Measuring Background Leakage in Domestic Buildings

Paper given at BRE Wind Engineering Group

15th Meeting, 3rd April, 1985

P.H. Baker, S. Sharples and I.C. Ward

Introduction

The total air leakage area of a house can be divided into 3 elements:

i) specific ventilation opening areas (air bricks, fans)

ii) identifiable component areas (door, windows)

iii) background leakage areas (?)

Measurements by several workers have indicated how whole house leakage areas are distributed. The early study by Skinner[1], together with more recent work by Warren and Webb[2], suggests that at 50 Pa pressure difference the background leakage area can represent 50% of the whole house leakage (see Figures 1 and 2). At the more typical pressure of 5 Pa Warren and Webb found the background leakage to represent 25% of the total.

Background leakage cracks are not easy to identify and quantify. There is a lack of measured data for:

i) the distribution of background cracks

ii) the air flow characteristics of such cracks

iii) the leakage paths for these cracks in buildings.

The Need for Background Leakage Data

A better understanding and quantification of background leakage would yield several benefits. Firstly, it would allow more accurate computer modelling of inter-room air flows to be developed. Secondly, it would be possible to identify those constructional elements which might be sealed during the building process for greater energy efficiency. Thirdly, it might be feasible to establish a data set of the flow characteristics of typical building constructions and joints, analogous to the work of Reinhold and Sonderegger[3], who are trying to catalogue component leakage areas to enable leakage to be predicted from architectural drawings.

Background leakage must also be considered in very tight houses, either where mechanical ventilation plus heat recovery may be proposed or as a means of ensuring a minimum base ventilation rate for satisfactory air quality and moisture removal.

The group at Sheffield are seeking to examine some of these points through the development of a portable, automated pressurisation system capable of identifying and quantifying background leakage areas in rooms. The initial stage of this work has been a laboratory study of the air flow through idealised model cracks.

Developmental Work

A series of cracks have been fabricated, and through a set of measurements these cracks have been "calibrated" to obtain their flow characteristics. It will be possible, when the portable pressurisation system has been developed, to validate its results against these standard cracks.

Crack flow measurements made with respect to building components normally use cracks several millimetres in width to simulate the gaps, for example, in window and door frames. However, background leakage cracks will frequently be typified by gaps of less than a millimetre and with complex geometries.

For the initial set of measurements only "straight-through" have been considered (see Figure 3), but in the future L-shaped, double-bend and multiple-bend cracks will be examined to see the effect of increasingly complicated geometries on the crack flow equations.

Experimental Arrangement

The experimental arrangement is shown schematically in Figure 4. One pressure box is connected to a fan and orifice plate to produce known flow rates. The front of this box is detachable to enable a range of cracks to be examined. The second box acts as protection against external pressure fluctuations in the laboratory, such as doors closing or windows opening. This two box system has allowed very low pressure differences (<0.01 Pa) across the cracks to be measured.

Experimental Results

The final aim of the project is the production of a portable pressurisation system. The portability of such a system partly depends upon how long the length of crack must be to obtain the true flow characteristics of that crack. Therefore, the first measurement took a 3.22 mm wide crack and measured the air flow through it for crack lengths varying from 0.1 to 1 m. The results are shown in Figure 5, where it is apparent that for any pressure difference ΔP the flow rate divided by crack length is independent of the crack length provided that the crack width is very much smaller than the crack length. A standard crack length of 0.5 m has been chosen for all other measurements.

For the straight-through cracks the dimensions shown in Table 1 have been used:

Table 1   Range of straight-through crack dimensions

Crack length = 500 mm	
Crack thickness (mm)	Centre line distance (mm)
0.38 0.90 1.40 3.05 6.15 9.40	152 mm
0.55 1.30 1.39 2.85 5.85 8.94	76.2 mm

The thickness of the cracks were originally set using end spacers, but bowing and surface irregularities, even with ground flat steel plate, gave large errors with the smaller cracks (<3 mm). Consequently, thicknesses were found by taking feeler gauge measurements at 21 points along the crack's length and finding the mean thickness.

Some 250 measurements have been made for a range of flows, Q, pressure differences ΔP and crack dimensions. The parameter used as the independent variable in the crack flow equation is:

$$\frac{z}{R_h\ D_h}$$

where z is the through distance of the crack and R_h is the Reynolds number based on D_h, which is equal to four times the hydraulic radius of the crack. Measurements by Hopkins and Hansford[4] had a maximum value of $z/R_h\ D_h$ of 0.4. The present work has extended this parameter to 30.

The results have been fitted to the crack flow equation discussed by Etheridge[5], which takes the form

$$\frac{1}{C_z^{\,2}} = B\,\frac{z}{R_h\,D_h} + C \qquad (1)$$

where C_z is the discharge coefficient and B and C are constants determined by the type of crack being examined.

The large range of $z/R_h\,D_h$ used in the present experiment (from 0.001 to beyond 10) caused some problems when a linear regression in the form of equation 1 was attempted, due to disproportionate weighting of the extreme values. Appendix A describes how this problem was tackled.

The results of these measurements are shown in Figure 6. They confirm the theoretical formula produced by Etheridge, and do so for a very wide range of crack thicknesses and pressure differences. Although the crack flow equation is useful for examining idealised cracks with known geometric characteristics, it is difficult to derive crack areas directly from the solution of the crack equation. For example, the crack equation can be written as

$$A^3\,\frac{2\Delta P}{\rho Q^2} - CA - \frac{BzL^2\nu}{4Q} = 0 \qquad (2)$$

where ρ,ν are the density and kinematic viscosity

Q is the flow rate

and A is the crack area.

The area A may be found, but only if the crack geometry and through distance are known. These parameters are not readily determined in actual background building cracks. Therefore, for 'real' cracks it will probably be necessary to adopt a more pragmatic analysis involving just Q and ΔP.

The idealised laboratory cracks will, however, be very useful for testing the validity of several proposed portable pressurisation systems for the full-scale background measurements. One option is a two box system using an outer guard box and an inner measurement box. Such an arrangement has been used by Siitonen[6], and is shown in Figure 7. An alternative approach is to use one measurement box combined with a large fan to pressurise a house or room. Pressurising a room would enable internal background leakage flow paths to be investigated.

Conclusion

The first stage of a project to study domestic background leakage has been described. Fundamental flow measurements have verified the crack flow equation for the simplest crack type for a much larger range of crack and flow parameters than have previously been examined.

References

1. Skinner, N.P., "Natural infiltration routes and their magnitudes in houses, Part 2". Conf. on Controlled Ventilation, University of Aston, September 1975.

2. Warren, P.R. and Webb, B.C., "Ventilation measurements in housing". Symposium on Natural Ventilation by Design, Building Research Establishment, December 1980.

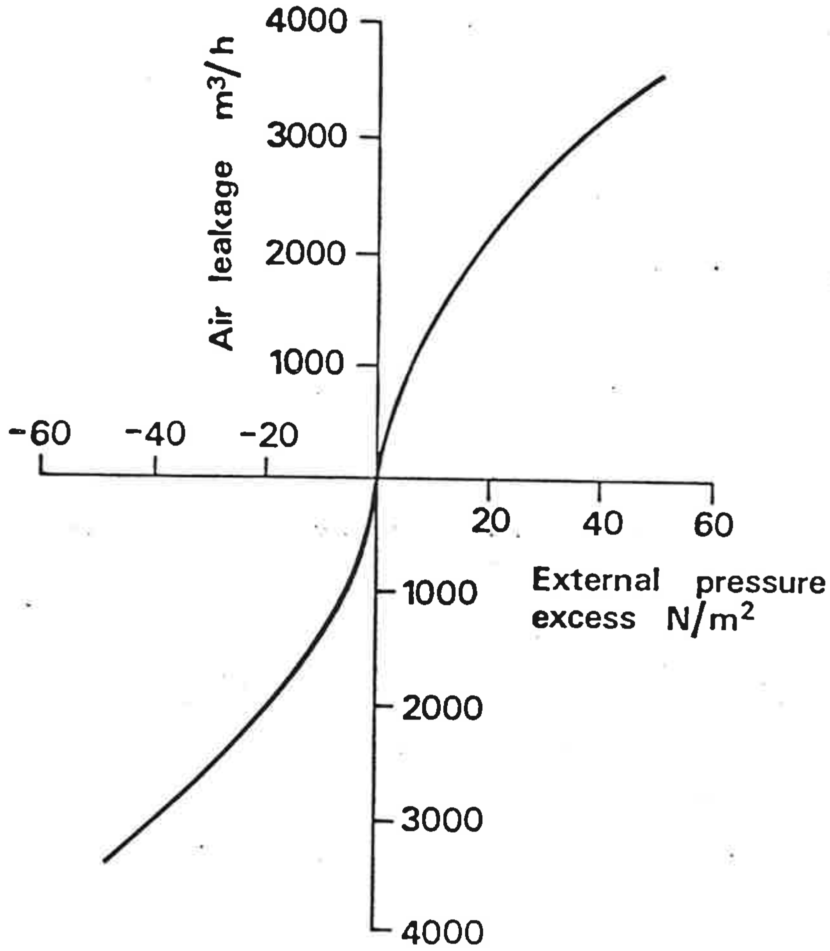
3. Reinhold, C. and Sonderegger, R., "Component leakage areas in residential buildings". Proc. 4th AIC Conference, Elm, Switzerland, September 1983.

4. Hopkins, L.P. and Hansford, B., "Air flow through cracks", Building Services Engineer, 42, 123-129, 1974.

5. Etheridge, D.W., "Brick flow equations and scale effect", Building and Environment, 12, 181-189, 1977.

6. Siitonen, V., "Measurement of local air tightness in buildings", Research Note 125, Technical Research Centre of Finland, 1982.

SS/LM
6/6/85



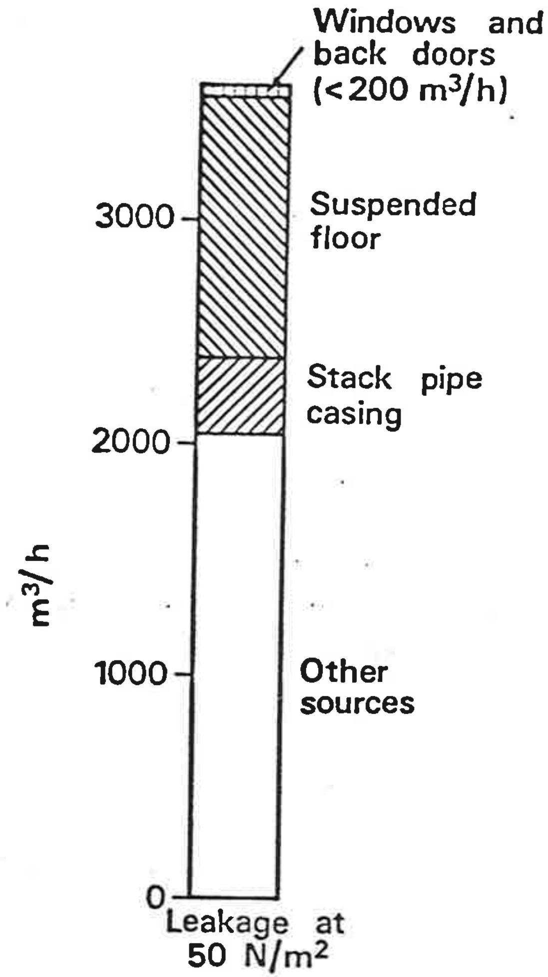


Figure 1 Air leakage on experimental house (after Skinner[1])

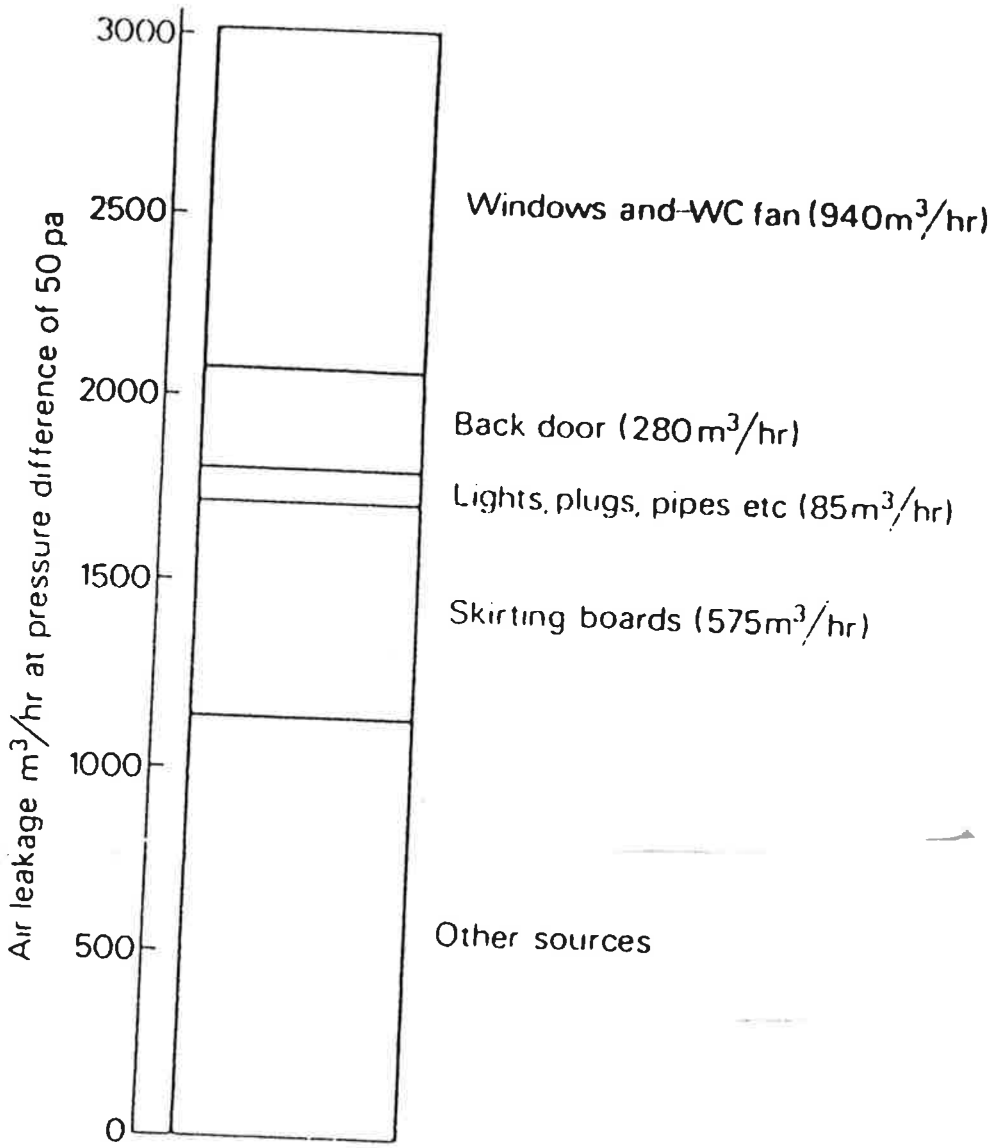


Figure 2. Distribution of Whole House Air Leakage between Components at 50 Pa (House 18)
(after Warren and Webb[2])

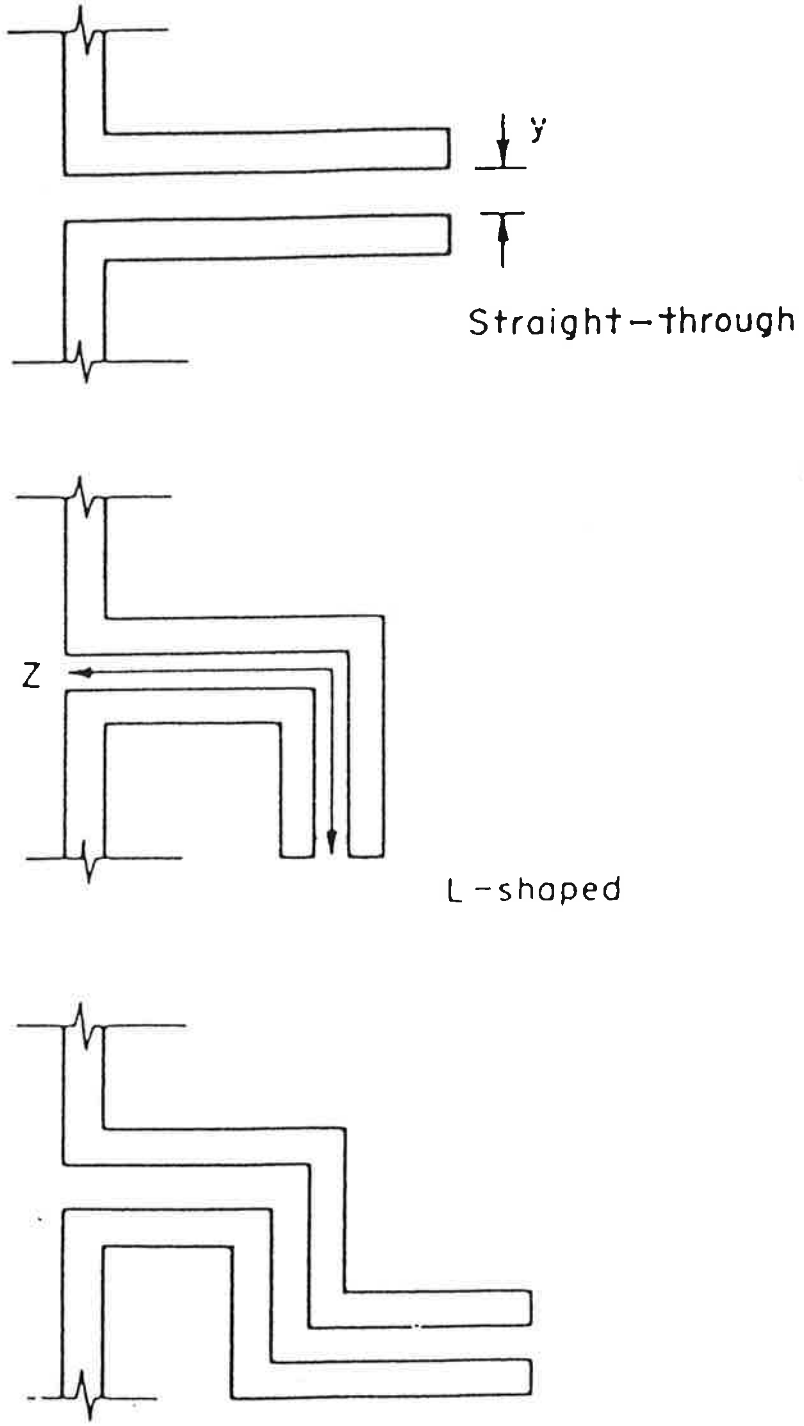


Figure 3 Crack types (after Etheridge[5])

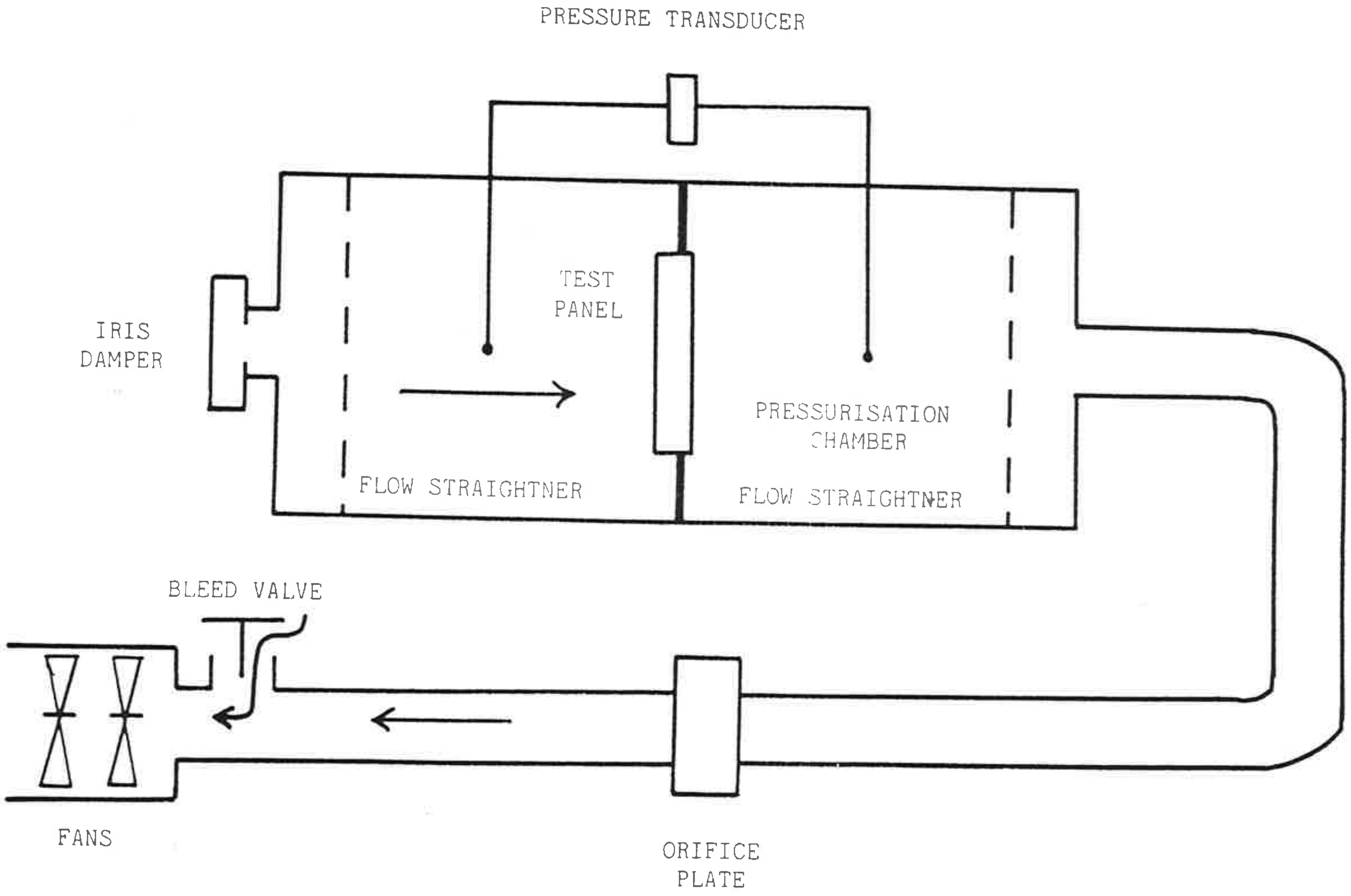


FIGURE 4 SCHEMATIC DIAGRAM OF TEST FACILITY

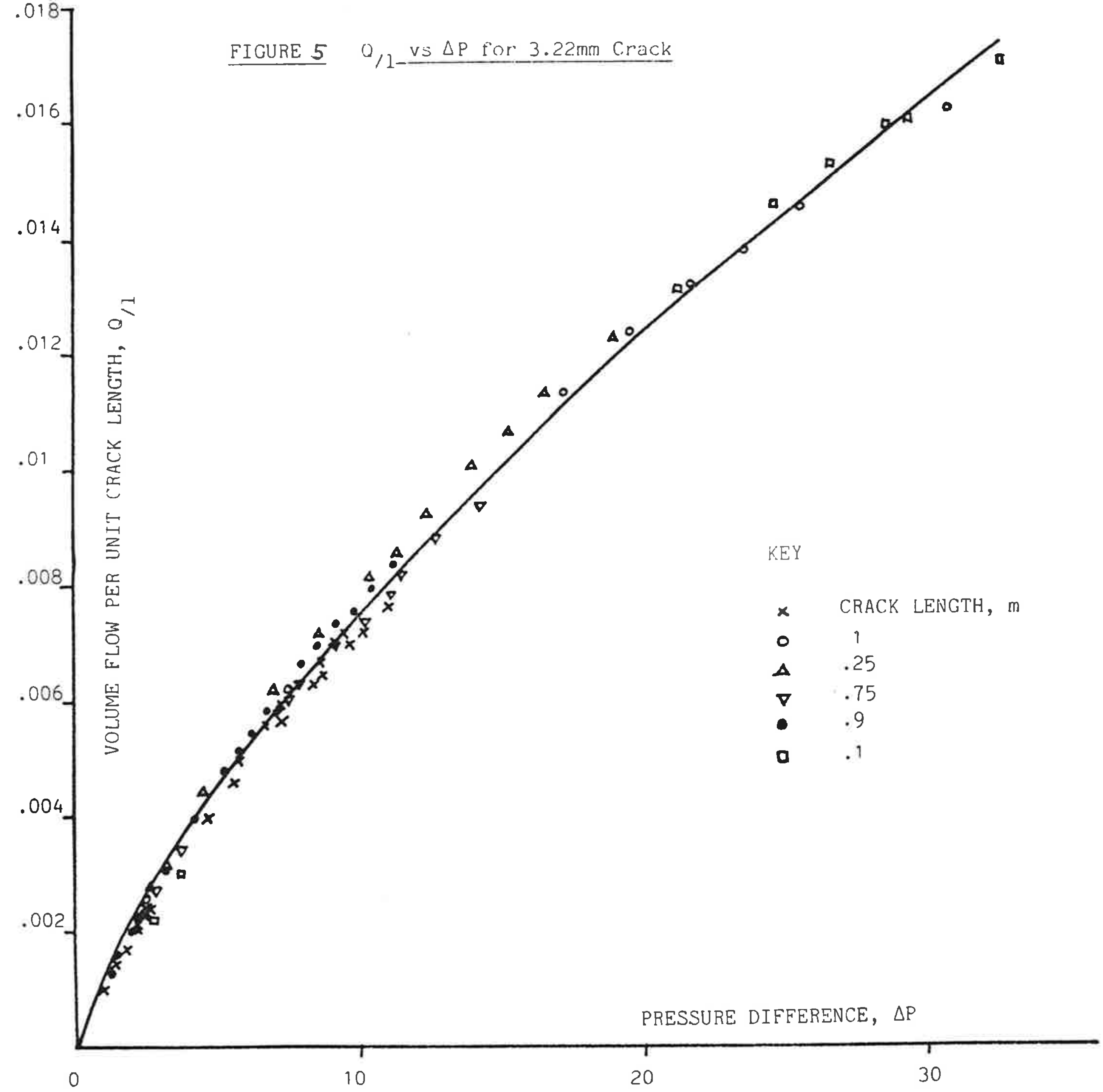
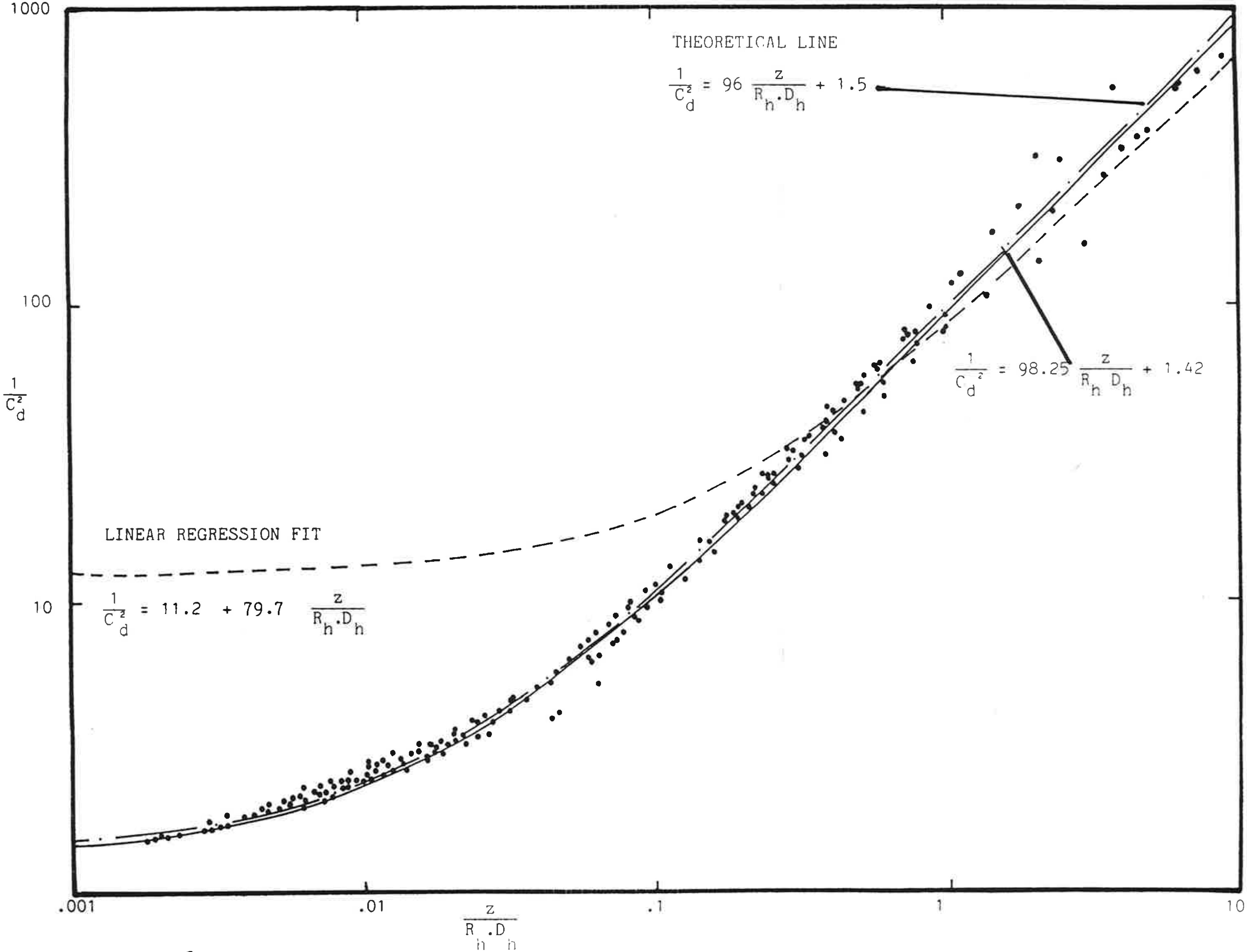


FIGURE 5 Q/1 vs ΔP for 3.22mm Crack
VOLUME FLOW PER UNIT CRACK LENGTH, Q/1
PRESSURE DIFFERENCE, ΔP
.018
.016
.014
.012
.01
.008
.006
.004
.002
0
10
20
30
KEY
CRACK LENGTH, m
1
.25
.75
.9
.1



1000
100
10
$\frac{1}{C_d^2}$
THEORETICAL LINE
$\frac{1}{C_d^2} = 96 \frac{z}{R_h . D_h} + 1.5$
$\frac{1}{C_d^2} = 98.25 \frac{z}{R_h D_h} + 1.42$
LINEAR REGRESSION FIT
$\frac{1}{C_d^2} = 11.2 + 79.7 \frac{z}{R_h . D_h}$
.001
.01
.1
1
10
$\frac{z}{R_h . D_h}$

Figure 6

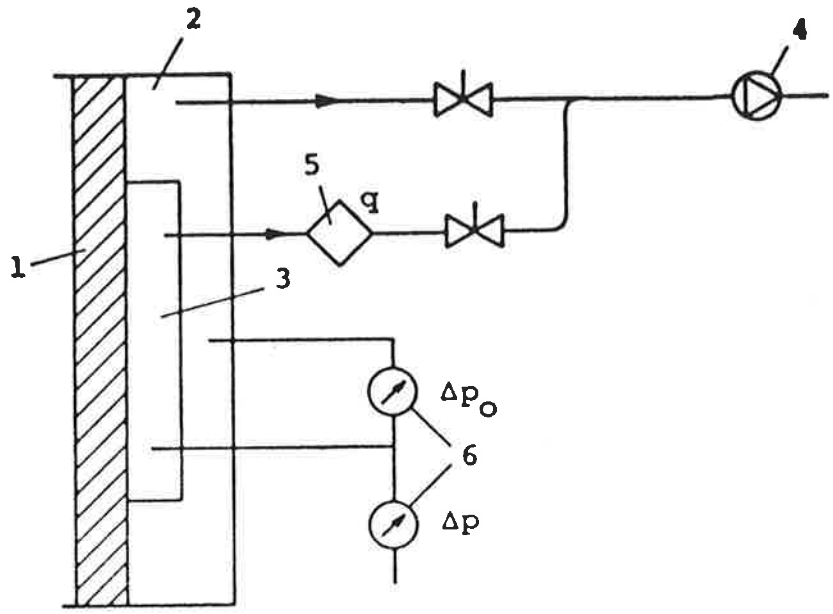


Fig. 7. Measurement of air permeance of sheet material by the guarded pressure box method

1. specimen , 2. guard box
3. measurement box, 4. air pump or fan,
5. measurement of volume flow rate q,
6. measurement of pressure differences Δp and Δp_o

The edge effect is eliminated by adjusting the air flows so that $\Delta p_o \Rightarrow 0$.

APPENDIX A Non Linear Linear Regression

The relationship $Y = aX + c$ may be written as

$(Y - c) = a.X$

thus $\log (Y - c) = \log a + \log X$

The deviation $F_i = \log(Y_i - c) - \log a - \log X_i$

$$S = \sum F_i^2$$

$$= \sum(\log(Y_i - c) - \log a - \log X_i)^2$$

Minimise S by making $\frac{dS}{dc} = 0$ and $\frac{dS}{da} = 0$

$$\therefore \quad \frac{dS}{dc} = -2\sum \frac{1}{(Y_i - c)}(F_i) = 0$$

$$\frac{dS}{da} = -2\sum \frac{1}{a}(F_i) = 0$$

These cannot be directly solved for c and a, but can be solved iteratively by guessing initial values of c and a; c_o and a_o. The true value of c and a are then given by:

$$c = c_o + \delta c \quad \text{and} \quad a = a_o + \delta a$$

where δc and δa are small correction terms.

Now $F_i = (F_i)_o + \delta F_i$

where $(F_i)_o$ is the value of F_i for the estimates c_o and a_o.

i.e. $(F_i)_o = \log(Y_i - c_o) - \log a_o - \log X_i$

We require true values of F_i and c and a to minimise $S = \sum F_i^2$

Now $F_i = (F_i)_o + \delta F_i$

where δF_i is a small correction term

F_i depends on both c and a so

$$\delta F_i \approx \frac{\partial F_i}{\partial c} . \delta c + \frac{\partial F_i}{\partial a} . \delta a$$

Now $$\frac{\partial F_i}{\partial c} = \frac{-1}{(Y - c)} \text{ and } \frac{\partial F_i}{\partial a} = \frac{-1}{a}$$

based on the initial estimates of c and a:

$$\left(\frac{\partial F_i}{\partial c}\right)_o = \frac{-1}{(Y - c_o)} \text{ and } \frac{\partial F_i}{\partial a}_o = \frac{-1}{a_o}$$

so $$\delta F_i \approx \left(\frac{\partial F_i}{\partial c}\right)_o . \delta c + \left(\frac{\partial F_i}{\partial a}\right)_o . \delta a$$

$\therefore$ $$F_i = (F_i)_o + \left(\frac{\partial F_i}{\partial c}\right)_o . \delta c + \left(\frac{\partial F_i}{\partial c}\right)_o . \delta a$$

Now $c = c_o + \delta c$ and $a = a_o + \delta a$

$$\gamma = \delta c = c - c_o \text{ and } \alpha = \delta a = a - a_o$$

$$\phi_i = \left(\frac{\partial F_i}{\partial c}\right)_o = \frac{-1}{Y - c_o}$$

$$\xi_i = \left(\frac{\partial F_i}{\partial a}\right)_o = \frac{-1}{a_o}$$

but since $\left(\frac{\partial F_i}{\partial a}\right)_o$ is constant for all X_i, Y_i we can write

$$\xi = \left(\frac{\partial F_i}{\partial a}\right)_o = \frac{-1}{a_o}$$

15

$$\therefore \qquad F_i = (F_i)_o + \phi_i\gamma + \xi\alpha$$

We wish to minimise $S = \sum F_i^2$

Now $\qquad S \approx \sum[(F_i)_o + \phi_i.\gamma + \xi.\alpha]^2$

Minimise by making $\frac{\partial S}{\partial c} = 0$ and $\frac{\partial S}{\partial a} = 0$

Now by the chain rule $\frac{\partial S}{\partial c} = \frac{\partial S}{\partial \gamma}\frac{\partial \gamma}{\partial c}$ and $\frac{\partial S}{\partial a} = \frac{\partial S}{\partial \alpha} \cdot \frac{\partial \alpha}{\partial a}$

$$\therefore \qquad \frac{\partial S}{\partial c} = 2\sum \phi_i[(F_i)_o + \phi_i\gamma + \xi\alpha] = 0 \qquad (1)$$

and $$\frac{\partial S}{\partial c} = 2\sum \xi[(F_i)_o + \phi_i\gamma + \xi\alpha] = 0 \qquad (2)$$

From 1

$$\sum\phi_i(F_i)_o + \gamma\sum\phi_i^2 + \xi\alpha\sum\phi_i = 0 \qquad (3)$$

From 2

$$\xi\sum(F_i)_o + \gamma\xi\sum\phi_i + n\alpha\xi^2 = 0 \qquad (4)$$

where $\quad n$ = number of measurements (X_i, Y_i)

These equations can be solved directly:

multiply (3) x $n\xi$ and (4) by $\sum\phi_i$:

$$n\xi\sum\phi_i(F_i)_o + n\xi\gamma\sum\phi_i^2 + n\xi^2\alpha\sum\phi_i = 0 \qquad (5)$$
$$\xi\sum\phi_i\sum(F_i)_o + \gamma\xi(\sum\phi_i)^2 + n\xi^2\alpha\sum\phi_i = 0 \qquad (6)$$

Rearranging gives

$$\gamma n\xi\sum\phi_i^2 - \gamma\xi(\sum\phi_i)^2 = \xi\sum\phi_i\sum(F_i)_o - n\xi\sum\phi_i(F_i)_o$$

thus $$\gamma = \frac{\sum\phi_i\sum(F_i)_o - n.\sum\phi_i(F_i)_o}{n\sum\phi_i^2 - (\sum\phi_i)^2}$$

16

From 5

$$\xi\alpha\sum\phi_i = -\sum\phi_i(F_i)_o - \gamma \cdot \sum\phi_i^2$$

thus $$\alpha = \frac{-\sum\phi_i(F_i)_o - \gamma\cdot\sum\phi_i^2}{\xi\sum\phi_i}$$

$\gamma = c - c_o$ and $\alpha = a - a_o$

$c = c_o + \gamma$ and $a = a_o + \alpha$

c and a become better estimates of c_o and a_o so we let $c_o = c$ and $a_o = a$ and repeat the iterative procedure until, say, both c and a are within 1% of last estimates.