INTERNATIONAL ENERGY AGENCY
energy conservation in buildings and
community systems programme

# 4th AIC Conference

# Air infiltration reduction in existing 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 Consevation in Buildings & Community Systems Programme.

Annex V Air Infiltration Centre

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# 4th AIC Conference

# Air infiltration reduction in existing buildings

(held at the Hotel Sardona
Elm, Switzerland
26–28 September 1983)

## Supplement to Proceedings

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# 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 groundwork 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, Netherlands, New Zealand, Norway, Sweden, Switzerland, United Kingdom and the United States.

# INTRODUCTION

This document is a supplement to the AIC's 4th Conference Proceedings AIC-PROC-11-83. It contains an additional paper prepared at short notice for inclusion in the conference programme and also a discussion record, based on written questions and answers prepared by conference participants and authors.

AIR INFILTRATION REDUCTION IN EXISTING BUILDINGS

4th AIC Conference, September 26-28 1983, Elm, Switzerland

SUPPLEMENTARY PAPER

# EXPERIENCES IN AIR INFILTRATION MEASUREMENTS IN DWELLINGS

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## 1. Introduction

The Department of Building Science at Sheffield University were asked by a private firm of Architects to evaluate a design for a low cost starter home and to carry out tests on the final development. Some time later the department was also asked by the Department of Planning and Design at Sheffield City Council to carry out some tests on a block of local authority flats which were being considered for modernisation.

This paper deals with the tests which have been carried out to date in the two types of dwellings and demonstrates the extent to which background ventilation predominates in these dwellings.

## 2. The Low Cost Starter Home

Starter homes have come to represent an increasingly popular choice of design for architects and building developers during the last five years. Their appeal lies in providing low cost dwellings for single people or young couples wishing to become home owners for the first time. Many starter home designs are based on a timber frame structure which makes their construction relatively quick and therefore attractive to developers.

The studies were carried out on a single storey, semi-detached design produced by the architectural firm of Sebire Allsop. This design has been developed for the Woughton Campus site competition at Milton Keynes, and its success in that competition has ensured its widespread development.

A prototype of the house was built at a site belonging to the builders at Wakefield, West Yorkshire, to allow pre-production tests to be carried out and also to overcome any detailing problems

### 2.1 Constructional details

The Wakefield house is a semi-detached, single storey unit with one bedroom in each dwelling. Figure 1 gives plan and sectional details of the design while Figure 2 shows the development at Milton Keynes.

The roof construction consists of a profiled aluminium sheeting above a 38mm air gap trapped by a sisalkraft membrane. A second air gap, 97mm thick, beneach this membrane is bonded by 100mm of glass-fibre insulation. This is held in position by a polythene vapour barrier attached to roof joists. The roof is finished with a plaster-board and plaster skim ceiling.

The external walls consist of an external skin of single brick bordering a 41mm air cavity on one side, while the other boundary of the cavity is 9mm plywood nailed onto a timber frame. Glass fibre, 80mm thick is held against the plywood by a polythene vapour barrier which borders 9mm thick air cavity before the internal plasterboard and skim finish are applied.

The windows located in the end panels of the houses are single glazed units in wooden frames. The panels themselves had an external surface of asbestos sheet backed by 80mm of glass fibre and a polythene vapour barrier.

These units were finished with plasterboard and a skim finish.

The floors of the dwellings were solid consisting of concrete laid over a hardcore and dpc base. They were uninsulated both vertically (at the edges) and horizontally.

## 2.2 Energy usage in the house

The design energy losses and running costs of the Wakefield house were examined using a computer program called ENGY. This program was developed within the Department of Building Science and uses a degree-day approach for predicting seasonal heating requirements. ENGY allows for regional differences in the contribution made by solar gain through any vertical glazing in the building(1).

The program was run for 1, 2 and 3 bedroom forms of the starter home and a typical output is shown in Figures 3 and 4. A summary of the results is given in Table 1, where costs relate to August 1981 prices and percentage savings relate to the then current building regulations.

| Energy Use | House Type | | |
|---|---|---|---|
| | 1 Bedroom | 2 Bedroom | 3 Bedroom |
| Heating/hot water usage<br>cost | 20 - 40 GJ<br>£47 - £94 | 38 - 58 GJ<br>£89 - £136 | 40 - 66 GJ<br>£94 - £155 |
| % saving over house built to Aug '81 regs | 26% - 53% | 20% - 37% | 37% - 47% |
| Cooking usage<br>cost | 7.6 GJ<br>£18 | 11.4 GJ<br>£27 | 13.3 GJ<br>£31 |
| Electricity usage<br>cost | 7.2 GJ<br>£62 | 7.9 GJ<br>£68 | 10.8 GJ<br>£93 |
| Total energy costs | £127 - £174 | £184 - £231 | £218 - £279 |

Table 1 Summary of ENGY Analysis

It is apparent from Table 1 that the Sebire Allsop design is, in theory capable of producing significantly lower energy bills than houses built to meet the building regulations.

## 3. Experimental Studies of the Ventilation Performance of the Home

The initial work carried out on this house design was of a theoretical nature dealing with projected energy performance. Once the house was completed it became necessary to verify these predictions. As part of the assessment of the performance of the test house at Wakefield a ventilation study was carried out with the objective of establishing the likely ventilation rate and leakage areas. Both decay rate using nitrous oxide and pressurisation tests were carried out on the house.

### 3.1 Experimental set up for gas decay tests

The standard decay rate procedure to estimate the ventilation rate of the house was followed, the sep up being as shown in Figure 5.

For the tests to give a valid assessment of ventilation rate the warm air heating system was switched off and the outlet grills sealed, the natural ventilation air outlets in the kitchen and bathroom were also closed. All other openings such as light roses, light switches, power sockets, etc. were left unsealed.

It is usual to quote ventilation rates as a function of wind speed and therefore the local wind speed and direction was measured throughout the experimental period. Figure 6 illustrates the position and height of the anemometer mast relative to the house. The 10m wind speed was considered representative of the local wind conditions as the site was flat and falls within the Wind Loading Guide Category 2 terrain.

### 3.2 Experimental set up for whole house pressure tests

The blower door technique was used to pressurise the house. Before the tests were carried out the air outlets from the warm air heating system were sealed but all other openings left unsealed as in the gas decay tests.

The house was pressurised by using dual 480mm diameter axial fans independently controlled, the air flow rate was measured by means of a calibrated vane anemometer system and the pressure difference was recorded using a strain gauge bridge type pressure transducer. The schematic layout of the pressure test rig is shown in Figure 7.

### 3.3 Results of decay rate tests

#### (a) Wind environment

Throughout the whole of the five hour test period the wind direction was South South-West (202$^{o}$) which resulted in the pressure profile as shown in Figure 8. This profile implies that air will be forced to enter the house through the south facing infill panels and the movement will then be towards the hall, kitchen roof and east wall. This condition was therefore considered favourable for the ventilation measurements.

#### (b) Decay rate measurements

The decay of the nitrous oxide tracer gas within the house was measured continuously but five minute readings were taken for the analysis

### (c) The air change rate

The ventilation rate was established for 20 minute periods of time. Figure 9 shows the results of the tests, and it can be clearly seen that as the wind speed fell so did the ventilation rate. The inside temperature remained reasonably constant over the whole test period although the outside temperature dropped by just over 2°C.

Figure 10 shows a tentative relationship for ventilation rate against wind speed.

### (d) Background leakage areas

The background leakage areas consist of cracks around the windows, doors, end panels and joins between the building components. The background leakage rates through windows doors and end panels were established using Jackmans(2) techniques as these areas were easily measurable. Figure 11 shows how the known background leakage rate compares with the total ventilation rate, it is easily seen from this figure that between 60% and 70% of the leakage is unaccounted for.

## 3.4 The results of the pressure tests

Throughout the whole of the test period the wind direction was West (270°) and below 10 m/s in speed.

The whole house characteristic is shown in Figure 12. The characteristic of the house was further examined by investigating the leakage through known crackage areas and the results obtained are shown in Table 2 for a standard pressure difference of 50 Pascals.

| Component | leakage $m^3/m^2$ hr. | % of total |
|---|---|---|
| Whole house | 14.3 | |
| Windows and doors | 1.78 | 12.45 |
| Roof vents | 2.27 | 15.87 |
| Unknown | 10.25 | 71.7 |

Table 2 House characteristics at 50 Pascal pressure difference

It is worth noting that from the pressure test some 71.7% of leakage can be classified as background through undefined areas. This figure compares very favourably with the figures established from the decay rate tests (60% to 75%).

## 4. Modified detailing design

It was fully recognised at the design stage of these houses that they would not be "air tight". As a result of the tests carried out on the Wakefield house modifications were made to the jointing details between the floor and walls and ceiling as well as joins round all openings. A restriction was to impose on the modifications to the effect that the extra cost in so doing would be minimal (bearing in mind low cost starter home). Sketches of the proposed jointing details are shown in Figure 13. Before these modifications were finally adopted for inclusion in the second phase of development at Milton Keynes laboratory tests were carried out on a full scale joint to establish if the proposals would be viable.

### 4.1 Laboratory testing of full scale joints

Joints were tested in the laboratory using a pressure box similar to that described by Siitonen(3) and shown in Figure 14. This rig is still under development although results obtained on defined crack geometries are in good agreement with those of Etheridge(4) and shown in Figure 15.

### (a) Wall floor joins

The wall to floor joins as built into the Wakefield House and Phase 1 of the Milton Keynes Houses was tested using the pressure box. Modified joins as proposed for Phase 2 at Milton Keynes were also tested. Figure 16 shows the resultant characteristics of the two joins.

### (b) Possible effects on background air leakage

Having established the effect of altering the detailing of the joins on the likely air leakage, calculations have shown that the expected reduction in background leakage can be summarised as follows:

The overall ventilation rate of the houses is likely to reduce by 50% and background leakage to be reduced to 30-40% of the total. This reduction in ventilation loss will reduce the annual heating bill by some 14%.

## 5. Local Authority Housing

A group of system built blocks of flats owned by Sheffield City Council are currently being investigated with a view to establishing the priorities for refurbishment. Part of these studies involves establishing the natural ventilation rates and leakage paths.

Due to the physical planning of these blocks it has proved impossible to carry out whole house pressurisation tests. Consequently room pressurisation using a blower door has been used.

## (a) Constructional details

The flats were constructed of precast concrete panels with a 12mm plaster skim finish. Modifications carried out in the mid 1970's resulted in the addition of 25mm rigid thermal insulation being added to some of the walls.

## (b) Pressure tests

An initial set of pressure tests have been carried out on one flat which was thought to be typical of the whole block. The results are shown in Table 3 and plotted in Figure 17.

| Degree of sealing | Positive Pressure tests $m^3/m^2$ hr. | Negative Pressure tests $m^3/m^2$ hr. |
|---|---|---|
| No sealing | 7.88 | 8.83 |
| Windows and doors sealed | 5.81 | 6.51 |

Table 3 Flat characteristics at 50 Pascals pressure difference

From these figures it can be seen that some 74% of air leakage can be attributed to background leakage.

## (c) Modifications to the fabric

The internal walls of the flat have been dry lined using 25mm polystyrene sheeting on to which has been added a 5mm cement render. This improvement has resulted in the fabric k value being reduced by some 60% to 70%.

At the time of writing this paper pressurisation tests on the modified flat are still being carried out and are not yet conclusive.

## Acknowledgements

The author would like to acknowledge the assistance given by Dr. S. Sharples in helping to carry out some of the experimental work.

## References

1. Department of Building Science, University of Sheffield, User Guide to ENGY.

2. Jackman, P.J. A study of the Natural Ventilation of Tall Office Buildings. H.V.R.A. Lab. Report No. 53, 1969.

3. Siitonen, V. Measurement of Local Air Tightness in Buildings. Nordtest Project 176-79. Technical Research Centre of Finland, Research Notes. Espoo July 1982.

4. Etheridge, D.W. Crack Flow Equations and Scale Effect. Building and Environment. Vol. 12, pp. 181-189. 1977.

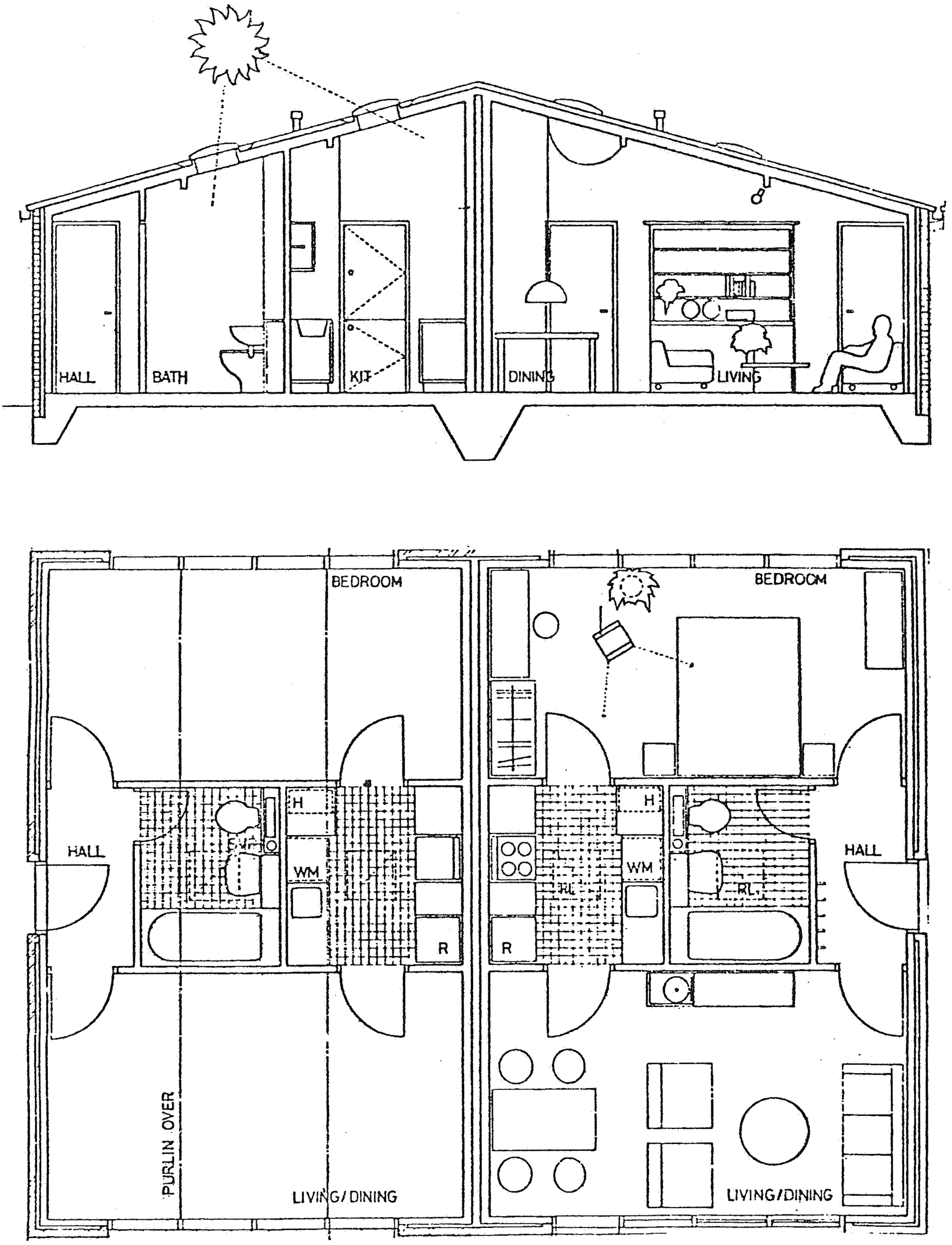


Figure 1 Section and plan views of starter home

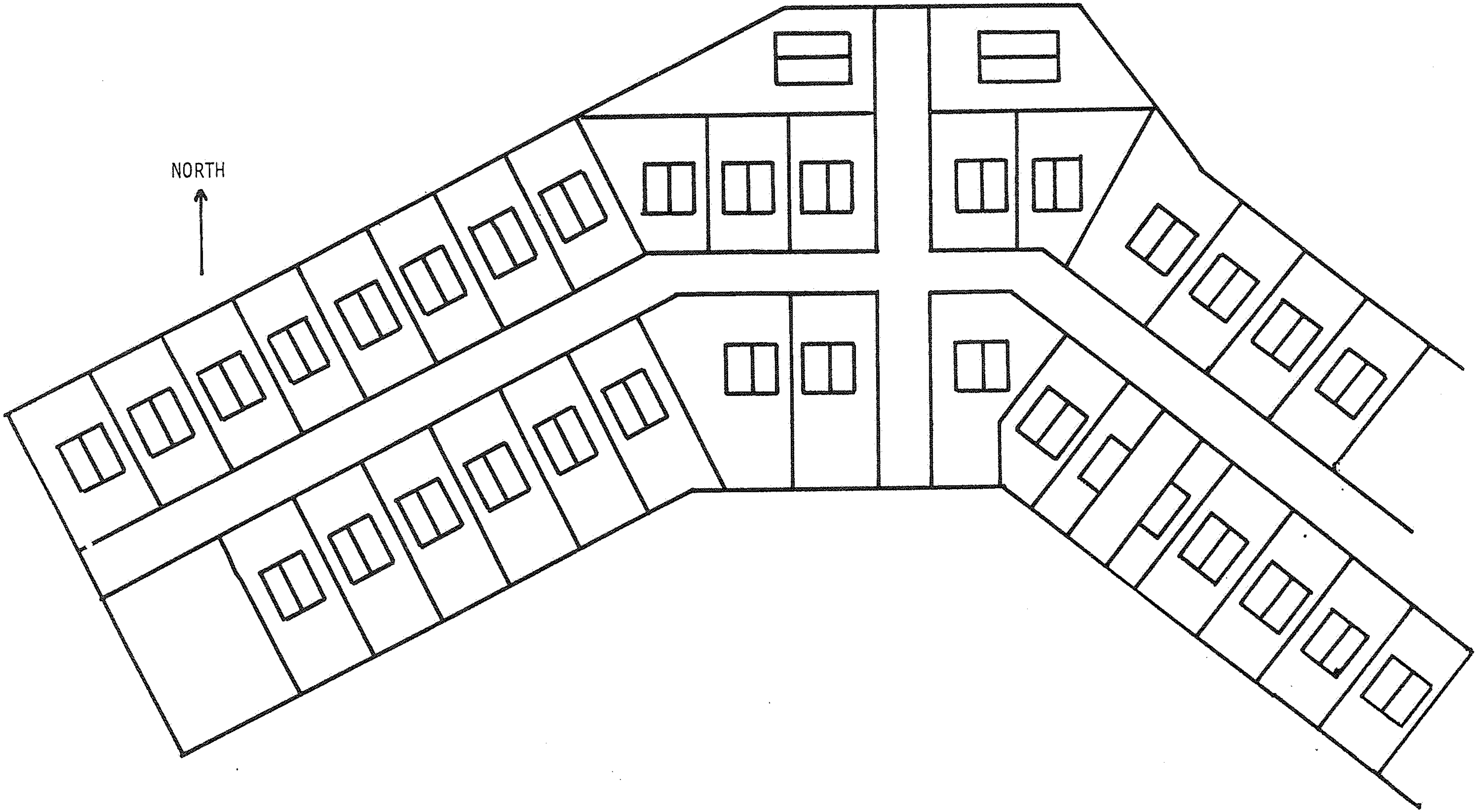


Figure 2 Woughton Campus Layout

```
DESIGN - DESIGN 10

                      DESIGN HEAT LOSSES
                      ------------------

INTERNAL AIR TEMP. = 20.0 DEG.C
EXTERNAL AIR TEMP. = -1.0 DEG.C

FLOOR AREA =      41.5 M^2
VOLUME OF SPACE =    120.3 M^3

                   DESIGN FABRIC HEAT LOSSES
                   -------------------------

COMPT. NO  NAME      AREA   U-VALUE   TEMP.DIFF. HT.LOSS % OF TOTAL
MAJOR SUB           (M^2) (W/M^2DEG.C) (DEG.C)    (KW)   FABRIC LOSS

  1        BED W     4.64    0.370        21       0.04        1
  1      1 S GLASS   4.89    5.700        21       0.49       20
  1      2 PANEL     6.34    0.440        21       0.06        2
  2        HALL W   13.82    0.370        21       0.11        4
  2      1 DOOR      1.89    4.170        21       0.17        7
  3        LIV W     4.63    0.370        21       0.04        1
  3      1 S GLASS   5.40    5.700        21       0.65       26
  3      2 PANEL     5.04    0.440        21       0.05        2
  4        ROOF     41.43    0.254        21       0.22        9
  4      1 R LIGHT   0.72    4.300        21       0.07        3
  5        FLOOR    41.50    0.690        21       0.60       24
                                       TOTAL       2.50

FABRIC LOSS PER UNIT FLOOR AREA =    60.0 W/M^2

                 DESIGN VENTILATION HEAT LOSSES
                 ------------------------------

VENT.RATE   VENT.LOSS  TOTAL LOSS  TOTAL LOSS/   VENT/TOTAL
 (AC/HR)      (KW)        (KW)     FLOOR AREA       (%)
                                    (W/M^2)

   0.0        0.00        2.50         60             0
   0.5        0.42        2.92         70            14
   1.0        0.83        3.33         80            25
   2.0        1.67        4.17        100            40
   3.0        2.50        5.00        120            50
   4.0        3.33        5.83        140            57
   5.0        4.17        6.67        160            63
   6.0        5.00        7.50        180            67
```

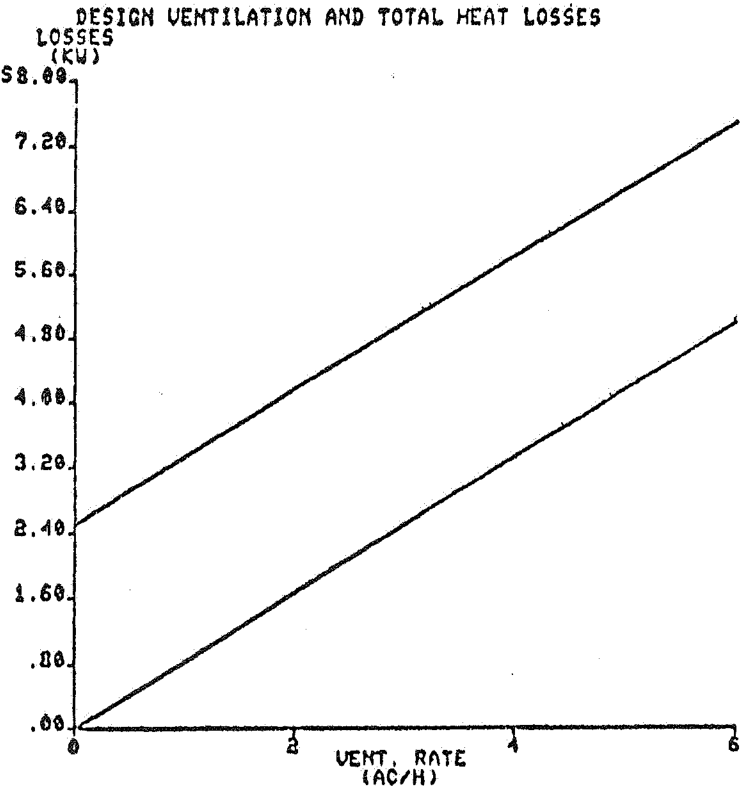


Figure 3   Design heat loss analysis from program ENGY

```
DESIGN = DESIGN 10

ANNUAL HEATING ENERGY REQUIREMENT AND FUEL COST
===============================================

BASED ON VARIABLE DEGREE DAY BASE TEMPERATURES

(N.B. FUEL COSTS EXCLUDE ANY STANDING CHARGE)

SITE IS IN REGION NO. 12 CAMBRIDGE

FUEL TYPE GAS(NATURAL)
BASIC UNIT THERM       HEAT CONTENT  29.3 KWH PER THERM
UTILISATION EFFICIENCY  60.0 %   RETAIL COST  24.80 PENCE / THERM
COST PER USEFUL KWH  1.41 PENCE

AVERAGE INTERNAL TEMP. = 20.0 DEG.C

AIR CHANGE RATE = 1.0 AC PER HOUR
ORIENTATION OF REF. PLANE =  0 0 DEG. FROM N.

MONTH  DEG DAY  DEGREE  ENERGY   ENERGY/      COST      COST/
        BASE     DAYS    (KWH)  FLOOR AREA (POUNDS)  FLOOR AREA
       (DEG.C)                   (WH/M^2)            (POUNDS/M^2)

 JAN    14.48     331    1251     30145      17.64    0.43
 FEB    13.75     273    1032     24863      14.55    0.35
 MAR    12 68     208     786     18943      11.08    0.27
 APR    12 17     120     454     10929       6.39    0.15
 MAY    11 56      44     166      4007       2.34    0.06
 JUN    11.32      10      38       911       0.53    0.01
 JUL    11.67       6      23       546       0.32    0.01
 AUG    11.84       9      34       820       0.48    0.01
 SEP    12.29      25      94      2277       1.33    0.03
 OCT    13.12     107     404      9745       5.70    0.14
 NOV    14.09     232     877     21129      12.36    0.30
 DEC    14.53     321    1213     29234      17.11    0.41
 TOT                     6372    153547      89.85    2.17

TOTAL AMOUNT OF HEATING FUEL REQUIRED       362 THERM

HOT WATER
MONTHLY  ENERGY     195 KWH  COST      2.74 POUNDS
ANNUAL   ENERGY    2335 KWH  COST     32.92 POUNDS
FUEL REQUIRED       133 THERM

TOTAL  ENERGY        8707 KWH   COST     122.77 POUNDS
TOTAL FUEL REQUIRED       495 THERM
```

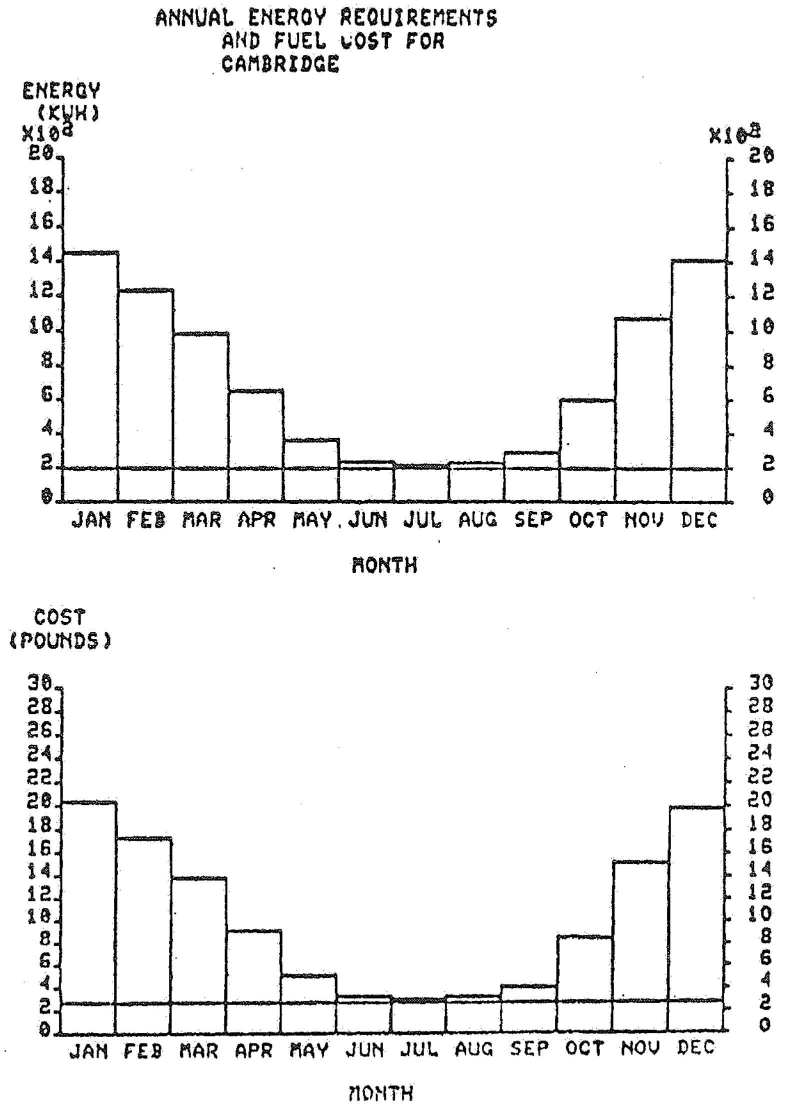


Figure 4   Design energy cost analysis from program ENGY

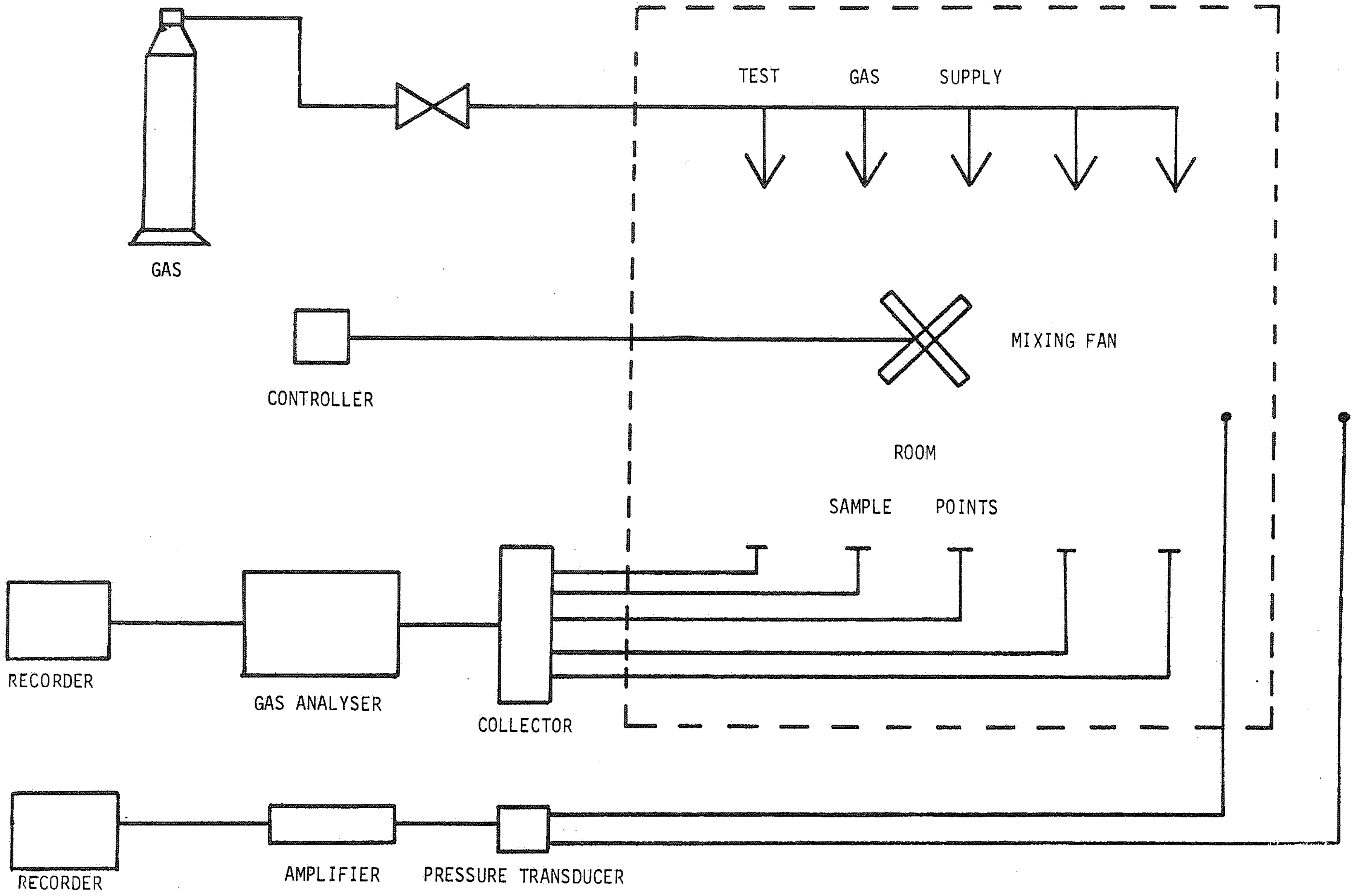


FIGURE 5 Decay Rate Tracer Gas Technique

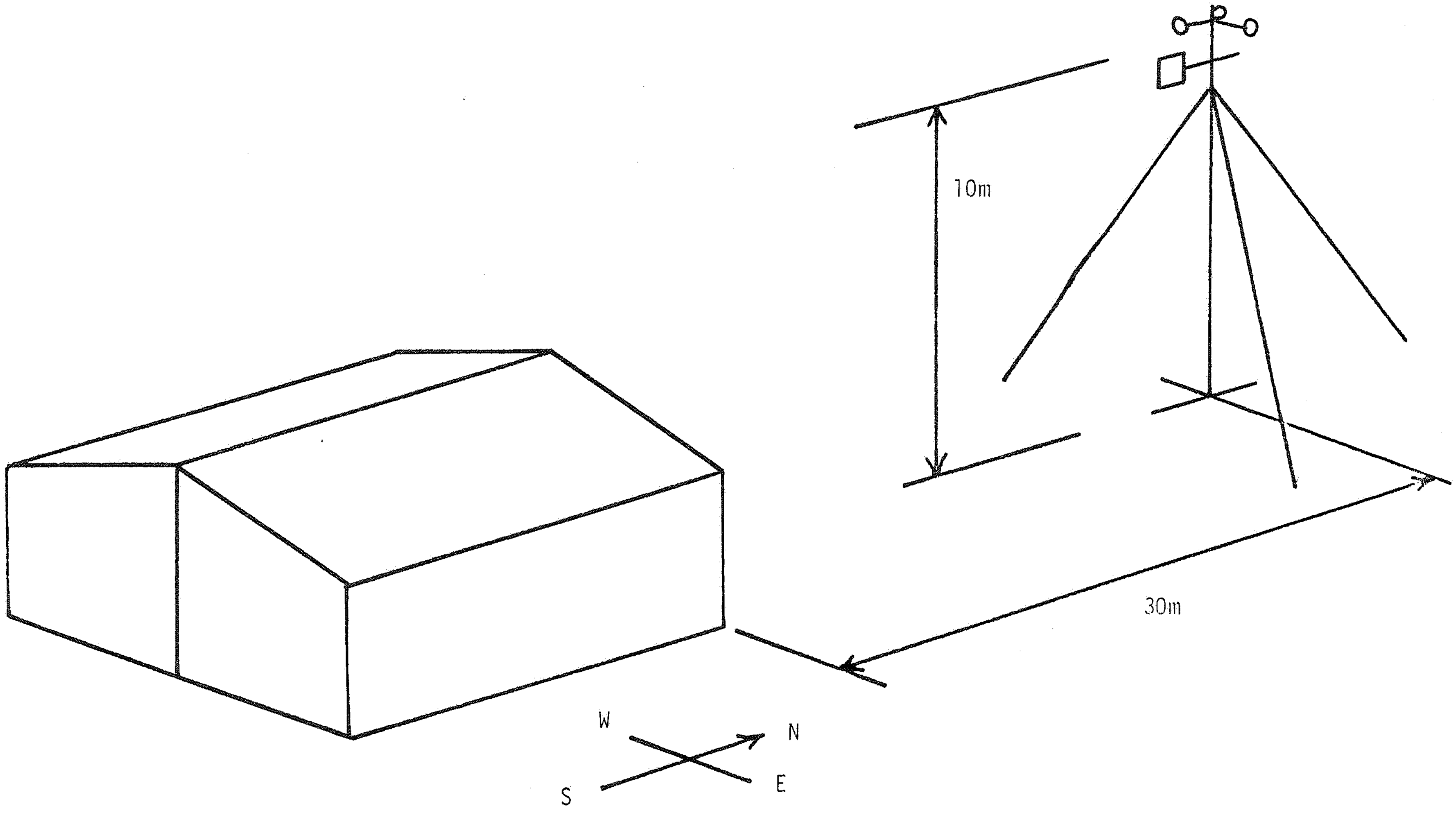


Figure 6    Position of Anemometer Mast Relative to Houses

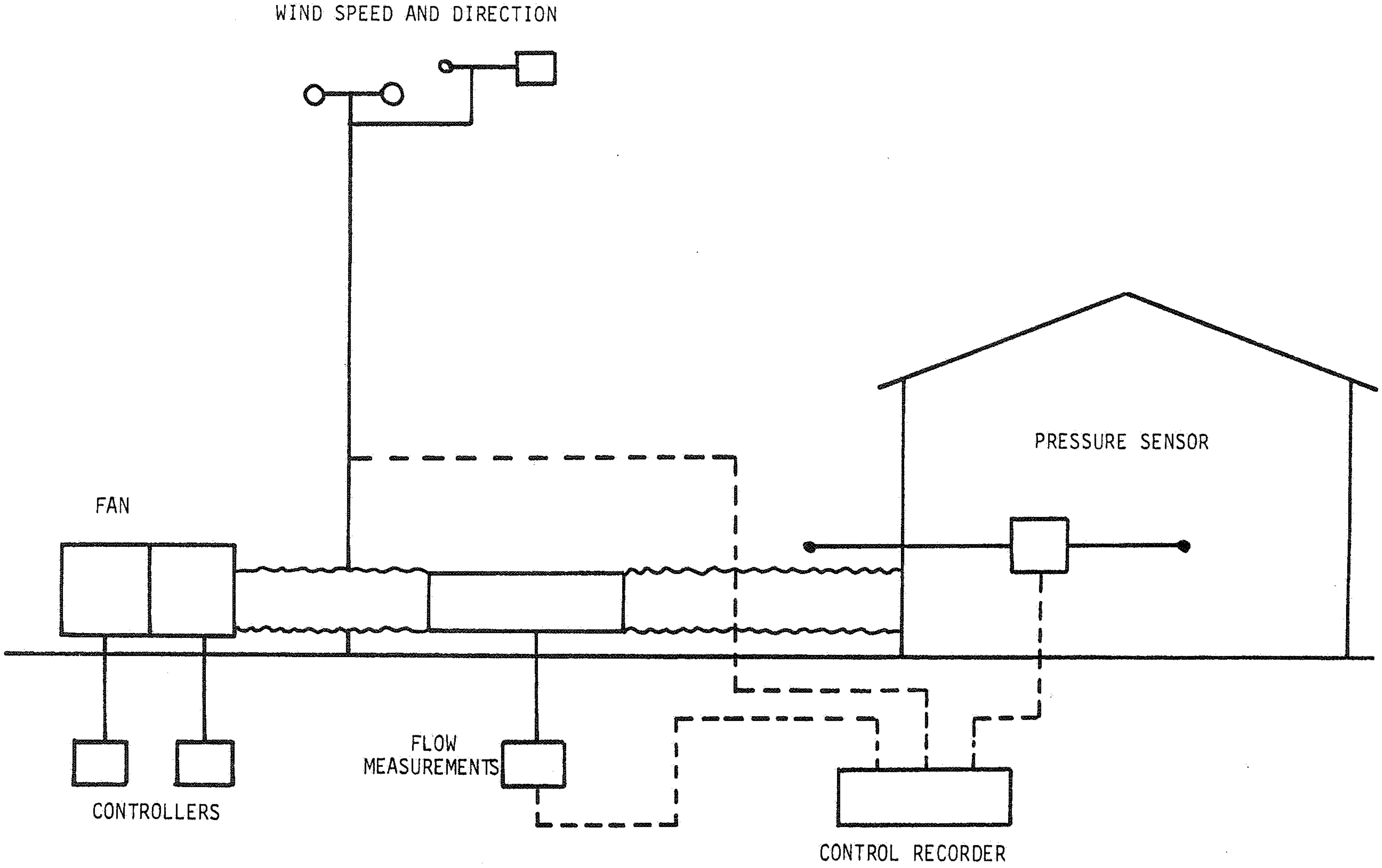


Figure 7 Whole House Pressure Test Layout

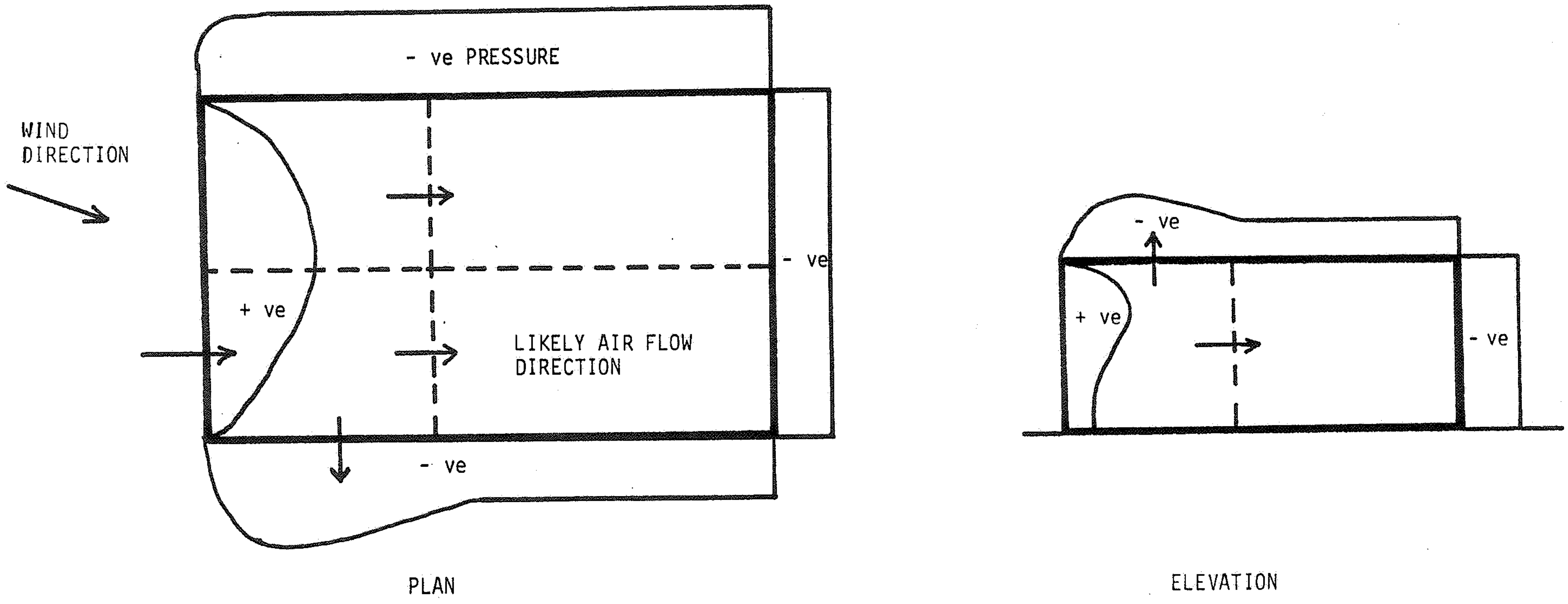


Figure 8 Pressure Profile with Respect to Inside of House

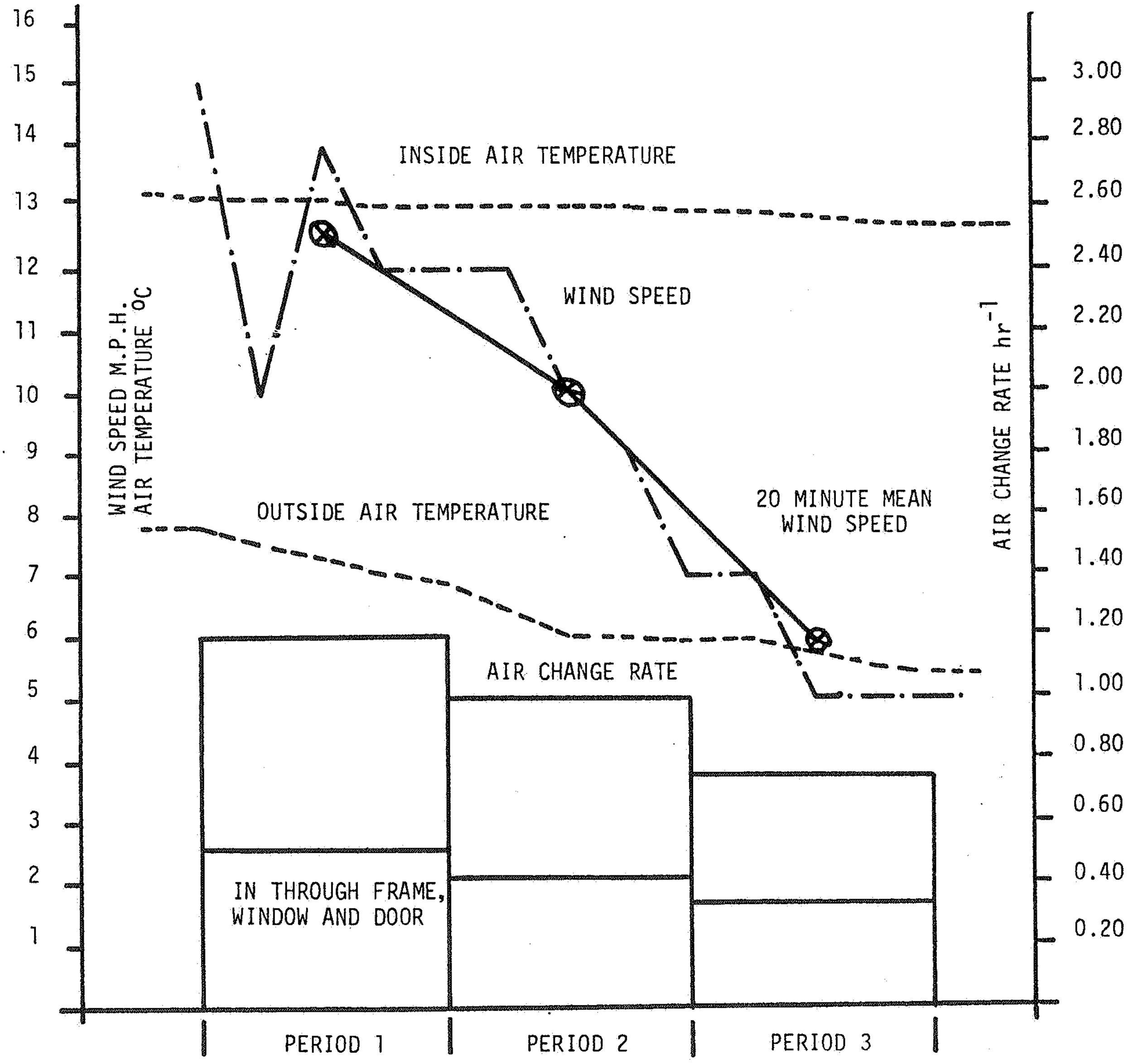
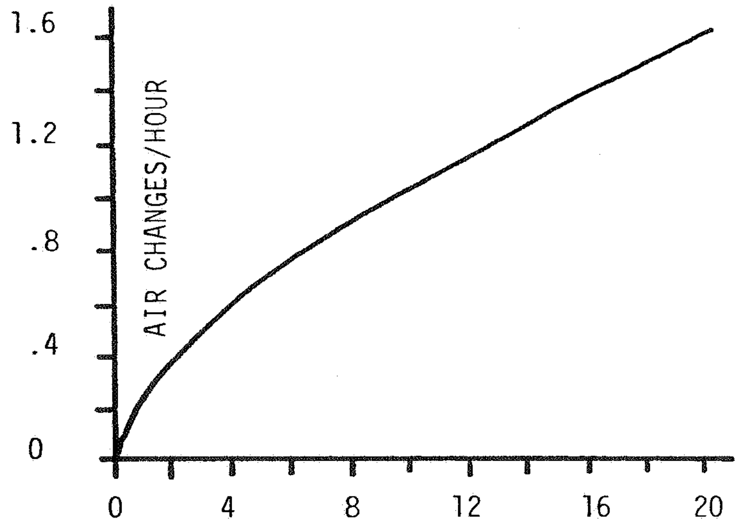


Figure 9 Ventilation Rate against Wind Speed and Temperature



WIND SPEED M.P.H.

AIR CHANGE RATE = $0.256 \times (\text{WIND SPEED})^{0.603}$
WHERE WIND SPEED IS IN M.P.H.

Figure 10

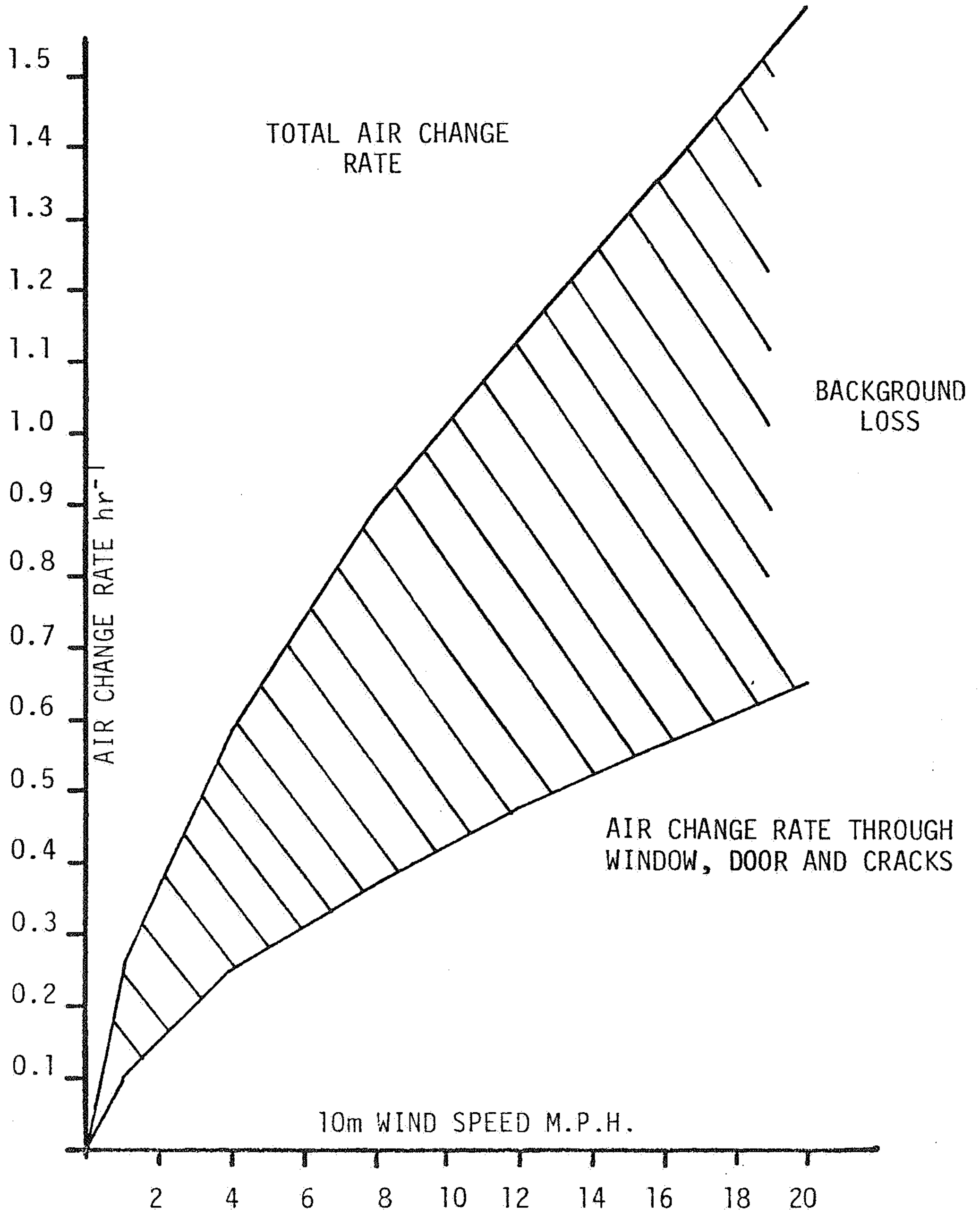


Figure 11 Background and Total Air Change Rate against Ten Metre Wind Speed

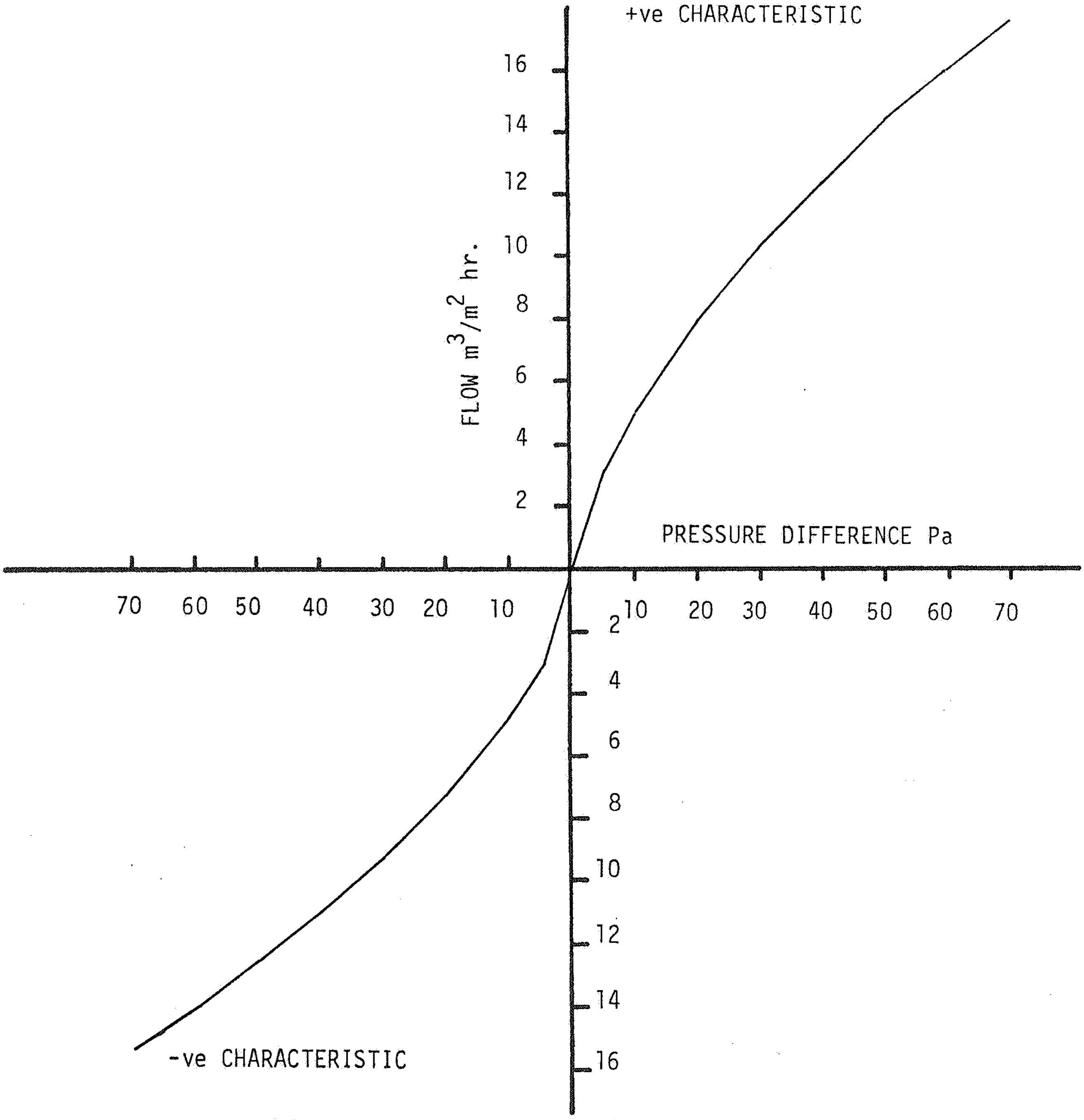
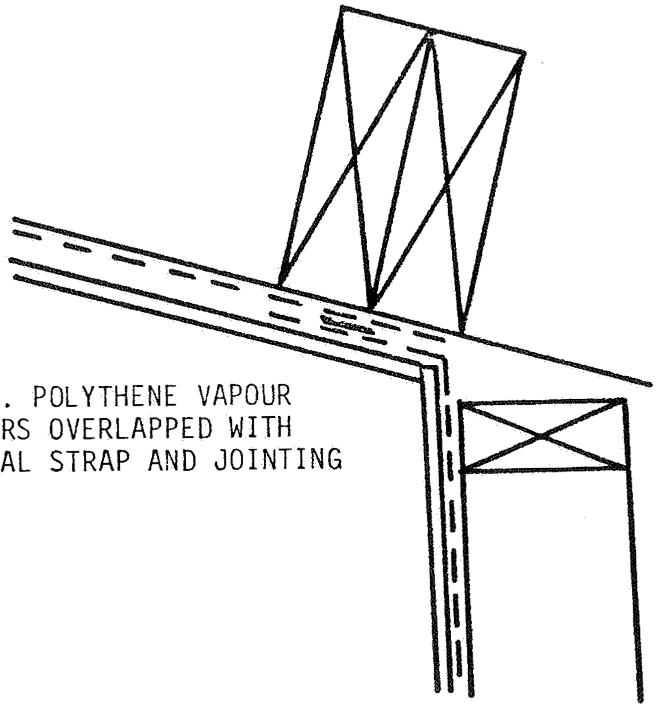
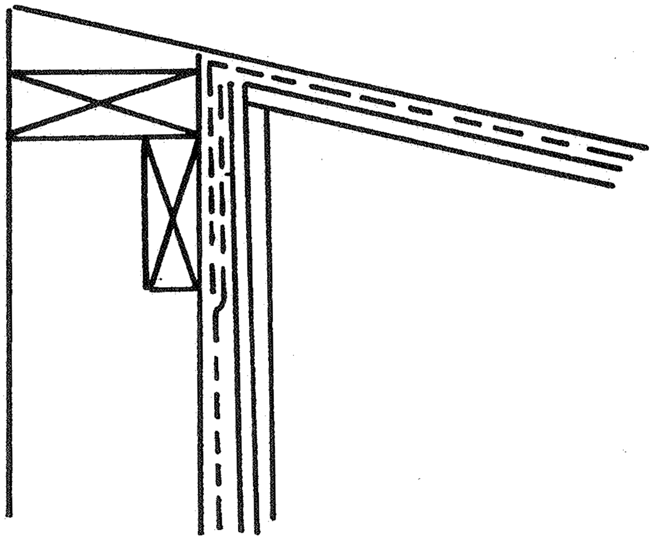


Figure 12 Whole House Pressure Tests



500 gm. POLYTHENE VAPOUR BARRIERS OVERLAPPED WITH KWIKSEAL STRAP AND JOINTING TAPE.

EXTERNAL WALL JOINT



ADDITIONAL S.W. NOGGING ON WHICH TO OVERLAP AND SEAL 500 gm POLYTHENE VAPOUR BARRIER

APEX JOINT

Figure 13

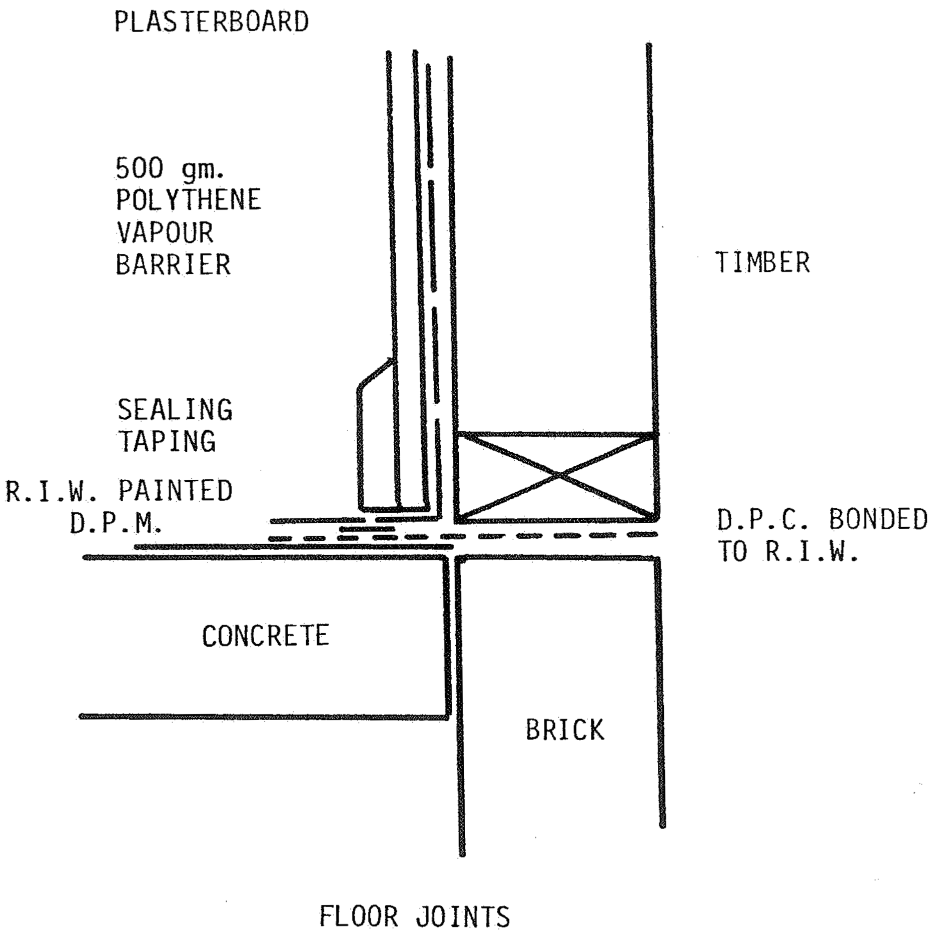

PLASTERBOARD
500 gm. POLYTHENE VAPOUR BARRIER
TIMBER
SEALING TAPING
R.I.W. PAINTED D.P.M.
D.P.C. BONDED TO R.I.W.
CONCRETE
BRICK
FLOOR JOINTS

Figure 13 a

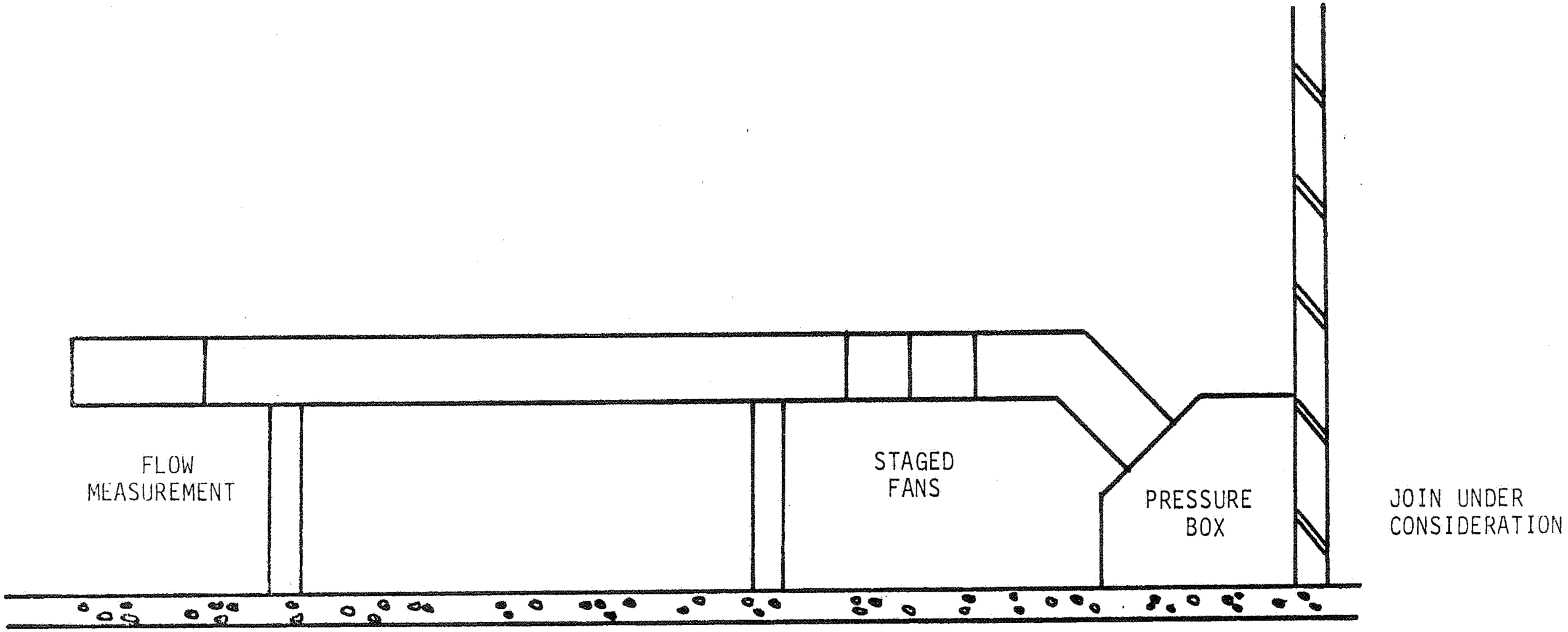


Figure 14 Layout of Pressure Box for Joint Floor Wall Join

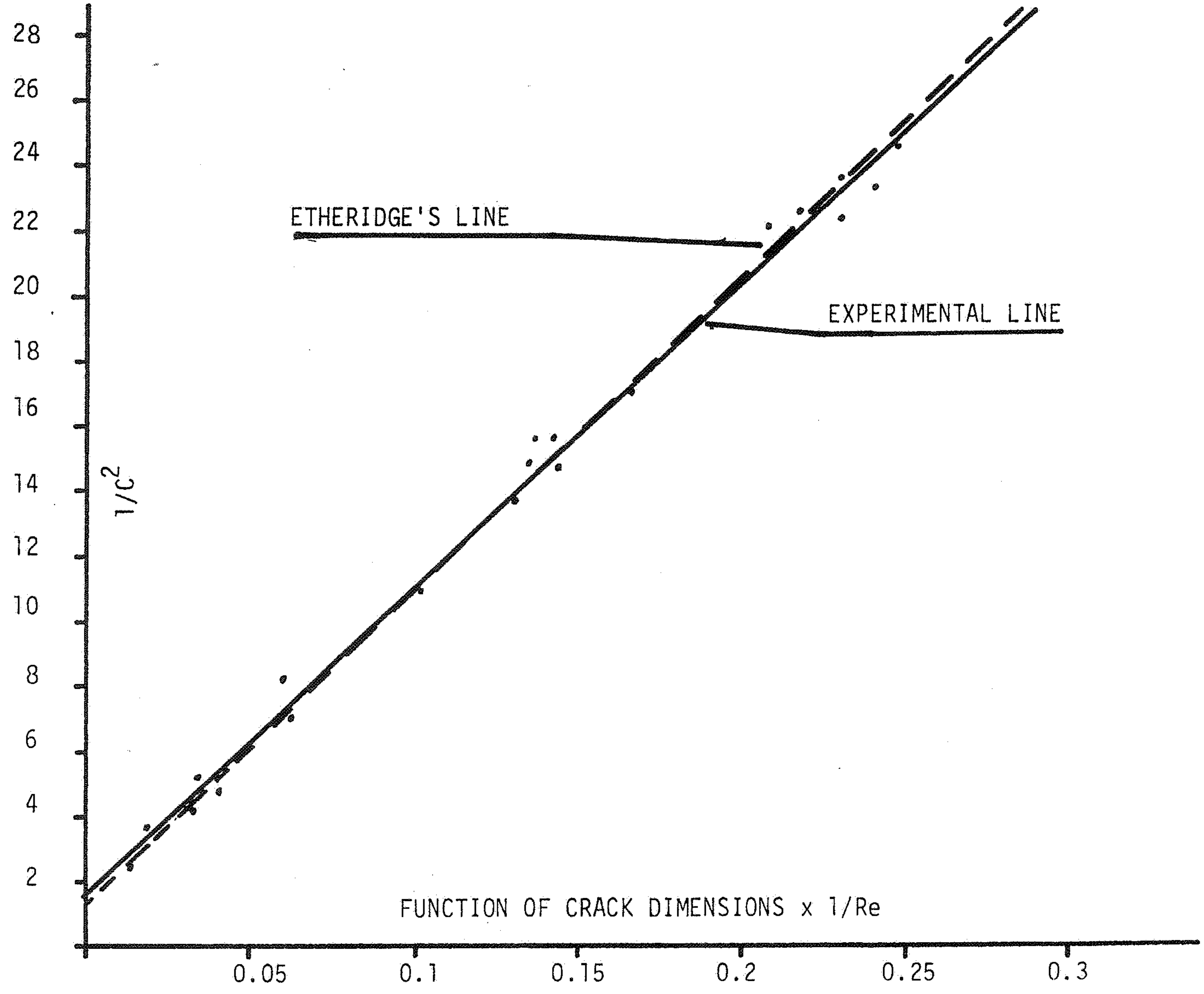


Figure 15 Pressure Box Results and Etheridge's Results

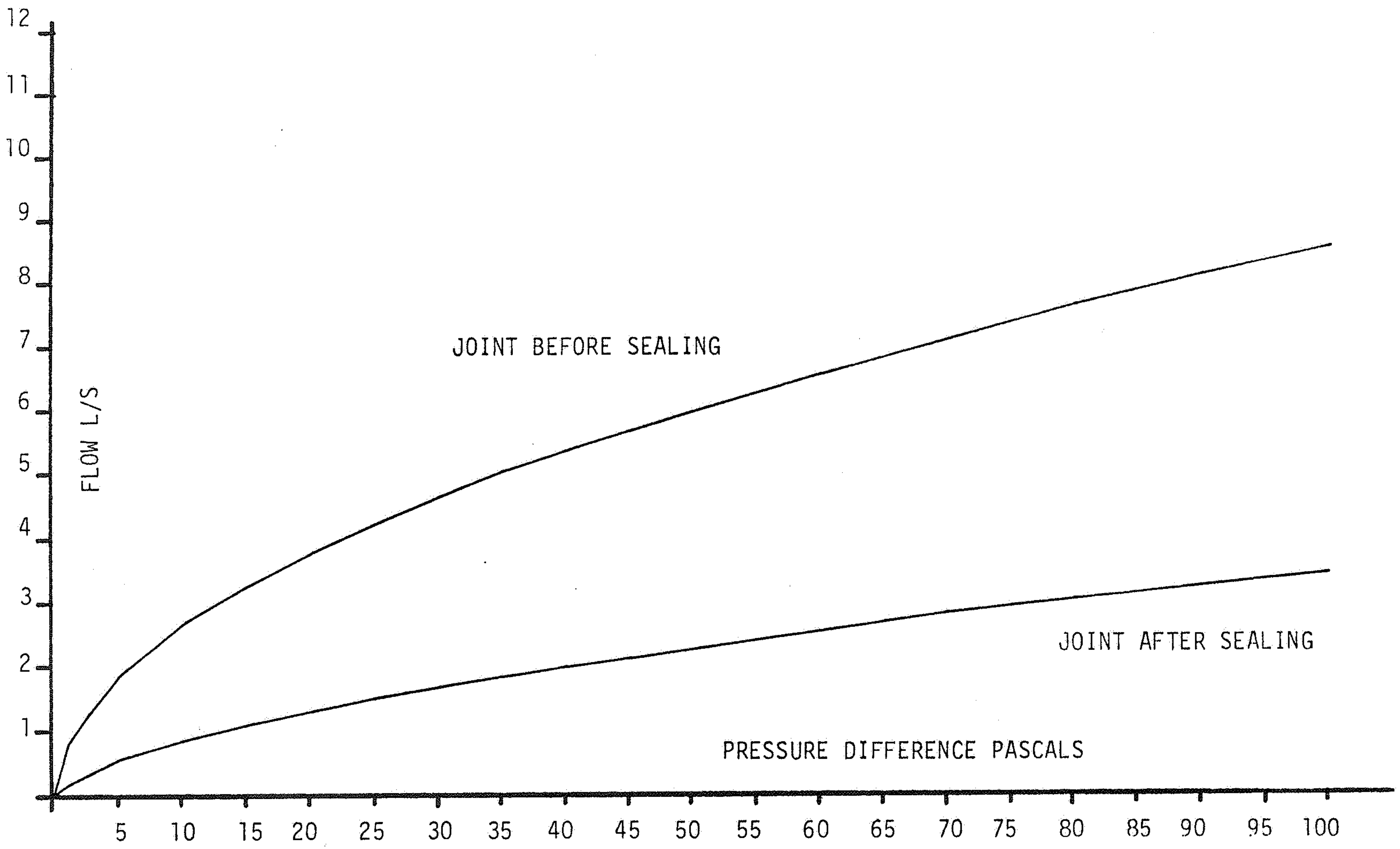


Figure 16 Air Flow through Floor/Wall Joins

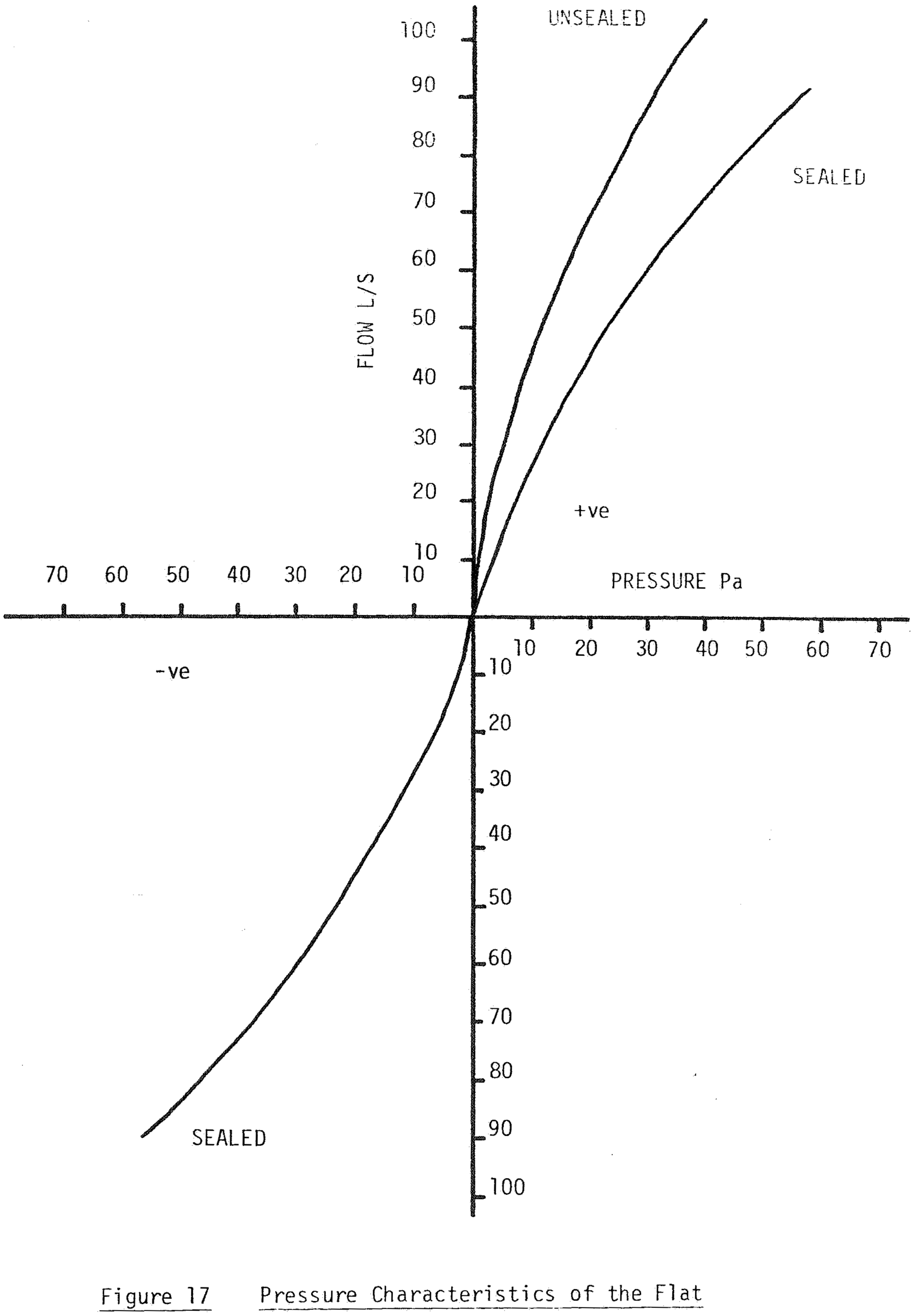


Figure 17 Pressure Characteristics of the Flat

# Discussion

# DISCUSSION

## Monday afternoon - 26 September 1983

Chairman: Peter Hartmann (Switzerland)

| | |
|---|---|
| Paper 1:<br>Keynote Address | 'Potential and limits of energy savings in the Swiss building stock'<br>presented by Conrad Brunner (Switzerland) |
| J. Dewsbury (UK) | In the experiment with improved heating control systems at Limmatstrasse, why did you only have 10 flats with improved control systems ? |
| *C. Brunner (Switzerland)* | *The investment for innovative technology provided by the City of Zurich was limited to this unit of 10 apartments for new control systems, 10 apartments for gas heat pumps and 10 apartments for solar hot water. Now we are thinking of installing control systems in 100 apartments across the street in the new Limmatstrasse which will be in operation by 1984.* |
| R. Grot (USA) | What is the air exchange rate which leads to an air infiltration energy contribution of 26% ? |
| *C. Brunner (Switzerland)* | *Air change rates in existing buildings, including user influence, vary between approximately 0.5 - 1.0 but in recent new construction they vary between 0.3 - 0.6.* |
| R. Grot (USA) | What was your assumed insulation level for the building ? |
| *C. Brunner (Switzerland)* | *Existing buildings are between 0.8 - 1.0 W.m$^{-2}$. New levels for external walls are between 0.3 - 0.5 W.m$^{-2}$.* |

## Session 1

Chairman: Peter Hartmann (Switzerland)

| | |
|---|---|
| Paper 2: | 'Recommended retrofit actions based on air infiltration evaluations in a variety of buildings'<br>presented by David Harrje (USA) |
| L.L. Gill (UK) | How do you reconcile smoke escape vents and garage ventilation with air infiltration control ? Will these *deliberate* extracts not be much greater than the air infiltration or exfiltration you are trying to control ? We were assessing and trying to achieve the correct pressure balance between different areas to avoid pollution transfer. |
| *D. Harrje (USA)* | *In the case of garage air reaching the working space in the example cited in the paper, the garage pressure* |

*exceeded that of the work space and a passage between zones was available (the crack area). In the further example cited at Elm, the stairwell pressurization system (a small fan on the first floor) was inadequate compared to the interior building pressure, allowing odours from apartments to be transferred by the stairwell. The same path would be followed in the case of fire causing smoke to enter the stairwells.*

R. Grot
(USA)

Did the buildings tested have smoke control systems ? If so, how did they operate ?

*D. Harrje*
*(USA)*

*Smoke control systems in the buildings tested were often found to be inadequate or defective. For example, in the building cited in Example 1, fire systems had been blocked open and building modifications had seriously compromised smoke removal from certain zones in the building. The fact that all four air handling units interacted means that smoke can be rapidly moved from wing-to-wing.*

P. Jackman
(UK)

What was the basis of selecting 7ms$^{-1}$ for the wind speed used for the prediction of air infiltration rates ?

*D. Harrje*
*(USA)*

*In the case cited for testing Saudi Arabian buildings, the 7ms$^{-1}$ was part of the specification, indicating that wind was an important factor in the air infiltration mechanism. However, the actual location where the wind speed is measured is also an important factor and cause for error.*

M.J. Holmes
(UK)

Do I understand that you are recommending that mechanically ventilated and air conditioned buildings are not pressurized to avoid condensation in the fabric ? In addition, would you comment on the relative rates of moisture flow through cracks due to internal/external pressure difference compared with typical partial pressures of the water vapour. Could there be a potential problem with cold air entering, cooling the structure and causing condensation ? In that case, pressurization is good ?

*D. Harrje*
*(USA)*

*The first recommendation is to make every effort to tighten the building envelope using the best methods available. The second recommendation is to reduce the pressure differentials to the minimum wherever possible. Clearly, moisture migration through the envelope is primarily via the air flow. Where the right combination of conditions are present, condensation will take place within the envelope. Seasonal factors will then determine whether permanent damage or only yearly cycles in moisture content will take place with full material recovery.*

R. Grot
(USA)

In very large buildings, I do not see how you can apply a zero pressure strategy. In the building we have measured in Newark (a 26-storey high-rise) we saw positive pressure of 25-30 Pa at the upper floors and a negative pressure of approximately 5 to -10 Pa at lower floors. It would be difficult and expensive to introduce a mechanical system to achieve a zero pressure on all floors. It is better to design a tight envelope.

*D. Harrje (USA)*

*Certainly it is better to design a tight envelope to begin with. Maintaining low differential pressures is clearly an increasingly difficult problem with higher buildings, but limiting between floor communications and properly balancing air distribution systems are some steps that can be taken to minimize pressure differentials.*

Paper 3:

'Air infiltration control in housing - a guide to international practice'
presented by Arne Elmroth (Sweden)

R. Grot (USA)

What is being done about the mechanism for distribution of the Air Infiltration Handbook ? Can different countries reproduce it ?

*A. Elmroth (Sweden)*

*Following the AIC Steering Group Meeting, arrangements are being made for the Handbook to be distributed by National Representatives of participating countries.*

M. Liddament (UK)

How durable are present airtightness techniques ? When we come to measure the airtightness of a 1983 building in 2083, how tight will it be ?

*A. Elmroth (Sweden)*

*The durability depends on many things. It is important to have a good design in that the airtightness is a part of the construction technique, for instance well designed joints, clamped joints in the air barrier, etc. Other important things are using durable materials, for example plastic films used in Sweden are tested from a durability point of view (see Figure A8.1 in the Handbook). If the service life of a material is unknown, the elements should be constructed in such a way that it is easy to replace the material.*

Tuesday morning - 27 September 1983

Session 2:

Chairman: David Harrje (USA)

| | |
|---|---|
| Paper 4: | 'The measurement of air infiltration rates in large enclosures and buildings'<br>presented by Jonathan Dewsbury (UK) |
| M.J. Holmes (UK) | Could you suggest a minimum air change rate for factory buildings, in particular when recognising high heat gains and high insulation values ? |
| *J. Dewsbury (UK)* | *No. The desired ventilation rate for a particular building would have to be calculated considering the location and size of pollution, heat and fresh air sources, efficiency of local extract arrangements, internal air movement, desired air quality and temperature and design weather conditions.* |
| M. Liddament (UK) | (In response to Mike Holmes' comment)<br>Approximately half the area Jonathan talked about refers to warehouses where there is no process heat - here is where substantial energy savings are possible. Enquiries to the AIC frequently relate to excessive air/heat losses from such buildings. |
| R. Grot (USA) | What tracer gases did you use ? How much did you need and what were the building sizes ? Were they really large ? The mixing you obtained after three hours was very good. Will the blower test used to validate the measurement method not cause an uneven distribution of tracer by such mechanisms as plug flow ? |
| *J. Dewsbury (UK)* | *So far we have used nitrous oxide for this work although we have used sulphur hexafluoride for other projects. A large proportion of industrial/warehouse buildings in the UK have volumes of the order of 10,000 $m^3$. We aim to produce an initial tracer gas concentration of not more than 1000 ppm, so for a 10,000 $m^3$ building we need about 10 $m^3$ of $N_2O$. The blower test may well cause an uneven distribution of tracer gas, but the aim for our multi-point measurement and analysis methods is to detect and cope with such a situation.* |
| M. Bassett (New Zealand) | Can you give a physical explanation of how the concentration decay rate in all zones (Figures 1 and 3) can either be less than, or even exceed, the perfect mixing case ? |
| *J. Dewsbury (UK)* | *A recent paper by Q.T. Pham (Building & Environment, Vol.18, No.1/2, pp55-60, 1983 'Generalized two-region model for infiltration studies') gives a theoretical account of this problem for two zones.*<br>*(a) Slope of concentration decay lines less than slope of perfect mixing line.* |

*Consider a well mixed room containing a box. The contents of the box are also well mixed but there is only a small air flow from the room into the box and from the box into the room. Initially, tracer gas concentration is uniform throughout the room and the box. If we now ventilate the room, the concentration in the room will become less than that in the box and the box will then begin to act as a source of tracer gas for the room so the gas concentration in the room will then decrease more slowly than if the whole space were well mixed. The concentration decay in the box lags behind that in the room as can be seen by considering the two extreme cases: when the airflow between box and room is very small the rate at which tracer is removed from the box will also be very small as a fraction of the quantity of tracer in the box. As the airflow increases to infinity the concentrations in the box and the room tend to the same value and the decays tend to the perfect mixing line.*

*(b) Slope of concentration decay lines greater than slope of perfect mixing line.*

*Consider two adjacent rooms, room A and room B. The air within each room is well mixed. Fresh air enters room A, air passes from room A to room B and vice versa room air leaves room B. If the circulation between the two rooms is small, then the rate of tracer gas concentration decay in room A will be approximately that resulting from the fresh air flow acting on the column of room A alone, i.e. greater than that resulting if rooms A and B are fully mixed with each other. After a delay, the concentration of tracer gas in room A will be much smaller than that in room B, and room B will then in turn have a tracer gas concentration decay rate approximately that which would result from the air entering room B being completely fresh instead of nearly so. As the circulation between the two rooms increases the concentrations in the two rooms tend to the same value and the decays tend to the perfect mixing line.*

M. Sherman (USA)

In large, poorly mixed spaces, the concept of a single air change rate or infiltration is not appropriate. Even though a decay measurement may yield a single value for the infiltration rate, it is not possible to interpret this easily. The effective volume in a poorly mixed space is always smaller than for the perfectly mixed case. The correct measurement technique depends on the question one is asking - heat loss, pollutant dilution, etc. For thermal balance the best method is probably constant emission (injection near heating system) with an average concentration measurement. If pollutant concentrations are of interest the concept of ventilation efficiency must be employed.

*J. Dewsbury (UK)*

*At present we are mainly (but not only) interested in measuring ventilation as a source of heat loss. It is difficult to arrange for tracer gas to behave in the same*

*way as heat from the heating system, especially with mainly radiant systems such as are common in the UK. We hope to be able to derive from our measurements an* approximate *value for the sum of the air flows out of the building, each multiplied by its appropriate temperature, i.e. the ventilation heat loss. We think we have shown that the average tracer concentration in a poorly mixed space does not give an adequate picture of what may be happening in the case of a concentration decay method. We have not yet performed any simulations or trials using constant emission as we feel it is difficult to control the very small gas release rates required at each of a number of release points. Discharging all the gas for a large building with poor internal mixing at a single or few release points would very probably result in concentration variations within the space which exceeded the range of our instruments.*

Paper 5: 'Ventilation measurements in large buildings'
presented by John Lilly (UK)

R. Grot (USA)

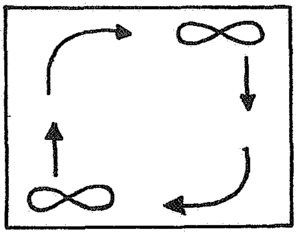
How long did you wait after start of injection of tracer in the constant flow rate method to begin measurement ? In the decay test, how long did you wait after injection ? What other methods would you consider using ?

*J. Lilly (UK)*

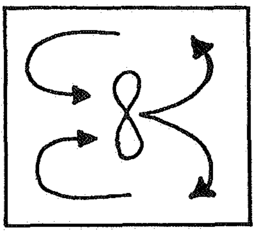
*In our experiments, we keep a constant injection of tracer gas running at all times, so that experimentation can take place when required. When changing the injection format, it generally takes 2-3 hours before an "operating concentration" is reached. We prefer to wait 6 hours in our building of 650* $m^3$ *with no artificial mixing. This is because the concentrations we measure are not at equilibrium so it is hard to specify when instantaneous concentrations have achieved a "pseudo equilibrium" condition. For this same reason, long term measurements are much more meaningful than instantaneous measurements.*

*In decay experiments, we have the facility to use many different types of mixing if required. The time taken for concentrations to stabilise depends on the method of injection. When no artificial mixing is involved, we monitor concentrations continuously after waving around the injection line and wait for natural mixing to diffuse the tracer. Considering the building is sensitive to wind, with an airchange typically of 1.5 - 2.0 per hour, natural mixing is not inconsiderable. We find adequate mixing takes place after* $\frac{1}{2}$ - $\frac{3}{4}$ *hour before useful measurements can be taken. When using artificial mixing, it only remains for the artificial airstreams to die down. If a "swirl" run around the building is employed, it may take* $\frac{1}{3}$ - $\frac{1}{2}$ *hour to die down in our naturally leaky building. A large central fan may take up to 15 - 20 minutes and 10 small locally placed fans only a few minutes after switching of*

*However, mixing is less adequate with small fans and it takes much longer to attain an even distribution.*



Swirl mixing



Central fan

*Constant concentration techniques, I feel, can produce a valid mean ventilation rate, but with slightly less accuracy than multi-cell buildings. We have used individual injection, sample and mixing for 50 m$^3$ imaginary volumes within the building. Tracer transport between zones means that the computer control cannot accurately predict the change in concentration leading to formation of "pockets" of tracer gas (excess and deficiency) which drift between zones. Artificial mixing and this "zone transfer" totally destroys the natural characteristics of the building, so no conclusions can be drawn, as yet, concerning the ventilation efficiency. Additional errors in the mean ventilation rate appear to be less than 5%.*

M. Sherman
(USA)

In large poorly-mixed spaces, the concept of a single air change rate or infiltration is not appropriate. Even though a decay measurement may yield a single value for the infiltration rate, it it not possible to interpret this easily. The effective volume in a poorly-mixed space is always smaller than for the perfectly-mixed case. The correct measurement technique depends on the questions one is asking - heat loss, pollutant dilution, etc. For thermal balance, the best method is probably constant emission (injection near heating system) with an average concentration measurement. If pollutant concentrations are of interest, the concept of ventilation efficiency must be employed.

*J. Lilly*
*(UK)*

*I agree that, for thermal balance purposes, constant emission techniques probably offer the most promise in ventilation heat loss measurements. However, I do not believe that an average tracer concentration measurement would be representative of the ventilation heat loss in a large single cell building. When using constant emission techniques, large concentration gradients can build up in short displacements and an impractically large number of sample points is required to obtain a mean value. Even then one has to assume that the airflow velocity distribution within the cell is uniform. In this respect, when injecting tracer gas into a heated air stream, I believe there is not much difference in samples taken in either decay or constant emission measurements. I think*

*there is much room for developing our interpretation of tracer concentrations at sites of exfiltration, which offer the best mixed tracer/air sample whether in decay or constant emission. At present, although lengthy tests are required, I believe decay methods are the most practical to determine overall air infiltration rates in single cell buildings, and constant emission techniques most suited to gaining information on local ventilation efficiency.*

Paper 6: 'Air leakage in industrial buildings - preliminary results' presented by Leif Lundin (Sweden)

W. de Gids
(Netherlands)

Is there an explanation for the difference in results between pressurization versus depressurisation ?

*L. Lundin*
*(Sweden)*

*I think you mean buildings B and C in the paper.*

*Building B: Due to the use of the building there were a great number of smoke vents in the roof. These smoke vents open outwards and therefore the building is tighter when depressurized.*

*Building C: I am not sure but I have to guess that the plastic air vapour barrier can act as a one-way valve.*

J. Dewsbury
(UK)

Are you doing any work to relate the results of your building airtightness measurements to air infiltration rates under natural conditions ?

*L. Lundin*
*(Sweden)*

*We are working on a project which we hope will give us the relationship between airtightness and air infiltration in dwellings. For industrial buildings we have no similar project. Our building authorities are discussing whether the Building Code should contain regulations about airtightness in industrial buildings. A decision will be made during the next few months.*

C-Y. Shaw
(Canada)

How do you calibrate your fan ?

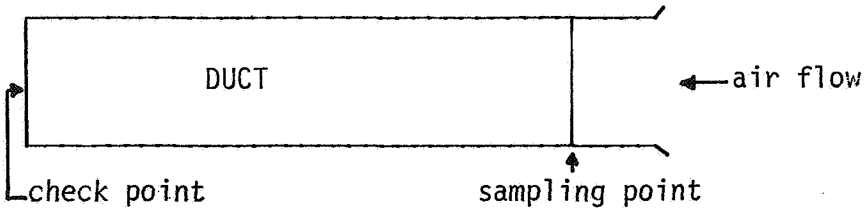
*L. Lundin*
*(Sweden)*

*The calibration points are:*

*(a) The mass flow meter can be calibrated to a volumetric flow meter - not to a rotameter.*

*(b) The gas analyser shall be calibrated following the manual. In this system I have used a MIRAN 101 and it is calibrated to the manual. When using the MIRAN calibration system, I have taken a greater number of points within the range 100 - 120 ppm.*

*The most important "calibrating point" is the gas mixing. It is checked by measuring simultaneously the tracer gas concentration at the sampling point and the downstream end of the duct (see illustration)*



Paper 7: 'An overview of ventilation research in large non-residential buildings' presented by Willem de Gids (Netherlands)

H. Yoshino
(Japan)

You have shown the results of air change rate at different points in the auction building. However, air change rate can be calculated, assuming that the contaminant is uniform in a whole space. How can you calculate the air change rate at different points ?

*W. de Gids*
*(Netherlands)*

*Because the building is divided into three sections.*

P. Jackman
(UK)

In your studies of the pressurized laboratories, did you take account of the effect of opening and closing the doors?

*W. de Gids*
*(Netherlands)*

*No, but this effect is investigated in a special scale model study.*

Tuesday afternoon - 27 September 1983

Session 3:

| | |
|---|---|
| Chairman: | Mark Bassett (New Zealand) |
| Paper 8: | 'Improvement of airtightness in four schools' presented by Chia-Yu Shaw (Canada) |
| J. Kronvall (Sweden) | After the tightening measures, there does not seem to be any significant change in the slope of the leakage characteristic in a logarithmic diagram of pressure difference - air leakage. Would this not have been expected if larger openings in the building envelope had been tightened ? |
| *C-Y. Shaw (Canada)* | *Most of the retrofit measures were applied by the school custodians. It is possible that some of the large openings were not sealed. As a result, except for school E, the flow exponents "n" after retrofit were not changed.* |
| J. Dewsbury (UK) | For each school you present air leakage graphs with the HVAC systems on and with the HVAC systems off. How do the differences between the two depend on the characteristics of the HVAC systems ? |
| *C-Y. Shaw (Canada)* | *With the HVAC system off, the air leakage through the intake and exhaust openings of the HVAC system is part of the overall air leakage. This leakage component would be greatly reduced with the HVAC system in operation.* |
| M.J. Holmes (UK) | What does the increase in tightness represent in terms of air change and energy savings ? |
| *C-Y. Shaw (Canada)* | *No attempt was made to correlate airtightness with air change rate and/or energy savings.* |
| Paper 9: | 'Air infiltration in high-rise buildings' presented by Christoph Zürcher (Switzerland) |
| M. Bassett (New Zealand) | Are there good prospects for simplified calculations of surface pressure coefficients for tall buildings in a complicated urban environment ? |
| *C. Zürcher (Switzerland)* | *No, not at the moment. It will be necessary to have many more results from research work comparing computed pressure fields (with the aid of surface coefficients of wind tunnel experiments) with corresponding field measurements.* |
| W. de Gids (Netherlands) | Did you take into account open windows in your calculations? |
| *C. Zürcher (Switzerland)* | *No, we did not.* |

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|---|---|
| D. Harrje<br>(USA) | Looking at Table 1, please describe what you anticipate as the characteristics with much lower outside temperatures. |
| *C. Zürcher<br>(Switzerland)* | *The different flow patterns in the stairwell as well as through the staircase envelope will change in accordance with increasing wind speeds.* |
| D. Harrje<br>(USA) | Will the vortex flow you described not counter the flow outward at the lower floors ? |
| *C. Zürcher<br>(Switzerland)* | *This question is much more difficult to answer because the air flow pattern in the staircase not only depends on pressure difference but is also strongly influenced by the distribution of air leakages throughout the structure as well as the design of the facade.* |
| J. Kronvall<br>(Sweden) | Why did you use the exponential formulation in the calculation procedure rather than the more widely used leakage area concept ? |
| *C. Zürcher<br>(Switzerland)* | *The reason for using the exponential formulation is that you can determine the crack coefficient as well as the pressure exponent directly from the recorded pressure-flow characteristics using blower door measurements.* |
| Paper 10: | 'Case study of retrofitting a 14-storey office building in Oslo' presented by Bjørn Vik (Norway). |
| H. Feustal<br>(Germany) | In the figure the air changes by pressurization/depressurization showed a significant difference. Is this caused by the location of supply/exhaust outlets in the building ? |
| *B. Vik<br>(Norway)* | *I do not believe that the differences have anything to do with the location of ventilation outlets. Most probably the measurements before treatment were very inaccurate. Analysis after treatment showed no difference between supply and exhaust measurements.* |
| M. Bassett<br>(New Zealand) | Would the leakage problems described in this particular multi-storey building be classified as inadequate quality control or inadequate specification ? |
| *B. Vik<br>(Norway)* | *The two leakage problems were due to different circumstances. One was a material fault which was built into the wall element. The other was due to indequate specification which is quite normal. Both faults should have been discovered and treated during the construction period.* |
| J. Kronvall<br>(Sweden) | Did you notice any dampness on the outer wall caused by moisture convection and condensation in the upper part of the building where, according to your measurements, there was an internal over-pressure ? |
| *B. Vik<br>(Norway)* | *Condensation was not being monitored. We would, however, expect to be informed if condensation was a severe problem.* |

J. Dewsbury
(UK)

Can you explain why the internal over-pressure on floor 8 was so much less than on the other floors, in the case of pressurization by the supply fans after treatment ?

*B. Vik*
*(Norway)*

*This is probably a result of a more dominant stack effect in system 2. In figure 3, you find the slope of the curves within system 2, due to the stack effect, much more pronounced than that of system 1.*

Paper 11: 'Air infiltration and airtightness tests in eight US office buildings' presented by Richard Grot (USA)

M. Sherman
(USA)

You have quoted the leakage values in air changes at 50 Pa and, when this value is compared to tight houses, it proves tighter. Does this not mean that quoting tightness in air changes does not allow a good comparison of buildings of different sizes ?

*R. Grot*
*(USA)*

*We compared leakages at 25 Pa (figure 13). This was done only to put these buildings into perspective with known data. We used two of the three ways adopted to analyse tightness data, and air exchange seemed better. It should be noted that these buildings varied in size by a factor of 20. We did not use leakage area because 4 Pa is probably not a good pressure for large buildings.*

M. Sherman
(USA)

When you plot infiltration vs tightness for these buildings you get a good fit. Since the weather at all sites was almost identical, is this apparent correlation not an overstatement of the relationship and might not weather play a bigger role ?

*R. Grot*
*(USA)*

*I am more worried about the size of the sample than your point. I feel that this data shows that models for large buildings could be developed which would be similar to those you have developed for residences and which would relate tightness to air infiltration. Such models will probably be as successful as those for residences.*

M. Sherman
(USA)

You present temperature correlations to the measured infiltration rates. Although there is an unmistakable dependence on temperature, the correlation coefficients are quite low - suggesting that a linear temperature dependence has little to do with explaining the scatter in the data. What *do* you think are the important sources of scatter in the data and what useful information can be extracted from the linear correlations ?

*R. Grot*
*(USA)*

*I feel that linear correlations are a useful technique for the preliminary analysis of air infiltration. This is not a substitute for a good model. However, such a model does not exist at present. Short term air infiltration data always seem to have large scatter when compared with other parameters. I do not feel that measurement errors are more* *than ± 0.1 ach. For the tight buildings, this explains much of the scatter. For the leakier buildings I feel that physical phenomena for similar parameters, such as average wind speed, direction and temperature, do not take into account pressure fluctuations, for example, especially in complex buildings.*

D. Harrje
(USA)

Following your presentation, especially the Huron building, far more data points with a somewhat different location were given as compared to figure 12. Please comment on these differences.

*R. Grot*
*(USA)*

*There was an error made by the computer programmer who rounded all data down to 0.1 ach. Thus many points may be plotted on top of each other in the paper. The slide is correct. Also our data sets grow as more field data is checked and analysed. Since there is a time interval of about two weeks in the plots, the slides could have more data in them.*

## Paper 12: 'Ventilation rates and intercell airflow rates in a naturally ventilated office building' presented by Richard Walker (UK)

M. Bassett
(New Zealand)

Can you use your multi-zone infiltration rate equipment to make comparative measurements with absorption tubes using different multiple tracers ?

*R. Walker*
*(UK)*

*We are hoping very soon to attempt comparative tests using* $SF_6$ *with absorption tubes, but no tests have actually been performed yet. If these are encouraging, we may then move on to include other tracer gases.*

J. Dewsbury
(UK)

When you took sampling tubes from several sampling points in each zone, why did you manifold them together before analysing the samples ? Were you not throwing away potential data on tracer distribution within each zone ?

*R. Walker*
*(UK)*

*Yes, we are losing information. This was a practical problem. In the first case, we only had the facility to sample six lines and in the second case, since three times the length of tube runs would be required, there were problems in laying without unduly interfering with occupants duties/ environment.*

Wednesday morning - 28 September 1983

Session 4:

Chairman: Peter Jackman (UK)

Paper 13: 'Retrofit-planning-tools for institutional and residential buildings with user-influenced air infiltration' presented by Peter Hartmann (Switzerland)

J. Dewsbury (UK)
What is the price of electricity in Switzerland and how common is electric heating ?

*P. Hartmann (Switzerland)*
*Price of electricity:*

- *low period (night): similar to oil ( ∿6-8 ct/kWh)*
- *high period (day) : 2-3 times higher*

*Electric heating:*

- *direct heating in Western Switzerland available (some 1000 apartments)*
- *storage heating all over Switzerland but only in a small percentage of apartments.*

W. de Gids (Netherlands)
Why didn't you take this opportunity to include the distribution of air leakage over the building envelope ?

*P. Hartmann (Switzerland)*
*This is possible and surely needed for small houses where different sets of such tables according to house type will be evaluated.*

W. de Gids (Netherlands)
On what information are the behaviour figures based ?

*P. Hartmann (Switzerland)*
*Figures of user behaviour are based on different observations and measurements. They show that window opening is more frequent in tight houses than in leaky houses.*

W. de Gids (Netherlands)
Why did you not give some impression of energy and/or cost in figure 3 ?

*P. Hartmann (Switzerland)*
*Consultants are used to calculating these effects, but we could include this information in an additional table.*

D. Harrje (USA)
In your figure 2, the difference in air change rates between "rather tight" and "rather leaky" is only 20%. Please comment further on this slight variation.

*P. Hartmann (Switzerland)*
*Data in figure 2 include natural infiltration and user-influenced infiltration. Natural infiltration alone would spread much more than 20%, but the final result is much closer because users tend to compensate by opening windows often in tight buildings and vice versa.*

P. Caluwaerts (Belgium)
Is it possible to extrapolate your graphs for international use ?

*P. Hartmann*
*(Switzerland)*

*The graphs can be used in other places but have to be re-calculated in connection with*

- *wind speed conditions of each country*
- *user behaviour (standard user with upper and lower limits)*

*Also other assumptions have to be considered in connection with local conditions, e.g. importance of stack effect.*

Supplementary Paper:

'The reduction of air infiltration in flats and timber-framed housing in the UK through simple retrofit procedures' presented by Ian Ward (UK)

P. Hartmann
(Switzerland)

For your experiment of measuring leakage of specific gaps, do you pressurize the box and the surroundings or only the box ?

*I. Ward*
*(UK)*

*At the moment, the tests are exploratory and we have not pressurized the surrounding areas. It is our intention to try both pressurizing the surrounding area by a blower door and also trying a double box system.*

D. Harrje
(USA)

In your tightening procedure, it would appear from other retrofit experience that levels of 6 ach might be a target value. In order to achieve such improved tightness more than cracks may be involved and infrared pressurization techniques would prove useful to check such areas as interior walls looking for bypass sites.

*I. Ward*
*(UK)*

*I quite agree with your comments, but as the slides indicated we have been unable to check the influence of internal walls to date.*

Paper 14:

'Air infiltration in New Zealand houses' presented by Mark Bassett (New Zealand)

J. Kronvall
(Sweden)

What kind of ventilation system exists in the houses with severe condensation problems ? Are there, for example, any pipes for natural ventilation at all ?

*M. Bassett*
*(New Zealand)*

*There are no mechanical ventilation systems or ventilation openings of a fixed nature. The ventilation addition to natural air ventilation is by occupant window opening.*

R. Weimar
(USA)

What were the sources of moisture in the houses discussed, i.e. were they from inside the house or from the outside atmosphere condensing on the walls, or both ?

*M. Bassett*
*(New Zealand)*

*In the examples discussed, the moisture was released in the living space and not transferred through the building cavities. There are, however, moisture problems in New Zealand houses that are caused by air-leakage-carried moisture; mostly they show up as a problem within the*

| | |
|---|---|
| | *building cavity with the potential to cause structural problems.* |
| D.Harrje<br>(USA) | Considering your rather mild climate and need to remove interior moisture, would it not make sense to consider the mechanical dehumidifying systems which could supply both the heat and the drying that is required ? |
| *M. Bassett*<br>*(New Zealand)* | *Mechanical dehumidification is one of the options that must be considered in evaluating retrofit measures to control indoor moisture problems. Others such as heat recovery ventilation will also stand a chance but, so far, we have not evaluated the options and cost effectiveness.* |
| D. Harrje<br>(USA) | Incidentally, the NBS US data - pointed out in figure 3 - are for relatively old housing (usually more than 40 years old) and are not representative of today's housing which would tend to cluster near the 10 ach level. |
| Paper 15: | 'Airtightness of residential buildings in Japan' presented by Hiroshi Yoshino (Japan) |
| J. Kronvall<br>(Sweden) | Were the pressurization tests conducted with over- and under-pressure and, if so, are the reported results each to the mean flow value ? |
| *H. Yoshino*<br>*(Japan)* | *In rather leaky houses belonging to Rank 5, no significant difference in airtightness between the two methods was found. However, in a tight house - for example No.12, airtightness obtained by depressurization is much less than that obtained by pressurization.* |
| J. Kronvall<br>(Sweden) | In some cases, as far as pressurization tests are concerned, you have a flow exponent ($\alpha$) larger than 2, which is physically "impossible". Have you any explanation for this? |
| *H. Yoshino*<br>*(Japan)* | *In those cases we have measured the low pressure difference under a slightly windy condition. This affects the measurement with the result that the calculated regression curve obtained using these measured results has a flow exponent larger than 2.* |
| W. de Gids<br>(Netherlands) | Why do you measure at lower pressures than others ? |
| *H. Yoshino*<br>*(Japan)* | *Pressure differences under actual conditions are under 10 Pa. Therefore I think it is not necessary to measure in the range over 50 Pa.* |
| W. de Gids<br>(Netherlands) | What kind of pressure transducers do you use ? |
| *H. Yoshino*<br>*(Japan)* | *We use the capacitance manometer type.* |

Paper 16: 'Component leakage areas in residential buildings' presented by Max Sherman (USA)

D. Harrje
(USA)

As the co-author of reference 9, which has used a very similar rational to form a component list, I am happy to see continued work along this line of thinking. Perhaps the biggest difference is that reference 9 stressed 50 Pa, whereas this paper has stressed 4 Pa data. The choice between these two pressures is debatable but recent data obtained in the field at 50 Pa is indicating ± 3% error bands, but extrapolated to 4 Pa ± 15% errors are found. Since different countries evaluate leakage at different pressures, retaining 50 Pa values was our choice. The important goal of the addition of more detailed component leakage values is one part of current research at Princeton where laboratory conditions allow evaluation at even low pressure levels, being free of wind fluctuations.

*M. Sherman*
*(USA)*

*The fact that a quantity can be measured accurately does not mean that it is the appropriate quantity to measure. Infiltration is driven by forces in the range of 4 Pa and, therefore, the appropriate leakage quantity is the leakage near 4 Pa - not 50 Pa. Any model that uses the 50 Pa value must, either implicitly or explicitly, convert it to the lower pressure. The process cannot be more accurate than the extrapolation that yields the 4 Pa value in the first place. If, however, one is measuring leakage for some purpose (other than infiltration) the use of the 50 Pa number may be appropriate.*

M. Liddament
(UK)

I think that your data base would be of greater value if it contained pressure coefficient and flow exponent data. Then it will be compatable with all methods of defining air leakage. By reducing this information to "effective area" the value of this data base will be restricted.

*M. Sherman*
*(USA)*

*The data base is designed for use by designers, auditors, architects and other non-experts. For their use, it should be simple to use and understandable. Effective leakage area has both these advantages; it can be used in such simplified physical models as the LBL infiltration model and can easily be understood in terms of the equivalent amount of open area. Furthermore, the data base represents an average of many individual components and, while it is quite simple to average leakage area, it is not possible to combine leakage coefficients and exponents and retain the meaningful information.*

R. Grot
(USA)

Do you think that all leakage areas are now known and that there is no large leakage area in another category ?

*M. Sherman*
*(USA)*

*For the study we conducted it appears that all major leaks have been characterised. In general, this will be true for new construction. In existing buildings, age and occupant modifications will make a component summation far less reliable.*

R. Grot
(USA)

If you know all leakage areas, is it still fruitful to worry about 4 Pa, 10 Pa, when models exist that use the exact solutions to the flow-pressure equations ?

*M. Sherman*
*(USA)*

*The concept of leakage area is useful for both construction quality and infiltration modelling. For modelling efforts it is important to use the correct value (the one that is most typical of infiltration pressure is 4 Pa). If one is using a large computer program and is not worried about simplified calculation procedures, then a more accurate solution is possible. This, however, is misleading because the uncertainty associated with other parts - particularly the wind shielding values - overshadows the effect of leakage assumptions.*

C. Weinmann
(Switzerland)

What about the capability of the energy signature to give an evaluation of the air infiltration rate ?

*M. Sherman*
*(USA)*

*The concept of the energy signature is to record the energy consumption in a building during several days or weeks. The measurement programme is organised so that difficult states of use of the building and of the heating plant can be analysed:*

- *heat losses from the heating plant alone.*
- *energy needed for hot water production.*

*It is possible to obtain, with a good accuracy, the energy effectively used for heating the house Q, which is equal to the sum of heat losses due to transmission* $Q_T$ *+ heat losses due to air change* $Q_{ach}$ *minus free heat coming from external and other internal heat sources* $Q_{FH}$

$$Q = Q_T + Q_{ach} - Q_{FH}$$

*With other considerations, one finds that a bar temperature* $T_b$ *can be defined for the considered house.* $T_b$ *means the temperature limit below which the house needs to be heated. The difference between* $T_b$ *and the effective indoor temperature* $T_i$ *gives exactly the amount of free heat which has contributed for the heating of the house between* $T_b$ *and* $T_i$ *during the measuring period.* $Q_{FH}$ *may then be evaluated. If* $Q_T$ *is evaluated too, then* $Q_{ach}$ *may be obtained with an accuracy which seems to be good enough for an efficient energy audit.*

*The air change rate may be determined as*

$$n \pm 0.2\ h^{-1}$$

*This result should justify the opportunity for calling the specialist for our leakage problems or not calling him.*

*Further work is made in Lausanne within our group and we wish to give more information on that later.*

M. Liddament
(UK)

Could you up-date us on the progress of the LBL AC pressurization technique ?

M. Sherman
(USA)

AC pressurization is a technique that uses a low pressure alternating pressure signal to synchronously detect air leakage. We are in the process of developing systems that will work in the 1-10 Hz (infrasonic) range. We hope that within a year we will have a working field device that would replace fan pressurization as the best way to measure airtightness.

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