that this standard applies to:

- dwellings or parts thereof
- other buildings with a volume of about ten times a normal dwelling.

In this paper we only focus on dwellings. If not specified the dwellings have natural ventilation provisions. Some attention is paid to mechanical exhaust and balanced ventilation systems.

2. OVERVIEW

2.1 THE SITUATION IN 1981

The best information available at that time were the results of pressurization tests on 130 dwellings. The mean air leakage of these dwellings was 0.1 m^3/s at 1 Pa pressure difference equaling to an a_{50} of about 12 (Figure 1). One should realize that this was measured with open ducts and flues.

With the aid of the IMG calculation model for ventilation of buildings [4] and some estimates on the distribution of air leakage over the building envelope - the pressure distribution - the air flow versus wind speed characteristics of the dwelling can be calculated (Figure 2).

As can be seen from Figure 2 the air flow through the dwellings will be almost 65 dm^3/s at mean weather conditions during the heating season (i.e. a wind speed of 5 m/s and an outdoor temperature of 5 °C) and a normal shielding.

According to the basis of the Dutch Standard for ventilation of dwellings [5] (7 dm^3/s per person) this flow is enough for about nine persons.

There is no doubt that energy savings can be made by improving the air tightness of the house.

2.2 THE IMPROVED SITUATION OF 1983

A reasonable improvement of the dwelling as we have seen from measurements and calculations can lead to a flow rate versus wind speed characteristic as shown in Figure 3. But even then during about 15 % of the time the flow rate is larger than the maximum requirements of the ventilation standard.

2.3 THE DESIRABLE CHARACTERISTIC

The Standard Committee decided to reach a flow rate versus wind speed characteristic with at zero wind speed and an outside temperature of 5 °C

a minimum flow rate of about 21 dm^3/s and at 10 m/s wind speed which will be exceeded about 5 % of the time a minimum flow rate of 42 dm^3/s.
This seems to be possible by reducing the ground floor leakage to about zero and to give little attention to façade leakages and improve the roof leakage again with about a factor 2 (see Figure 4).

2.4 THE UNDESIRABLE SITUATION OF 1984

During the last eight mounths infiltration rate measurements were made in anappartment. The results are shown roughly in Figure 5.
According to the builders, the houses (appartments) had been built by "normal" building techniques for 1984. The appartments had leakage values up to ten times better than the present Swedish standard [6]. These appartments had natural ventilation. No body made any attempt to deliver the occupants information how and when they had to use their ventilation provisions. A lot of moisture and back (flue) drafting problems occurred.
In an attempt to save energy people living in dwellings with mechanical exhaust systems, switched off their system during the heating season or at the best case they switched the system on only during too short periods (i.e. only while cooking and bathing).
Again moisture problems occurred.

3. CONSIDERATIONS

At this point the Standard Committee was divided into two groups, realizing that:

- building practice sometimes goes faster than expected
- occupants' behaviour had to be changed in better air tight houses.

The first group who might be called the loosers does not want a standard on air tightness requirements. They argued to go over to the following actions.

- Produce some publications in which it is stated that:
  - normal building practice have not to be improved for façades except for houses with balanced ventilation systems
  - floors above ventilated crawl spaces must be as air tight as possible
  - roofs must be air tight to such degree that no cross ventilation will occur under mean weather conditions during the heating season.
- To ensure that minimum ventilation requirements are reached, a good education and instruction to occupants is necessary.

The second group (who might be called the tighters) wants a standard with requirements. They considered the situation as follows:

- Do not improve the 1984 building practice too much.
- Try to reach reasonable leakage values as shown in Figure 4. As a minimum desirable value, take 75 % of the curve in Figure 4.
- When designers or builders want to build better air tight dwellings they are obliged to:

  install at least a mechanical exhaust system with exhaust in W.C., bathroom and kitchen or install a balanced ventilation system with air supply to livingrooms and bedrooms and exhaust in W.C., bathroom and kitchen.

This means that a builder has to know about the air tightness of his constructions before building a house. If he makes the house more air tight than the standard he has to plan a mechanical ventilation system.

- Make instructions for occupants.

4. MODELING

If the Standard Committee decides on requirements they will make an attempt to produce a model with which any user can estimate what consequences the leakage or tightness has in terms of:

- air flow rates
- infiltration heat losses
- seasonal gas or fuel consumption.

Some attempts in other countries were a stimulation to do so ([1], [7]).

4.1 MODEL FOR NATURALLY VENTILATED DWELLINGS

The model for naturally ventilated dwellings consist of three basic equations:

$$q_v = (A + B \times C \times v + D \times \Delta T) L \qquad (1)$$

$$Q_v = q_v \times \rho \times c \times \Delta T \times E \qquad (2)$$

$$G = (Q_v \times \tau)/c_{gas} \times \eta \qquad (3)$$

in which:

q_v = total volume flow rate through the dwelling [dm^3/s]

A = constant for the effect of turbulence

A = 0.05

B = shielding coefficient

B_1 = 0.75 shielded areas

B_2 = 1.00 normal surroundings

B_3 = 1.25 open terrain

C = coefficient for the distribution of air leakage

C_1 = 0.070 normal distribution

C_2 = 0.080 high relative floor and façade leakage

C_3 = 0.060 low relative floor and façade leakage

v = meteorological wind speed [m/s]

D = constant for the temperature effect, with three values for different heights:

- $D = 0.020$ 5 m height
- $D_2 = 0.010$ 2 m height
- $D_3 = 0.050$ 10 m height

ΔT = mean weighted difference [K]

L = measured air leakage [dm^3/s at 1 Pa]

Q_v = ventilation heat losses [W]

ρ = air density [kg/ m^3]

c = specific heat of air [J/kgK]

E = coefficient for the temperature distribution over the dwelling

- $E_1 = 0.9$ normal temperature distribution livingroom 18 °C, bathroom 15 °C
- $E_2 = 1.0$ uniform distribution (bedrooms heated)

G = seasonal natural gas consumption due to ventilation [m^3]

τ = length of the heating season [s]

C_{gas} = specific heat of the natural gas [J/m^3]

η = seasonal boiler efficiency [-]

4.2 MODELS FOR DWELLINGS WITH MECHANICAL VENTILATION

Attempts have been made to correct equation (1) for mechanical exhaust systems. So far no satisfactory approach can be reported.
In the case of balanced ventilation simply adding the mechanical flow rate to the "natural" rate seems to be succesfull.

The coefficient and constants quoted in this paper may be modified, because a calculation study to verify these values is being carried out at the moment. The goal is to predict the flow rate with this model in comparison with the multicel model results within a range of about 10 %.

5. REFERENCES

[1] Sherman, M.H., D.T. Grimsrud
Measurement of Infiltration
Using Fan pressurization and Weather Data
Proceedings of the 1st AIC Conference, Berkshire 1981.

[2] Gids, W.F. De
Problems and consequences of the pressurization test for air leakage of houses
Proceedings of the 1st AIC Conference, Berkshire 1981.

[3] Gids, W.F. De
The influence of different parameters on infiltration and infiltration heat losses
Proceedings of the 2nd AIC Conference, Stockholm 1982.

[4] Gids, W.F. De
Calculation method for the natural ventilation of buildings
IMG-TNO, Publ. 632, Delft 1977.

[5] NEN 1087
Ventilatie van woongebouwen, Eisen
(Ventilation in dwellings, Requirements)
Nederlands Normalisatie-instituut, Rijswijk 1975.

[6] Swedish Building Code
SBN 1980.

[7] Hartmann, P., H. Mühlebach, U. Steinemann
Retrofit-planning-tools for institutional and residential buildings with user influenced air infiltration
Proceedings of the 4th AIC Conference, Elm 1983.

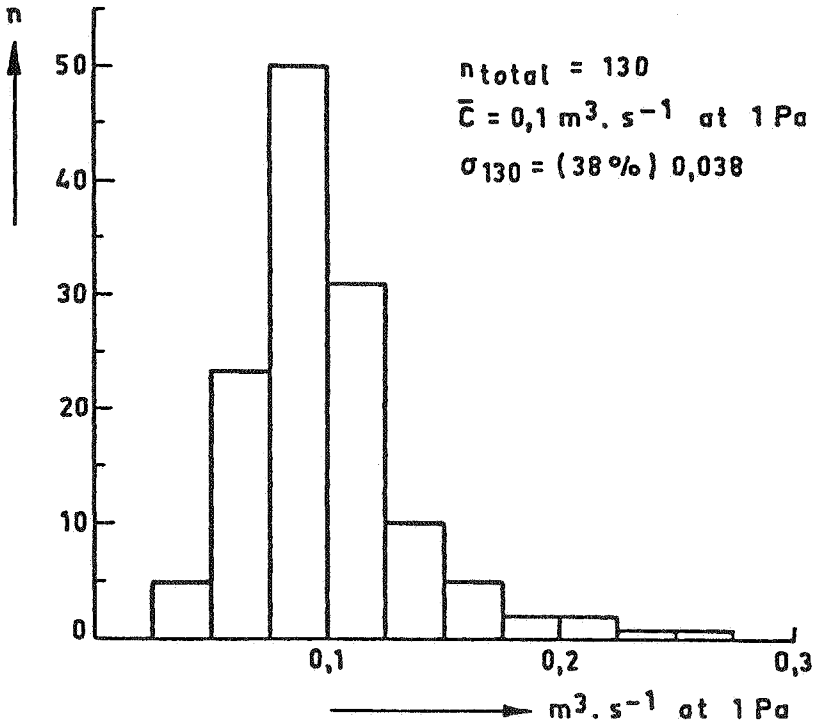


Figure 1 Distribution of air leakage for 130 dwellings in the Netherlands

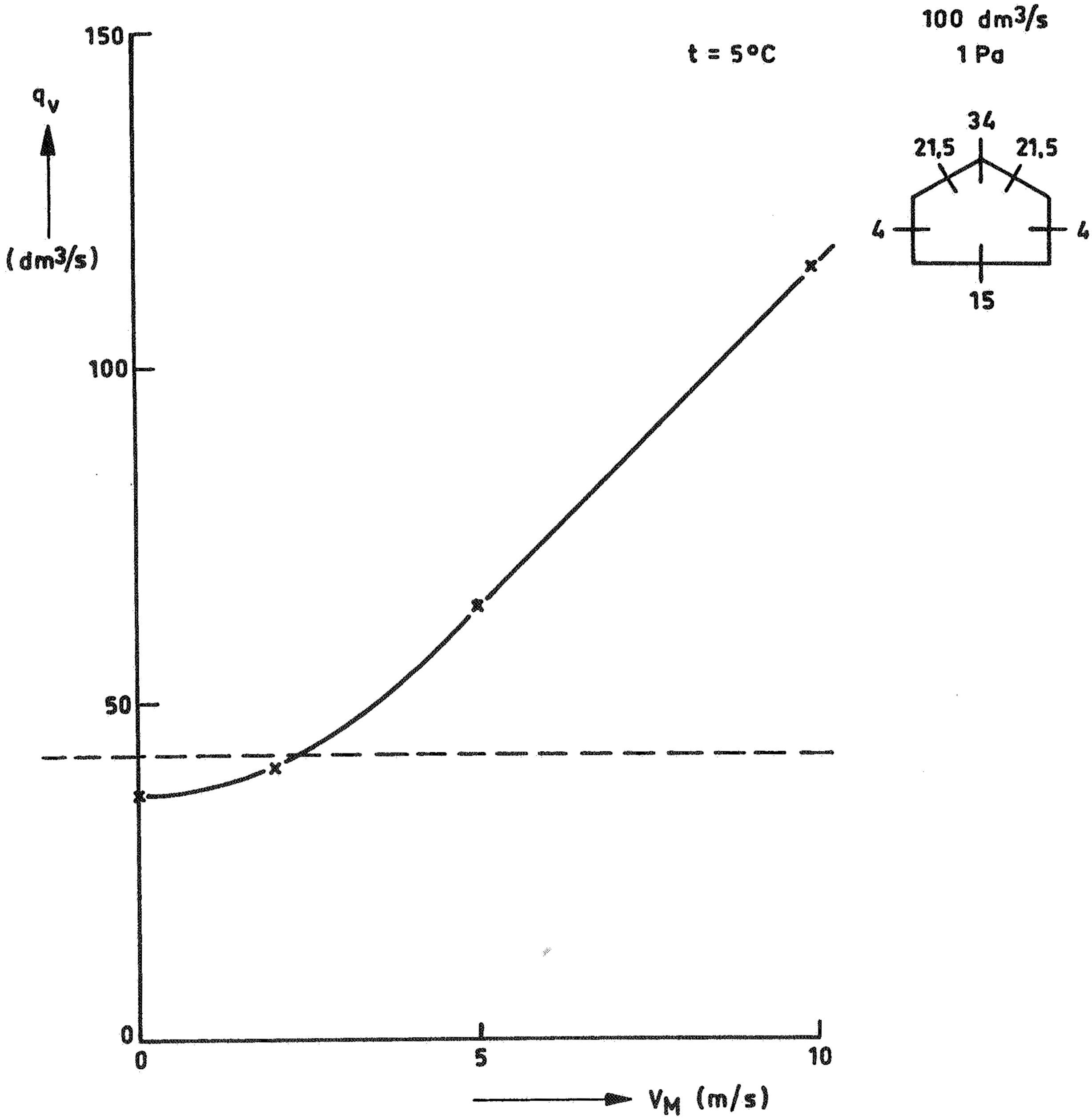


Figure 2 Flow rate versus windspeed
Situation 1981

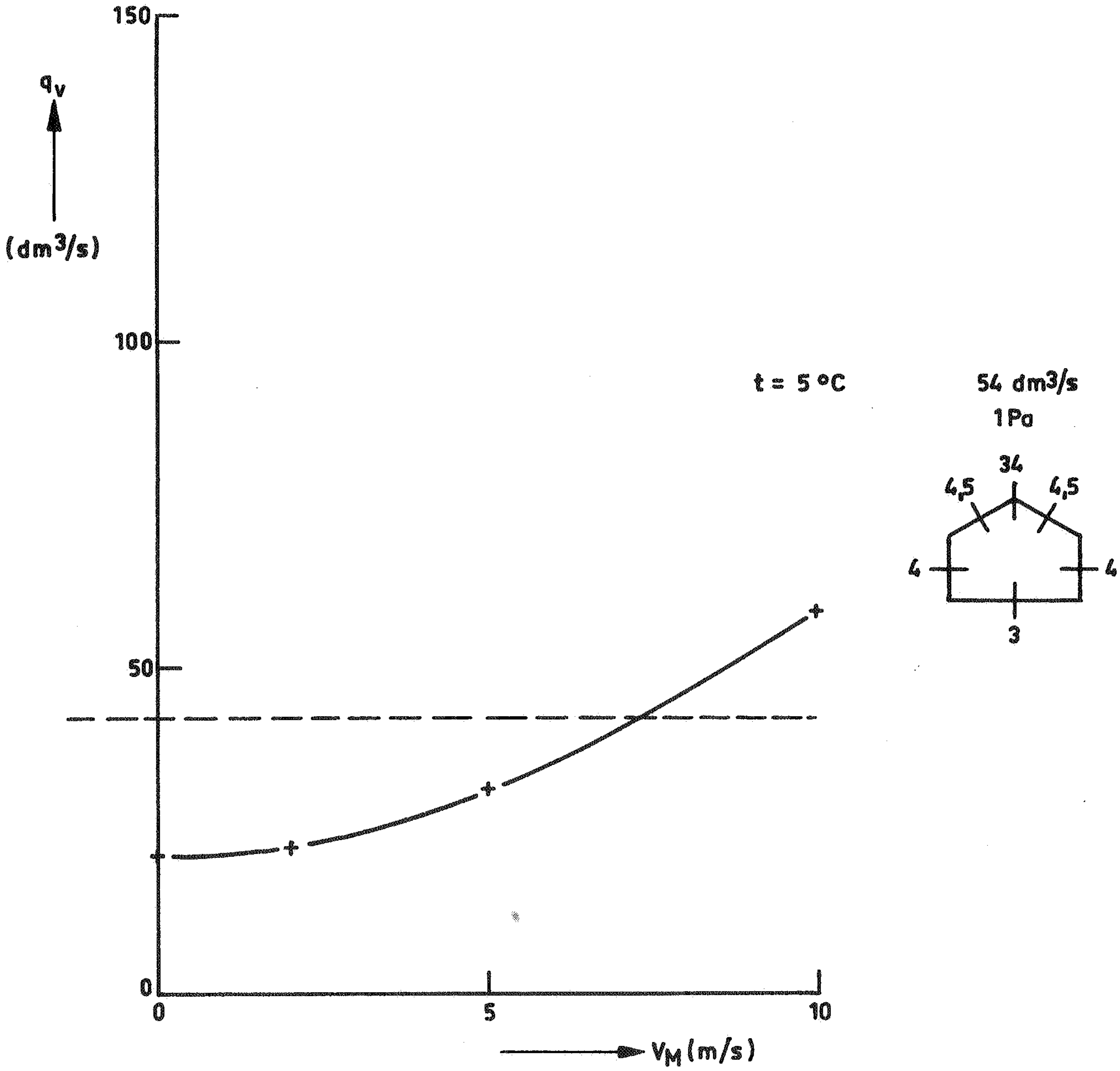


Figure 3 Flow rate versus windspeed
Situation 1983

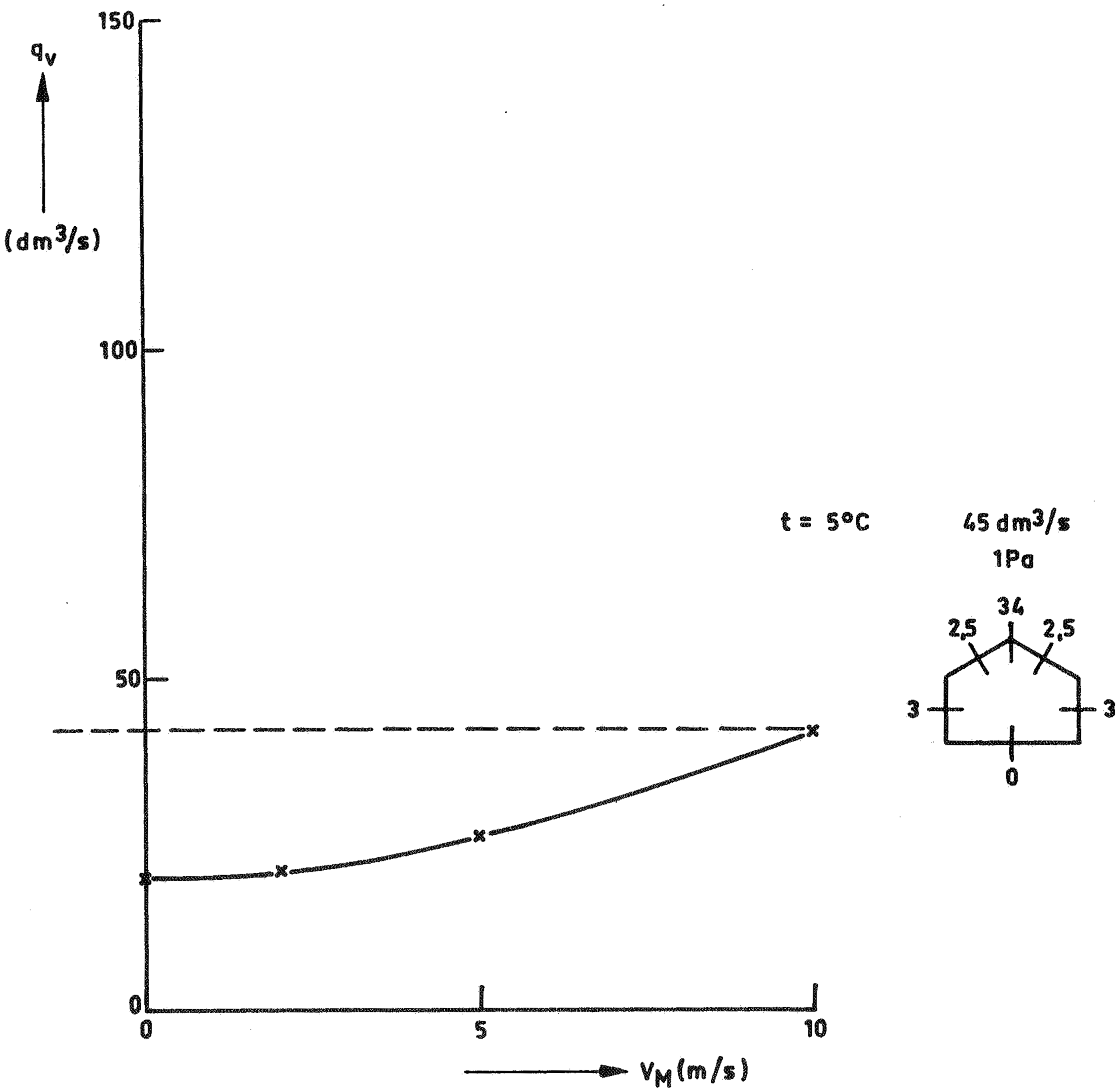


Figure 4 Flow rate versus windspeed
Desirable situation

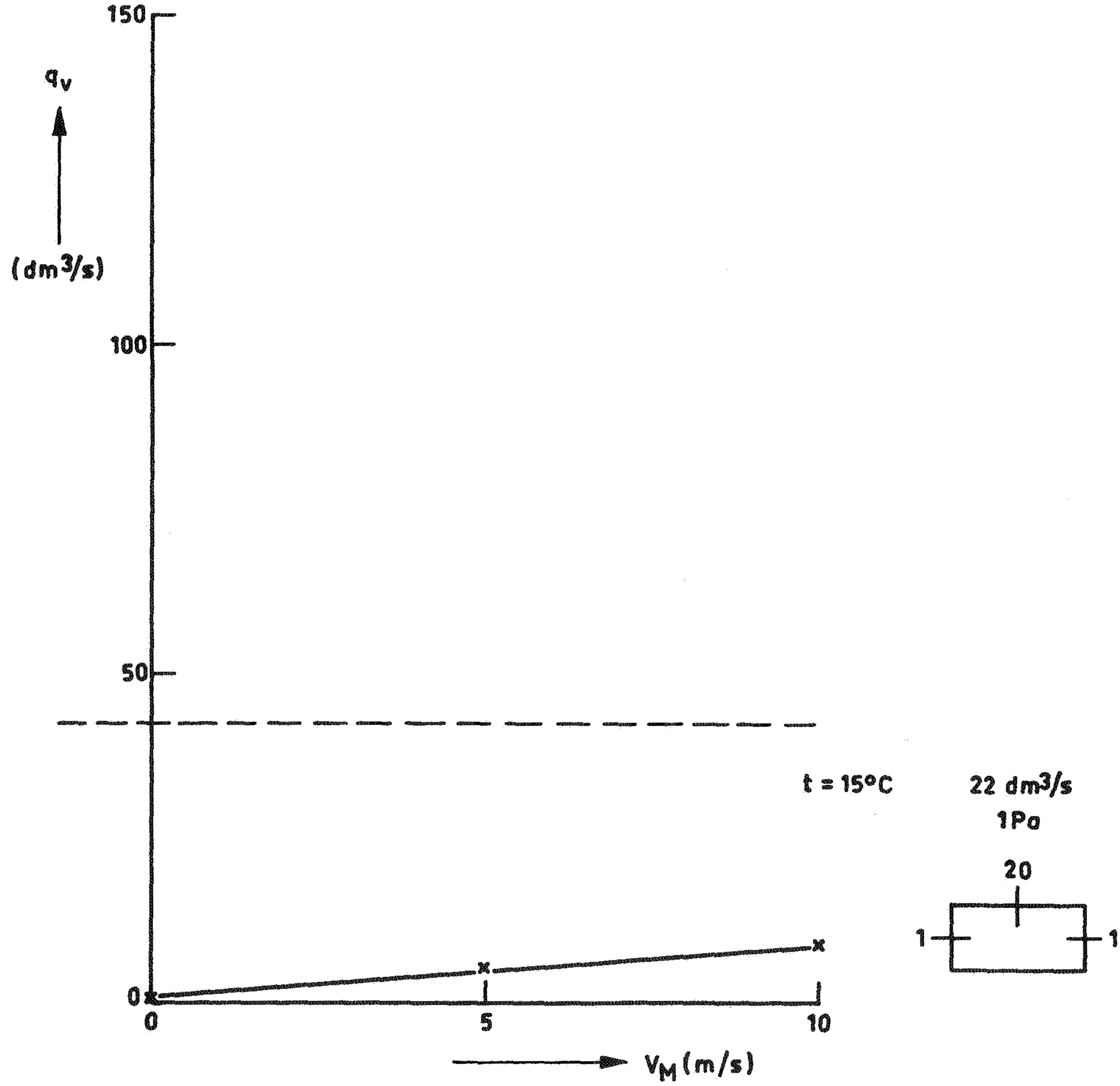


Figure 5 Flow rate versus windspeed
The undesirable situation

AMENDMENTS TO PAPERS

Paper No : 3

Title : A standard for minimum ventilation

Amendment: The equations given on page 3.8 should be numbered as follows:

$$Q_{10-s} = s(1-r)Q_{01}\{1 + rs + (rs)^2 + \ldots\} \qquad (1)$$

$$\frac{Q_{10-s}}{Q_{01}} = \frac{s-sr}{1-sr} \qquad (2)$$

The ventilation efficiency, n, can be defined as:

$$n = \frac{Q_{01} - Q_{10-s}}{Q_{01}} = \frac{1-s}{1-sr} \qquad (3)$$

Paper No : 4

Title : Airtightness standards for buildings - the Canadian experience and future plans

Amendments: Page 4.3, 1st paragraph, 2nd line.

- change 1982 to 1981

Page 4.6, last line should be:

$Q = C\Delta p^{n}$

Page 4.7, 3rd line should read:

Δp = interior/exterior pressure difference (Pa)

Page 4.7, 13th line should read:

$ELA = 0.001157 \sqrt{\rho_0} \cdot C \cdot 10^{n-0.5}$

Page 4.7, 15th line should read:

ρ_0 = density of the exterior air (kg/m^3)

Paper No : 6

Title : Energy performance standards regarding air infiltration of buildings in Switzerland

Amendments: Page 6.4, Table 1

offices with deep spaces ($<6m^2$) should read

Offices with deep spaces ($>6m$)

Paper No : 10

Title : Development of occupancy-related ventilation control for Brunel University library

Amendment : Acknowledgement

The co-operation of the Librarian Mr. N. Childs and all the Brunel Library staff during the work is gratefully acknowledged.

Paper No : 16

Title : Constancy of airtightness in buildings

Amendment : Units of ELA should be dm^2 and not cm^2 as printed.

Paper No : 20

Title : Verification of calculation models of air infiltration using three types of test houses

Amendments: Equation 17, page 20.15, should read:

$$B = 2\ TgH/(T + 273)\ v^2 \quad = \quad 2A_r$$

Equation 20, page 20.16, should read:

$$Q = Q_0(\rho v^2/\Delta p_0)^{1/n} \ . \ F\ (A_r, \phi)$$

DISCUSSION

Paper 1: 'Review of building airtightness and ventilation standards' presented by Peter Jackman (UK)

R. Grot (USA)

The USA ASTM pressurization method standard states that the pressure variation across the envelope should not be more that a certain percent and a strict application of the method would require that this be verified. The philosophy of the US has been that a building should be tested in the condition in which it is used and that openings for flues and exhausts are holes that normally exist and should not be taped or sealed unless this is the way they are normally used. The only exception is when a safety hazard could exist during the test if the opening was not sealed - for example a fireplace in which ashes would be blown into the building by the fan. The biggest difficulty we have experienced with the standard is the definition of the conditioned space and particularly if the basement volume is to be included. In US data, the basement is excluded unless it is finished; in Canada the basement is included.

D. Grimsrud (USA)

Two comments:

1. The Nordic standard should be added to your ventilation rate standards list.

2. It should be pointed out that ventilation rate standards in the US are design standards, i.e. they do not apply to the actual operation of the building. Is the same situation true in Europe ?

P. Jackman (UK)

1. *Yes, I agree. That is an important and relevant standard.*

2. *My impression is that all of the ventilation rate standards are design specifications and that there is no obligation to demonstrate that they are actually achieved in the completed building. Whether or not action could be taken against a designer if a building were shown to fall short of the specified ventilation rates would depend on the legal status of the standard in the country concerned.*

C. Eberdt (USA)

Your discussion showed three (basically) different ways to plot the results of pressurization testing (Norway & Sweden, Canada, USA). Are there any significant advantages or disadvantages to each of these ?

P. Jackman (UK)

The advantages or disadvantages of alternative ways of expressing test results depends largely on the purpose for which the data are required. From a research viewpoint, the most suitable presentation would be the figures actually recorded during the test. All other methods of are likely to modify the data in some way, e.g. averaging.

If the intention were to convey some impression of the extent of the leakage problem, then it can be argued that equivalent leakage area is a parameter the magnitude of which is easiest to visualise. If the main purpose is to provide a parameter that simply defines a limit of acceptability and that can easily be related to the measurements made on site, then the leakage rate at a given pressure difference is appropriate.

D. Kehrli (USA)
Of what value are the current test methods for component air leakage at standard atmospheric conditions, when fenestration products are probably in an open condition at these temperatures when installed in an envelope ? Should we be concentrating our efforts in standards that more closely simulate field conditions ?

P. Jackman (UK)
The tests at or near standard atmospheric conditions provide a basis for the general assessment of component quality and for the comparison of performance from one product to another. I agree that a logical extension of the requirements would be a test under temperature/humidity conditions that represent more severe site conditions.

C. Uglow (UK)
Do the four national standards on whole building air leakage specify at precisely what stage of building construction the pressurization test should be carried out ? For example, are the tests carried out after all the service connections have been completed ?

P. Jackman (UK)
No, the stage at which leakage tests are to be carried out is not specified.

W.R. Jones (Canada)
Are the Swedish/Norwegian whole house airtightness requirements mandatory ? If so, what happens to houses that do not meet the requirement ? Are all houses tested or just a sample ?

P. Jackman (UK)
(a) No - except when made so by local authorities.

(b) Sealing treatment is applied and house re-tested.

(c) Just a statistically-based sample, again prescribed by the local authority.

Paper 2:
'IEA Annex IX - "Minimum ventilation rates". Survey and outlook'
presented by Lutz Trepte (Federal Republic of Germany)

E. Sterling (Canada)
Regarding use of CO_2 as a surrogate indicator for overall indoor air quality:

1. CO_2 does not respond to ventilation in the same way as other common indoor contaminants, i.e. CO and particulates.
2. Level of acceptable exposure is unclear (we have recently recommended to Health and Welfare Council that an exposure limit of 600-1000ppm be adopted for residences, based on a detailed review of health and comfort literature).

L. Trepte (Germany)

Carbon dioxide is only one of the factors influencing indoor air quality, although one of the most investigated and under consideration for many years. Therefore, it was obvious to use, in an initial approach, CO_2 as an indicator. However, it was also found from investigations that there can be considerable variations in CO_2 between rooms and within rooms. There are, for example, no correlations between CO_2 and factors such as formaldehyde, so defining indoor air quality only by the CO_2 content is unsatisfactory and generally inadmissable.

The proposed CO_2 limits for European countries for example, range from 1000 to 1500 ppm based on the relationship between odour and CO_2 concentrations. Other standards specify a limit of 2500 ppm. We would recommend the lower levels.

Paper 3: 'A standard for minimum ventilation' presented by David Harrje (USA)

W.R. Jones (Canada)

Do you believe that the revision to ASHRAE Standard 62-1981 will include outdoor air requirements ?

D. Harrje (USA)

The final version of 62-1981R will depend on the careful weighing of all the factors discussed in this paper, plus other factors that we are sure will be raised at future meetings of the committee. Certainly a number of factors would point towards increased outside air requirements. However, we believe the revised standard will have more flexibility to respond to the variety of ventilation requirements and that the consequence of various actions will be better outlined in that standard.

E.M. Sterling (Canada)

1. Prediction of tobacco-related indoor air quality constituents modelled with data obtained in chamber studies, as well as measurement studies undertaken with inadequate and often faulty instrumentation (TSI piezo balance), does not correspond with measurements obtained in buildings measured under conditions of real occupancy and use. Particulate levels, even where smoking occurs, never reach those levels that would be expected judging from chamber studies. Therefore, the expressed requirement for 42 cfm to control tobacco smoke is probably unwarranted.

2. Are results of fan pressurization tests for air leakage appropriate as the basis for design standards/guidelines ? We do not design for 50 pascals. Buildings have different leakage characteristics under normal conditions (respond to seasonal variation); fan pressurization masks this.

D. Harrje (USA)

1. *We agree that chamber studies often cannot predict the entire 'real life' situation in an actual building. However, the error is not necessarily in one direction.*

2. *The use of an elevated pressure, such as 50 Pa, is useful in the comparison of individual building tightness as well as an aid to pinpointing air leakage sites. Seasonal variations, with all the associated complexities such as wind speeds and direction, temperature differences, humidity level and occupancy behaviour, can only be ascertained using tracer gas methods which measure the air flow directly.*

D.T. Grimsrud (USA)

Please comment on the effects that occupancy would have on the seasonal infiltration measurements made in the two study houses in Gaithersburg, Maryland.

D. Harrje (USA)

The experiments in the two unoccupied houses in Gaithersburg were generally free from occupant effects such as opening and closing doors, except where technician activities necessitated door openings. On average, door openings were made during one out of eight hours. Comparisons were made with the same ΔT and wind speed categories. Those brief door openings had no measurable effect on the hourly air exchange rate. Cooking activities and other occupant interior activities also had no measurable effect. Clearly the opening of windows, even slight amounts, would have been immediately noticed, but they were not part of the research agenda.

D. Saum (USA)

Have you tried to model the seasonal variations in infiltrarion using models such as that of LBL ? If so, what correlation was found between models and measurements.

D. Harrje (USA)

The modelling efforts by the researchers at Geomet involved the use of the Reeves/EMPS model and regression models to estimate seasonal variations in air infiltration. General trends were certainly evident in the models. For the Reeves model to more closely simulate the measured air infiltration rates, it was necessary to make adjustments to account for the individual houses (bringing the explanation of variation to almost 90%). This necessity for individual building corrections is not that unusual (based upon other modelling experience) and it represents the limitations in the modelling approach. Factors such as where infiltration is taking place and the nature of the openings (orifice vs small crack flow) can directly influence the field vs theory comparisons.

W. de Gids (Netherlands)

Are the numbers in Figure 5 reasonable, when you have sufficient air flow for a room and proper design of the system ? In addition, in an occupied room people themselves are also mixing the air.

D. Harrje (USA)

A 'proper design of the system' implies that return and supply systems are adequately mixing the room air. This is best achieved if they are located at different room heights. If supply and return are located in the ceiling as shown in Figure 4, then all too often short circuiting can occur above the dashed line. Depending on the level of that line in the room, occupant movements can 'mix' the room air 'more or less' as you point out.

R. Rothman (USA)

1. The standard (ASHRAE 62-81) refers to filtering efficiency as a possible means of reducing fresh air intake. A formula is provided (based on filter efficiency) to calculate required ventilation rate. Except for particle removal, there is no filtering process that will give a predictable removal efficiency. Therefore, although it is good procedure in theory, it is not practicable from an implementation point-of-view.

2. It is also important to establish a procedure to determine when filtering is necessary. With the exception of particles (smoking), it is not clear which pollutants are of realistic concern and how they can be mitigated. The standard proposes an air pollution screening procedure but it does not seem to apply this very well to indoor sources.

While I realise there is no easy answer, I believe the standard should attempt to deal with this problem in a more direct manner. (If we do not have a good system to analyse existing indoor air quality and a realistic means to mitigate, the standard should acknowledge this defficiency)

A further note on implementing ASHRAE 62-81. BPA has adopted certain portions of ASHRAE 62-81, in particular the table prescribing ventilation rates. We have not adopted, in full, other portions dealing directly with air quality - primarily because, as indicated below, there does not appear to be a realistic means of implementing the recommendations nor does it address what we see as potential indoor air quality problems.

I am curious to know if (a) you agree with my concern - if so what plans are being made to address the issue and (b) others have made similar comments.

Recommendation: Because each building will have a potential for unique sources of air pollutants and because it is not reasonable to monitor all possible pollutant types, ASHRAE should consider simply prescribing:

1. Ventilation rates that typically provide acceptable air quality (define acceptable air quality). BPA is carrying out some work in this area now.
2. Outline all measures/procedures to avoid source problems.

D. Harrje (USA)

Your comments point out perceived deficiencies in the standard as it is now constituted. However, as stated in our paper, each aspect of the standard is being studied by a group of subcommittees to review comments such as those you have expressed. We quite agree that each building has unique sources of air pollution and the Ventilation Rate Procedure is the approach that specifies air exchange rates that typically provide acceptable indoor air quality. The Air Quality Procedure is an alternative approach which, if used properly, can provide even better assurances of appropriate

indoor air quality. For example, if monitoring were carried out for particulates because they presented the indoor air quality problem in the building in question, then ventilation rates would be adjusted to solve that problem (which might not have been addressed by the Ventilation Rate Procedure). We also agree that source control would be the preferred route, but is it feasible to prescribe comprehensive source control within the standard ?

<u>Paper 4</u>: 'Airtightness standards for buildings - the Canadian experience and future plans' presented by John Haysom (Canada)

R. Grot (USA)

Do you have any data to support the statement that the typical pressure difference of a Canadian house is 10 Pa ? How does the Canadian pressurization standard differ from the existing ASTM standard ?

J.C. Haysom (Canada)

The 10 Pa figure was chosen for use in calculation of ELA not because it was assumed to be typical of cross-envelope pressures on Canadian houses but because it is the lowest pressure used in the test. As we are not seeking a correlation between the results of the airtightness test and actual air leakage and because the ELA figure obtained is seen as a relative measure of envelope quality rather than an absolute "real" parameter, the choice of Δp for use in the ELA equation is not critical. Also, the form of the equation, in which the Δp value is raised to a power of 0.5 or less, makes it relatively insensitive to the Δp value chosen. However, since the Committee is now planning to drop the 10 Pa test pressure to make the test less sensitive to wind, we should perhaps consider using 4 Pa rather than 10 Pa in the ELA formula for the sake of international uniformity.*

I am not familiar enough with the ASTM standard to comment on the differences.

J. Kronvall (Sweden)

How are you planning to make it possible to relate the test result expressed in equivalent leakage area to the house tested and thus enable the comparison of airtightness levels for different types of houses ?

J.C. Haysom (Canada)

At the meeting of the CGSB Committee in July 1984, it was decided to add to the standard the concept of "Normalised Leakage Area". NLA is equal to ELA divided by the exterior surface area of the building envelope. This latter parameter is intended to include the area of exterior below-grade walls and floors. In introducing the NLA concept, the Committee intended to facilitate comparison of airtightness among houses of different sizes and to encourage building code authorities, who might be considering the introduction of airtightness criteria, to use this format.

** This is recognised to be considerably lower than 10 Pa*

C. Uglow (UK)

Does the draft Canadian standard (CGSB 149.10) include any advice or instruction on the calibration of the fan used in the de-pressurization rig ? If so, is the fan calibrated in isolation or is the complete piece of equipment calibrated, i.e. fan plus ducting ?

J.C. Haysom (Canada)

CGSB 149.10 includes calibration procedures for:

- *air flow measuring devices which can be calibrated separately from the driving fan, e.g. orifice plate in entrance duct.*
- *calibrated fans which are used without entrance ducts.*
- *devices for measuring the indoor/outdoor pressure difference.*

A separate CGSB standard, just beginning to be developed, deals with certification of airtightness testing contractors. it addresses such considerations as:

- *means by which a client can be assured that the equipment has indeed been calibrated in accordance with 149.10.*
- *assurance that the contractor's personnel are qualified to use it.*

Paper 6: 'Energy performance standards regarding air infiltration of buildings in Switzerland' presented by Conrad Brunner (Switzerland)

J.P. Millhone (USA)

How do you determine whether the design of a new building is in compliance with your recommendations ?

C. Brunner (Switzerland)

Design values are to be checked by the authorities during the process of getting a building permit. Because the calculation is to a standard format, the regular staff are thought to be able to do the checking.

Actual energy performance is checked by the owner after two full years of operation. If the values exceed 20-30% of the previously planned figures, a thorough check of actual user conditions will be carried out by the architects and engineers. Liability for deviation will be cleared. However, this procedure will only be brought into effect by the authorities if there is evidence of malpractice.

H. Feustel (USA)

Who controls whether the calibrated data and the measurement data agree ? Who carries out the measurements ?

C. Brunner (Switzerland)

(See reply to question by J. Millhone). Also:

If a major deviation (> +30%) and an intention to defraud the building administration authorities is found, a detailed check of the energy balance will be made. Standard testing

	procedures and testing facilities (like EMPA) will be asked to take the measurements. We anticipate this will be necessary only in 1% of cases.
	The measurements of energy consumption are taken by the owner himself or his representative.
B. Nelson (USA)	Do home builders (not architects) object to the performance standard, and what has been done to help them adopt it ?
C. Brunner (Switzerland)	*No. Home builders are a minority in the Swiss building market. The small house (below 500m^2 gross floor area) is to be designed to an easier component standard (with strict values) but without complicated energy computations.*
Paper 7:	'Description of ASHRAE's proposed air tightness standard' presented by Max Sherman (USA)
R. Grot (USA)	In the establishment of ASHRAE proposed airtightness standard, have there been any other considerations in the establishment of the tightness levels other than energy usage or cost, i.e. factors such as indoor air quality or the potential for moisture damage ?
M. Sherman (USA)	*Standard 119 serves as a link between two other ASHRAE standards - Standard 90 which is an overall energy standard and Standard 62 which covers indoor air quality. Standard 119 is specifically designed to economically minimise energy use due to infiltration, but specifically states that it is up to the user of the standard to separately assure adequate indoor air quality. Issues such as moisture damage are not addressed in the standard because they are far more complex than air tightness considerations. For example, a building that is tight on the warm side may have no moisture problem while the same may not be true for a building that is tight on the cold side. Furthermore, it is the intention of the standards committee that guidelines or a manual of acceptable practice be produced in parallel with 119 which would offer recommendations on the design and construction of houses that would meet the standard and thus address the issue you have raised.*
S. Flanders (USA)	The US military currently uses heating and cooling degree days as an imperfect basis for calculating energy conservation investments. Can the IDD described be used on an equivalent basis ?
M. Sherman (USA)	*"Infiltration degree days" is a concept which bears exactly the same relationship to infiltration-induced load that conventional degree days have to conduction-induced load, i.e. a quantitative measure of the severity of the climate. Factors other than temperature, i.e. wind and humidity, have a significant impact on infiltration load and are included in the definition of IDD. I would hope that infiltration degrees would get the same treatment that is currently given to heating degree days. Furthermore, IDD solves many of the problems associated with using degree day concepts in cooling climates.*

Paper 8: 'Air quality issues in ventilation standards' presented by David Grimsrud (USA)

J. Armstrong (USA)
If we base concentration levels on health considerations, what responsibility do we have to include micro-organisms in our list of pollutants ? Many illnesses and losses on productivity are caused not by inorganic or non-living pollutants, but by micro-organisms. These may have a higher "relative risk" than those currently included in ASHRAE 62-1981.

D. Grimsrud (USA)
That is an excellent point. The pollutants covered in 62-1981 are not a complete list and only include those that have been identified as problems. The standard will continue to be incomplete until the relative risk of each of the major pollutants is understood and used as the basis for setting limits.

A. Weidman (USA)
Of the 44,000 jurisdictions in the USA that adopt building codes, how many have adopted ASHRAE Standard 62, how is it enforced and what is the level of compliance ?

D. Grimsrud (USA)
Standard 62-81 was not adopted by ANSI because of the formaldehyde issue. As a result it has not been put into local building codes. Instead these codes continue to use some variation of Standard 62-1973. This has caused ASHRAE to move to an early revision of 62-1981.

D. Harrje (USA)
You mention a criterion based on mortality, but comfort has been an important factor in establishing Standard 62-1981. How do you handle that aspect, e.g. HCOH ?

D. Grimsrud (USA)
That is an important issue. The problem that we see with the present standard is its lack of consistency in setting limits. A limit set on the basis of lifetime risk of mortality should not be used for one pollutant while a limit based on comfort is used for another. Perhaps the solution will be a set of graduated limits based upon special criteria as health risk and comfort information becomes available.

R. Grot (USA)
In the cost of using a building, the salary costs of the occupants are by far the largest single expense. If the poor quality of the indoor air is responsible for factors which lead to reduction in worker productivity or increased absenteeism due to what may be considered minor complaints (increased headaches, colds, fatigue, etc.), then these costs are probably more significant than the increase in risk due to cancer caused by the pollutions. I do not feel that risk analysis is the appropriate method for determining the level of indoor pollutants.

D. Grimsrud (USA)
We agree. Given present knowledge, risk analysis cannot produce a set of indoor air quality guidelines that are appropriate for all pollutants. In our paper, we do not recommend that risk analysis be used to set concentration

limits. What is recommended is that a consistent basis be used in choosing concentration limits for pollutants. The present version of the standard does not meet that criterion. Perhaps the ultimate version will contain values that take into account relative risks or mortality, morbidity and discomfort for each pollutant. Until that sort of information is available we should recommend ventilation values that assure comfort and make every effort to avoid designing and constructing buildings containing major pollutant sources.

Paper 9: 'Air leakage or controlled ventilation?' presented by Magnus Herrlin (Sweden)

M. Sherman (USA) The work you have done is quite interesting, but I am confused about the intended application. You have shown that if chambers are linked in series and the same amount of ventilation air is used, indoor air quality will be improved - but this appears impracticable. In a single dwelling, it would be impossible to link individual rooms; in a large building the amount of air that would be introduced would be so large as to make the air velocity unacceptable. Could you comment on the applications of your work.

M. Herrlin (Sweden) *As is stated in our paper, the "connection in series" case is a reference case. In figure 5 that value is given in order to relate the efficiences of the other cases to the highest possible efficiency, with the calculation method used.*

It was not our intention to propose that "connection in series" should be used in practice but merely to illustrate a possible method of evaluating different ventilation schemes.

Paper 10: 'Development of occupancy-related ventilation control for Brunel University library' presented by Bryan Smith (UK)

A. Wilson (UK) How many CO_2 sensors were in the library and where were they situated, i.e. more than one, how were they combined ?

B. Smith (UK) *One CO_2 sensor was positioned in one of two library exhaust air ducts. More work is required to establish whether or not CO_2 (or other air quality) sensors should be installed on all or some floors of the library. A recent survey has shown some (relatively small) variations between different floors of the library related to occupancy.*

B. Nelson (USA) Will the follow-up monitoring also measure other contaminants to verify the hypothesis that CO_2 level alone is an adequate indicator of ventilation needs ?

B. Smith (UK) *It is hoped to carry out a follow-up study of the relationship between CO_2 and other contaminants which would not necessarily be confined to the Brunel Library building.*

Paper 11: 'Performance of passive ventilation systems in a two-storey house'
presented by Rob Dumont (Canada)

D. Harrje (USA)
With regard to the addition of a vent direct to the furnace, does this result in house pressurization and the possibility of moisture penetration into the upper walls of the building ?

R. Dumont (Canada)
Adding an outside air vent to the lower part of the house does lower the neutral pressure plane and increase the positive pressure acting on the upper part of the structure. However, the increased air change due to the vent will result in lowered relative humidity within the structure, thus lessening the vapour pressure driving potential and the risk of condensation.

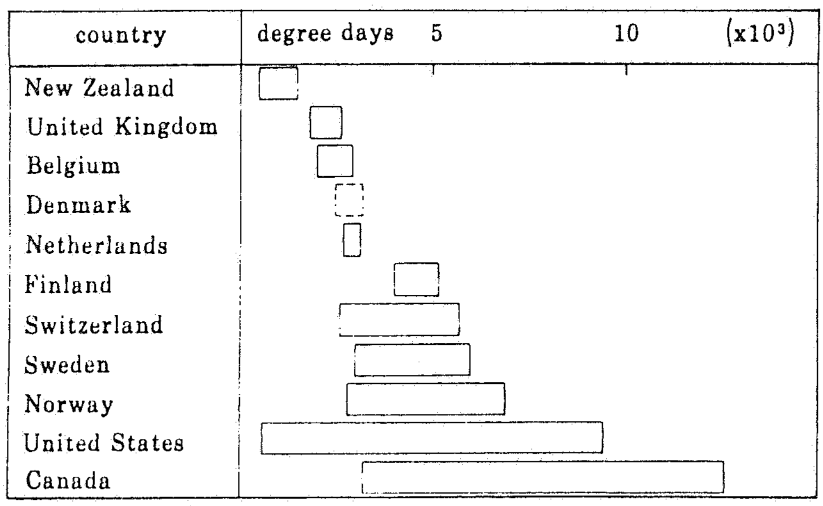
The coupling of the outside air vent to the return air plenum on the forced air furnace will usually increase the pressure within the house slightly. However, the Canadian experience has generally been that the benefits of mixing the cold outside air with the return air outweigh the possible adverse effects of slightly increasing the pressure within the structure.

Paper 12: 'Implications and analysis of airtightness and ventilation standards'
presented by Martin Liddament (UK)

P. Wouters (Belgium)
Please confirm your published degree day data for Belgium.

M. Liddament (UK)
My most recent data for each AIC participating country, including Belgium, is reproduced in the following diagram.

Degree day ranges for AIC participating countries



D. Saum (USA) — You suggest 50 Pa ach <1 for the use of mechanical ventilation with heat recovery. Was there not an article in Air Infiltration Review* on Swedish work showing that it was probably not cost effective to achieve this level of airtightness ?

M. Liddament (UK) — *Certainly the ach at 50 Pa should be <3 and it seems from an energy efficiency point of view even tighter. The cost effective "threshold" will depend on climate and operating costs including the cost necessary to achieve airtightness. Inclusion of the cost data in Equations 4 and 5 will enable the severity of climate at which cost effectiveness will be achieved to be determined.*

C. Brunner (Switzerland) — There seems to be a misunderstanding that if, in Winter, the air change rate due to airtightness increases, the ventilation rate, due to the user's influence, rises also. This is normally not the case if the heating system is limiting the heat supply to a nominal load depending on outdoor temperatures. We observed that people were more likely to close windows in Winter than in Spring or Fall.

M. Liddament (UK) — *The reactions of occupants are very important and it is essential to document and disseminate the results of occupant studies.*

S. Flanders (USA) — Does "SEK" stand for Swedish Kroner ? If so, can one convert your nomogram (figure 6) into a currency of choice, simply, i.e. scaling according to the ratio of the exchange rates, or is an elaborate conversion necessary ?

M. Liddament (UK) — *Yes, any currency or units may be used. Simply fit the units of your choice on the scale illustrated.*

D. Kehrli (USA) — Your paper indicates that as the climate changes from Summer to Winter, i.e. temperature, the ach increases accordingly. What influence does the building envelope and its components have on this increase ? Is there an increase in the ELA causing increased flow ? If so, could it be possible that the envelope and its components are expanding and contracting due to these temperature changes and causing the increased air leakage ?

M. Liddament (UK) — *The increase in air change rate in Winter has been assumed to be entirely due to the increase in intensity of the driving force - especially due to stack effect.*

Paper 13: 'The influence of climate and ventilation system on airtightness requirements'
presented by Ake Blomsterberg (Sweden)

C. Brunner (Switzerland) — The desired level of 0.5 ach for the naturally ventilated house means something like 50 m^3/h average fresh air over the whole Winter period. This is not desirable and is much too high. Where does the user come into the picture in these figures ?

**The Air Infiltration Centre's quarterly newsletter.*

A. Blomsterberg (Sweden)	*The desired level of 0.5 ach actually means 55 m^3/h. The level which was achieved was 0.25 ach for the Winter period. For most conditions this may be sufficient for this particular house. The 0.5 ach is what is required in the Swedish Building Code and considered adequate to control most pollutants. The level is what the ventilation system (mechanical or non-mechanical) should be able to supply. The user can of course raise or lower the ventilation rate by opening or closing vents, windows, etc.*
Paper 14:	'A consequence analysis of new Norwegian building regulations on air infiltration' presented by Jørn Brunsell (Norway)
J.R. Armstrong (USA)	Norway appears to have adopted airtightness requirements without corresponding ventilation requirements. This would seem to be a very risky regulatory approach. Would it not be better for countries to adopt ventilation requirements before or, at most, in concomitance with airtightness standards ?
J. Brunsell (Norway)	*In Norway we had ventilation requirements for several years before we acquired quantitative airtightness requirements. For single family houses and flats there is a choice between natural and mechanical ventilation. If you choose natural ventilation you have to use a certain size of pipe from each "wetroom". If you use mechanical ventilation you have to ventilate at a specified rate of m^3/h from each "wetroom".*
P. Jackman (UK)	Is there a specific reason why the Norwegian airtightness standards were set at a less stringent level than those of Sweden ?
J. Brunsell (Norway)	*I think the reason is that the Government did not want to push mechanical ventilation in new detached houses in order to keep the building costs down. With a leakage rate at 50 Pa of 4 ach the ventilation rate is high enough on average with natural ventilation.*
P. Hartmann (Switzerland)	Norwegian regulations demand good values for wall and roof tightness. 1. Is it worthwhile testing these values in the laboratory without having any idea about airtightness values on site ? 2. Is it worthwhile to have tight components and then to allow high infiltration through gaps and joints, e.g. wall leakage 10%, gap leakage 90%, ?

J. Brunsell (Norway)

1. *Laboratory tests of building components will gave an idea of the tightness level obtainable in situ. Besides the specific air leakages, allowances are made to cover prefabricated elements.*

2. *I partly agree, but site measurements made on windows and walls etc. up to 15 years old correspond approximately to the new requirements.*

Paper 15: 'Measured and building code values of air change rates in residential buildings'
presented by Carl-Axel Boman (Sweden)

C. Brunner (Switzerland)

Do you have energy consumption data on the 600 houses you have surveyed ?

C-A. Boman (Sweden)

We have data from fewer than 100 buildings in this database. This is divided between single and multi family houses constructed between 1980-84.

R. Dumont (Canada)

Please comment on the Swedish standard for ventilation (0.5 air changes per hour). Is it based on considerations of diluting the pollutant generation from occupants, i.e. CO_2, body odour, moisture generation, or on diluting the pollution from the building materials and surrounding soil, i.e. formaldehyde, radon, off-gasing from building materials ?

C-A. Boman (Sweden)

The Swedish code for ventilation requires 0.5 ach to take care of most pollutants. Ten to fifteen years ago, the required value of 0.5 ach was dependent upon moisture conditions in bathrooms, kitchens, etc. Recently we have added radon and formaldehyde. The level is that which the ventilation system (mechanical or non-mechanical) should be able to supply.

M. Lubliner (USA)

1. What type of building inspection, if any, is required to ensure that the mechanical ventilation system provides ½ ach (avg. annual) and that even mixing occurs from room to room ?

2. Does the building code require testing and/or guidelines and, if so, I would like a copy. Washington State is investigating this for our building code development.

C-A. Boman (Sweden)

1. a. *For new buildings the city administration are responsible for inspections. They are not able to control all new buildings or determine whether uniform mixing occurs from room to room.*

   b. *Every city and town in Sweden has an official health committee. Occupiers can complain to the committee if, for example, the air change rate is too low. The committee can then investigate the complaint themselves or instruct a consultant to act on their behalf.*

c. Some of the manufacturing companies make tests while the larger property owners sometimes make air change measurements, especially if they are attempting to save energy.

2. No.

Paper 16: 'Constancy of airtightness in buildings' presented by Anders Carlsson (Sweden)

C. Uglow (UK)

The initial measurements of airtightness were made during the months of November to March, whereas the second measurements were made during May and June. Is is possible that there are seasonal variations in airtightness which are hidden in the results ?

A. Carlsson (Sweden)

It may well be so. However, as you mention, there is only one combination winter (1st) - summer (2nd) in the material. We hope to also be able to follow up the seasonal variation in future work.

Paper 17: 'Baseline data: Health and comfort in modern office buildings' presented by Elia Sterling (Canada)

R. Helmeste (Canada)

Did you consider noise as a factor in your study and, if not, will it be included in future studies ?

E. Sterling (Canada)

Noise was not considered as a factor in the study reported here. Questions related to noise and sound level have been included in the revised questionnaire now being administered in Canada and Great Britain.

J. Hockman (USA)

1. Is there a correlation between perceived symptoms and actual medical symptoms ?

2. Will not the data on energy-efficient offices in Canada and UK be influenced to a significant degree by different cultural factors in those locations eg the New York office, i.e. many people in the UK do not live in centrally-heated homes which may affect their perception of comfort ? Might not the data also be influenced by different ambient outdoor environmental conditions that exist in the different locations, i.e identical indoor air quality in smog-bound Los Angeles will be perceived differently than in non smog-bound Los Angeles or Grand Rapids, Michigan ?

E. Sterling (Canada)

1. The survey did not include a clinical examination so there is no actual medical verification of symptoms. However, symptoms noted are primarily chronic and non-specific, such as headache, eye irritation and fatigue and are thus known to be reliably assessed by interview techniques.

2. *The data collected in the UK and Canada could be influenced by cultural factors such as central forced air heating and type of fuel used for heating and cooking. Data may also be influenced by ambient outdoor environmental conditions. We have observed previously that outdoor air quality has a much greater influence on indoor air quality than do many building and occupancy factors such as ventilation and smoking.*

   The questionnaire has been designed to cater for both cultural and locational factors and will be evaluated to determine the significance of such effects. However, even if such effects exist, they are probably too small to emerge through analysis of interviews as neither cultural differences nor differences in the quality of ambient air are very large among urban areas of the US, UK and Canada (including smog incidents).

D. Grimsrud (USA)

What measurements would you add to these surveys which could be used to characterise the physical conditions in the building, e.g. temperature, relative humidity, ventilation rate or lighting level ?

E. Sterling (Canada)

Our surveys indicate that there are a variety of problem conditions occurring in existing buildings. However, routine measures of physical conditions, including air quality, ventilation, temperature, humidity and illumination, have failed to enable investigators to identify specific causes of occupant complaints. By experimentally manipulating both ventilation and lighting, we have shown that reducing the antecedent conditions for photochemical smog production indoors significantly reduces symptoms of Tight Building Syndrome, particularly the ever-present eye irritation (Canadian Journal of Public Health 74:385-392, 1983; ASHRAE Transactions 89(2A):198-207, 1983). To explore this more fully, in addition to routine measures of physical conditions, oxidation measures should also be made of antecedents of photochemical reactions including ultra-violet radiation (from fluorescent lamps, photocopiers and video display terminals), ozone (lower levels indoors than out may indicate increased chemical reactivity indoors) and organic constituents such as aldehydes and hydrocarbons and others.

R. Derickson (USA)

With regard to reduction in reported health problems when occupants have control of their indoor environment, have you explored possible "placebo" effects, i.e. is real control necessary to produce positive health effects ?

E. Sterling (Canada)

There is substantial justification in the literature to assume that occupants can accurately judge variation in both thermal conditions and odour. In addition, we reported previously (Canadian Journal of Public Health, Vol.74, pp385-392) that occupants responded in a "blind" experiment to changes in both lighting and the percent of outdoor air supplied to their office environment. On the *other hand, the literature is replete with demonstrations of a "placebo" effect. There is, however, evidence that the "placebo" effect occurs primarily when discomfort (or pain) is small and does not persist over extended time periods. Based on our findings and the available literature it is very likely that real control is necessary to produce positive effects on occupant health and comfort.*

P. Hartmann (Switzerland): Did you measure the ventilation rate in these buildings or did you carry out other checks to see if these buildings comformed to "normal standards" ?

E. Sterling (Canada): We did not measure physical parameters in this study. However, the ventilation systems were evaluated and found to be operating normally.

Paper 18: 'First phase occupant reaction to well-sealed indoor environments'
presented by Gunnar Lundqvist (Denmark)

D. Kehrli (USA):

1. The existing windows appeared to be of wooden construction and of the casement type. What were the details of the retrofitted windows, i.e. material, mode of operation, glazing, etc. ?

2. Did you make any measurements of the field leakage of the existing windows ?

3. What type of weatherstripping was in use in the old windows and what condition was it in ?

4. Did the replacement windows have any air leakage and sound transmission class rating on them ?

5. Were re-weatherstripping, caulking and storm windows considered as alternatives to replacement prime windows ?

6. What was the cost of the replacement windows and installation ?

G. Lundqvist (Denmark): It was initially decided that the study should be epidemiological and not deal with building component details. Nevertheless, from a practical point of view all the questions raised are very relevant and should be covered by data from a follow-up study dealing with ventilation measurements in a random selection of the dwellings recruited from the main study material.

D. Harrje (USA): Your charts showing reduction of complaints of cold floors and low temperatures and the probability of increased humidity levels, together with substantially reduced joint, neck/back pains point out very positive effects to both the general and especially older population of your test buildings. Recommendations from your study as to what constitutes a preferred indoor environment represents a very important and perhaps unexpected result of your studies. Although one would wish for additional temperature and moisture measurements, the use of "human sensors" is clearly the only way to measure the symptom improvements in this important study.

G. Lundqvist (Denmark)
This comment agrees with our own evaluation of the results obtained.

P. Hartmann (Switzerland)
The study shows exactly the impact on human behaviour and health. Could you give some estimates of air change rates and temperature conditions in rooms before and after retrofit ?

G. Lundqvist (Denmark)
Room air temperature has been found to be raised on an average by 2°C and indoor window surfaces by at least 7°C in the winter months, while absolute humidity was increased by 1-2 g/kg in the retrofitted dwellings. Measurements on changes in ventilation rates are being carried out at the moment.

Paper 19: 'Contaminant build-up in houses'
presented by Richard Helmeste (Canada)

J. Armstrong (USA)
Was the relationship between radon daughter concentration and ventilation rate statistically significant ?

R. Helmeste (Canada)
A monthly variation in overall radon concentrations was evident. This coincided with the monthly variations in infiltration rates in a manner that indicates excellent correlation.

The data also showed expected variation in individual samples taken at the same house on different sampling days. This can be explained by the effects of various meteorological parameters that have been shown in other studies to be statistically significant, including barometric pressure, air and soil temperature, relative humidity and wind speed.

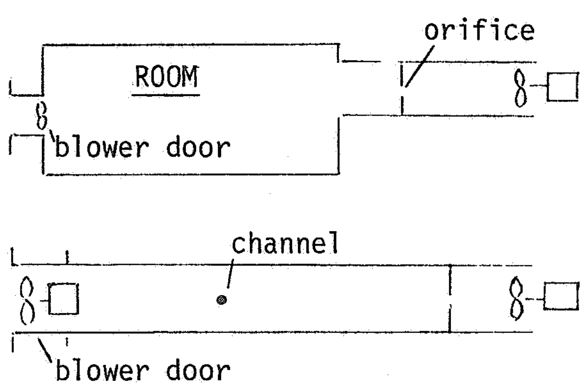
Using analysis of variance tests, it was determined that there were significant differences among the houses regarding radon and radon daughter concentrations.

B. Smith (UK)
Is the local soil radioactivity above or below normal ?

R. Helmeste (Canada)
The soil in this area exhibits normal background radium and uranium concentrations.

Paper 20: 'Verification of calculation models of air infiltration using three types of test houses'
presented by Hiroshi Yoshino (Japan)

J. Kronvall (Sweden)	Your measured wind pressure coefficients seem to be very low. I would have expected such low values only if your reference wind speed had been measured on flat ground ∿10m above ground level. Do you have any comment on this ?
H. Yoshino (Japan)	*In the first year, we were of the same opinion. So, in the second year, we verified the wind pressure coefficient. The reason is, I think, that the area to the south of the test houses is covered with trees of 2-3 m high and these trees make the approach wind profile highly sheared.*
M, Modera (USA)	The over-prediction of the LBL model at low infiltration rates shown in figure 9 is probably due both to the separation and superposition of wind and stack-induced infiltration, and the use of 0.5 as the flow exponent. The errors to be expected from these assumptions are described in a paper presented at the ASHRAE Semi-Annual Meeting in June 1983.
H. Yoshino (Japan)	*Thankyou for your comment. I will review the paper you have mentioned.*
<u>Paper 21:</u>	'Air flow calibration of building pressurization devices' presented by Andrew Persily (USA)
W. de Gids (Netherlands)	Why did you finally choose the tracer gas technique instead of orifice plates and what is the difference in accuracy ?
A. Persily (USA)	*I did not choose orifice plates in a pipe because of the pressure drop across such a meter and my wish to avoid the need for an exhaust fan. I did not realize that I would still require an exhaust fan with the tracer gas technique. The accuracy of the tracer measurement depends on the accuracy of the injection flow rate measurement, the accuracy of the concentration measurement and the uniformity of mixing at the tracer and the airflow. If careful procedure is followed, both techniques should be capable of comparable accuracy, i.e. in the order of ±2%.*
P. Hartmann (Switzerland)	If you compare the following arrangements, what disadvantages does the second bring in comparison with the first ?



A. Persily (USA) *The second technique may lead to inaccuracies because the blower door is blowing into a channel or pipe instead of a larger chamber. When used in testing a house, a blower door in effect blows into a larger chamber. The air flow patterns associated with the channel will be different than for a chamber and this may affect the flow rate. The existence and amount of the associated errors are not known. Even with a chamber, it is not clear how large such a chamber needs to be.*

D. Saum (USA) Your comparison of differences between the two equations assumes no error in Δp and w. If you assume a Δp error of ±2Pa, I think you will find q errors that are similar to the differences between the two equations.

A. Persily (USA) *The table below lists the percentage errors in q caused by a ±2Pa uncertainty in Δp using both equations 9 and 11. Comparing these values to the errors in Table 3, we see that the differences between the curve fit and the straight line are larger than the errors associated with uncertainty in the pressure difference. Also, the pressure difference errors are of a random nature while the difference between the straight line and the curve fit represents a bias in one direction only. It is interesting that the pressure difference errors dominate the difference in the two calibration formulae at high fan speed.*

Percentage errors in air flow rate caused by ±2Pa uncertainty in pressure difference

Fan speed (s^{-1})	Equation 9 Curve fit	Equation 11 Straight Line
13.33	± 9%	± 32%
14.17	± 7%	± 17%
15.00	± 6%	± 10%
15.83	± 6%	± 8%
16.67	± 5%	± 6%
17.50	± 5%	± 5%
18.33	± 4%	± 4%

Paper S.2: 'Airtightness and wall construction in prefabricated Swedish single family houses, 1984' presented by Lars-Goran Mansson (Sweden)

D. Harrje (USA) Please describe further the significance of moving to air heating (60%, Table 1) and air exhaust heat pumps (71%, Table 3) with regard to ventilation performance in individual rooms and energy savings for the house as a whole.

L-G. Mansson (Sweden) — *Air heating is new in Sweden. In some houses electric radiators in each room are installed to be used during the coldest days. However, this innovation has happened rapidly - within less than 12 months.*

The use of heat pumps is favoured compared with a heat exchanger.

Supply air in each room. Energy savings with the heat pump. Only half of the recovered energy is used for hot tap water. Therefore we can use the other half for preheating supply air or preheating the hydronic system.

Companies have learned the hard way that proper ventilation systems must be installed in single family houses. With well insulated houses, the energy demand has been reduced. As they strive to minimise the cost, so they combine heating and ventilation in one system.

P. Hartmann (Switzerland) — We have heard about the design of energy efficient new houses in Sweden:

1. Is there a programme on retrofitting existing buildings, mainly multi-family houses ?

2. Are there construction guides for these houses ?

L-G. Mansson (Sweden)

1. *Yes. Sweden has a big programme for retrofitting existing buildings. By 1990 50% of all Swedish homes will be more than 30 years old which corresponds to the time interval for large scale retrofitting, i.e. extra insulation, plumbing, carpets, wallpaper, new kitchen fittings (cupboards, cookers, refrigerator, freezer), ventilation system, reduction of water consumption etc.*

2. *If you mean existing buildings, the answer is no. In Sweden it is thought (at least by some of us) that all single buildings must be inspected before retrofitting because so many different things can affect the problem.*

A. Wilson (UK) — With regard to very low values for wall and roof K-values, is there a maximum % of glazing in walls and rooflights ?

L-G. Mansson (Sweden) — *There is a minimum glazing area of 7% floor area and a maximum glazing area of 15% floor area.*

D. Kehrli (USA)

1. Are the seals for the window joints for the frame/envelope interface, or for the operable sash as well ?

2. Is the ach for the window, i.e. sash and frame, for the installation, or both ?

L-G. Mansson (Sweden)

1. *The paper refers to frame/envelope sealing. For the sash/frame interface EPDM-tube rubber strips are always used.*

2. *The ach data is for the whole house using the pressure method. I have, however, some data for wall elements including windows.*

C. Brunner (Switzerland)

1. Do you have energy consumption data for the 10,000 houses you have surveyed for air infiltration ?

2. What is the cost/benefit feasibility of lowering:

   a. K-values from around 0.2 to 0.1 ?

   b. ach from 3 to 1 in 1986 ?

L-G. Mansson (Sweden)

1. No.

2.a. Political decisions have been made to get a low interest rate on the money for financing a new house. It is also cheaper to transport ceiling elements than wall elements. It is only a matter of material cost, i.e. the cost for labour is the same.

2.b. From 3 to 1 ach, I would say, will not cost anything.

M. Modera (USA)

1. Is there a similar verification scheme for K-values as for airtightness ?

2. How does it operate ?

L-G. Mansson (Sweden)

1. Yes.

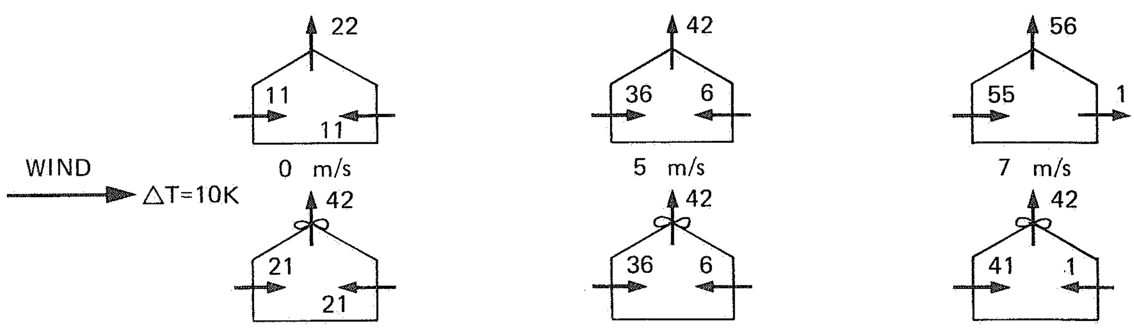
2. I am not sure. Some organisations carry out only indirect measurements with a thermographic camera.

Helmut Feustel (USA)

Could you please explain why the level of infiltration with an exhaust fan might be lower than that of natural ventilation ? How much is this phenomena dependent on the exponent of the pressure difference of the structure ?

W. de Gids (Netherlands)

The reason for this is the difference in pressure distribution. At higher windspeeds from about 5 m/s and up, the fan is more or less stabilizing the flow (see figure below).



Two comments have to be made here:

1. *The fan flow is also wind-dependent. This effect has been neglected in the figure above.*

2. *This effect is not dependent on the flow exponent.*

G. Lundqvist (Denmark)

Are internal openings such as doors supposed to be closed or open during the measurements or modelling shown ?

W. de Gids (Netherlands)

The internal doors are supposed to be closed, but nevertheless the air leakage of normal internal doors exceeds the value of facades by a factor of 5.

FINAL DISCUSSION (Report compiled by Martin Liddament - AIC)

An informal discussion session on standards was chaired by David Harrje from Princeton University , USA.

The discussion centred on:

1. Other standards in progress with particular emphasis on
   - disagreement between standards.
   - comparison of standard concepts including the needs of different ventilation strategies.
2. Calibration methods to achieve uniformity.
3. Avoiding confusion over definitions.
4. Standardisation of pressure test reporting.
5. The problems of tight buildings
   - ventilation requirements.
   - sources of pollution.
6. Economics of ventilation strategies for
   - existing buildings.
   - new buildings.
   - non-residential buildings.
7. Future tasks for the AIC.

With respect to item 1. Hiroshi Yoshino from Japan took this opportunity to describe the development and implementation of standards in Japan. The first related to the National Building Code on air quality in airconditioned office spaces. This code is mandatory and demands the maintenance of the following environmental conditions:

- CO_2	< 1000 ppm
- CO	< 10 ppm
- Particulates	< 0.15 mg/m^3
- Temperature	17-28 ^{o}C
- Humidity	40-70 %
- Air velocity	< 0.5 m/s

The second standard related to that of ventilation which is due for revision this year. This demands air ventilation requirements in occupied rooms of >35m^3/h/person (9.7 litres/sec/person). Several Japanese Industrial Standards (JIS) relate to measurement methods. These include:

- measurement of air infiltration using CO_2 tracer gas.

- measurement of air infiltration in two zones using two tracer gases (draft).

- measurement of airtightness in residential buildings (draft).

- measurement of the heat loss coefficient of a house (draft).

The proposed standard on the measurement of airtightness covers:

- whole house leakage.

- single room measurement.

- component leakage.

- pressurization and depressurization testing method.

- measurements in 3-30 Pa range.

- effective leakage area to be specified at 10 Pa.

- ELA/floor area for whole house specified.

Continuing with standards, Peter Hartmann of EMPA, Switzerland, made reference to the International Standards Organisation (ISO) who are embarking on the preparation of a pressurization air leakage standard.

Following on from these discussions on specific standards, David Harrje asked why standards are in apparent disagreement and in particular what constitutes comfort and health problems. The feeling from some participants was that, as regards comfort, different countries have different comfort criteria, while from the risk point of view it was suggested that a measure of agreement is required. Peter Jackman from the AIC in the UK suggested that the background to the various standards must be unearthed and disseminated.

The calibration and uniformity of measurement methods was regarded as important. Peter Hartmann pointed out that in much of Europe no commercial instrumentation is available for airtightness testing but when such instrumentation does become available, some sort of portable calibration method would be required.

It was widely agreed that a portable checking method, which itself was calibrated at some central agency, would be a good idea and was feasible.

There was much discussion on the lack of uniformity over the definitions relating to effective leakage area and air leakage in general. Definitions concerning air infiltration and exfiltration were also questioned. It did not appear possible that universal agreement on the choice of terminology will be possible in the foreseeable future.

Problems relating to tight buildings were discussed at length. David Harrje pointed out that very often exceptional effort was put into measuring contaminant levels, whereas no real effort was put into measuring the fresh air ventilation rate. Robert Dumont from the National Research Council in Canada pointed out that the problem was not just related to airtightness or inadequacies in the apparent fresh air change rate. Recirculation of exhaust air into the fresh air stream is a common problem. David Harrje cited poor controls and poorly balanced HVAC systems as also being culprits.

The need for cost effective ventilation approaches was emphasised. Peter Hartmann said that an immediate way of improving air quality in the existing building stock - especially in non-residential buildings - was necessary. Other speakers agreed and the general concensus was that HVAC systems should be introduced to satisfy standards at the minimum cost. Clearly cost benefit studies need also to include comfort and health requirements.

Proposed future tasks for the AIC in the area of standards included recommendations on measurement techniques, units and definitions. It was suggested that information on energy consumption and the influence of occupants on air change rates could be usefully researched. Researching the impact of occupants on the effectiveness of airtightness standards was thought to be particularly important.

THE AIR INFILTRATION CENTRE was inaugurated through the International Energy Agency and is funded by the following eleven countries:

Belgium, Canada, Denmark, Finland, Netherlands, New Zealand, Norway, Sweden, Switzerland, United Kingdom and United States of America.

The Air Infiltration Centre provides technical support to those engaged in the study and prediction of air leakage and the consequential losses of energy in buildings. The aim is to promote the understanding of the complex air infiltration processes and to advance the effective application of energy saving measures in both the design of new buildings and the improvement of existing building stock.

Air Infiltration Centre
Old Bracknell Lane West,
Bracknell, Berkshire,
Great Britain,
RG12 4AH.

Tel : National 0344 53123
International + 44 344 53123
Telex: 848288 (BSRIAC G)
ISBN 0 946075 17 4

Operating Agent for International Energy Agency, The Oscar Faber Partnership, Upper Marlborough Road, St. Albans, Herts, Great Britain.