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Air Flow Resistances in Timber Frame Walls

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PAPER 3

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SYNOPSIS

This paper deals with the air leakage paths through timber framed walls of houses built in New Zealand. It identifies three series resistances to air flow corresponding to the external cladding, the underlayer (building paper) and the interior lining. Two types of parallel resistance are identified; one connecting stud cavities to each other and another connecting cavities formed between building paper and the cladding. Various methods were used to measure these resistances to steady air pressure. Although variety in building materials and standard of workmanship contribute to variation in the air flow resistances, a picture has emerged of linings generally forming the plane of highest leakage resistance, but with certain new types of underlayer having the potential of even higher resistance. Weatherboard claddings, which have in the past contributed little to wall airtightness, tend to have become even less airtight in recent times.

1. INTRODUCTION

Little attention has been given in the past to detailed descriptions of the air flow paths in timber framed walls, but there are reasons why these details should be known. The first concerns moisture transport into or away from wall cavities by humid air. Large quantities of moisture can travel this way, which in certain conditions could lead to prolonged high moisture contents in framing timber and eventual decay. Studies of wind driven rain leakage can also make use of component airflow resistances. The trend is towards less airtight rain screen claddings that shed and deflect water without having to resist high wind forces. To be sure that air flows through the less airtight claddings do not drive water inside, many of the airflow resistances must be known. This paper gathers together as much as is known about air flow resistances in domestic timber frame walls in New Zealand.

2. CAVITY WALLS

The external walls of most New Zealand houses are a cavity construction formed by a timber frame, a lining and a cladding. In some regions a brick veneer is the favoured cladding but more generally it is timber or fibre reinforced cement weatherboards. There should be a layer of building paper under the cladding and the cavity will generally contain a thermal insulating material. A vapour barrier such as a polyethylene sheet is not normal practice in urban areas of New Zealand and no special attempt is made to seal air leaks and make buildings more airtight. Fig 1a is a cross section of a cavity wall showing studs and dwangs (horizontal framing). Dwangs are less common in new houses so that wall cavities will run from bottom to top plate unless interrupted by windows or doors.

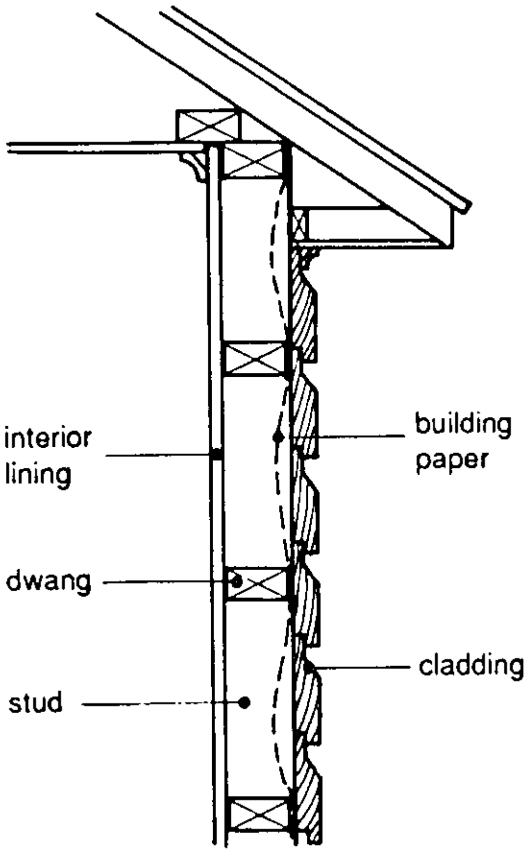


Fig.1a: Side view of wood framed cavity wall

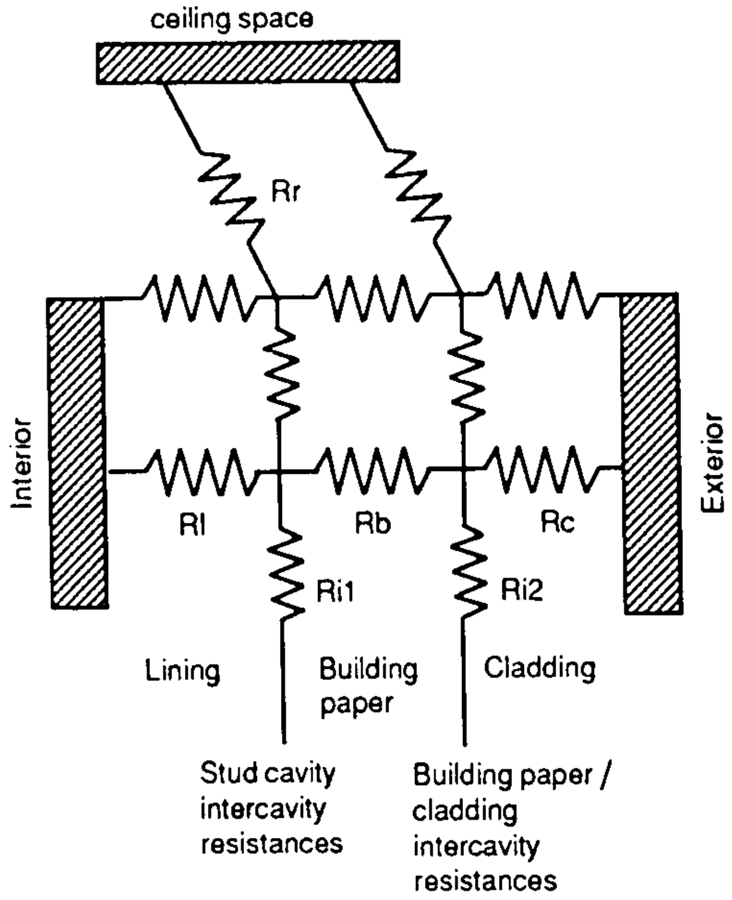


Fig.1bPart of airflow resistance network

Also shown in Fig 1b is a schematic of the air flow resistances through the cladding, lining and the parallel resistances connecting cavities with each other and subfloor and roof space. Five main air flow path types can be identified from Fig 1.

1. Through the cladding (R_c)
2. Through the lining (R_L)
3. Diffusion through the building paper (R_b)
4. Between stud cavity (Type 1 intercavity air flows(R_{i1})
5. Between cavities formed by building paper and cladding (Type 2 intercavity air flows) (R_{i2})

Air leakage and the driving pressure are generally related by the power law equation found in the ASHRAE Handbook[1].

$$Q = C\ \Delta P^n \qquad \ldots \quad (1)$$

$$\text{and} \quad Q = \frac{A\ \Delta P}{R} \qquad \ldots \quad (2)$$

where
Q - air flow rate 1/s
C - flow coefficient
ΔP - air pressure difference Pa
A - area m^2
R - air flow resistance N.s/l
n - exponent

For physical reasons, the exponent must lie in the range $1.0 \geqslant n \geqslant 0.5$. The higher limit of $n=1$ characterises air flow through porous materials. In this case the resistance is conveniently independent of applied pressure. More generally, however, the important air leaks in buildings are at cracks and joints where air flow will be turbulent and the exponent closer to the lower limit $n=0.5$. In these cases the resistance will be a function of the driving pressure as derived from equations 1 and 2.

$$R(\Delta P) = \frac{A\ \Delta P^{(1-n)}}{C} \quad . . \quad (3)$$

In this paper we have elected to report an air flow rate driven by a 50 Pa pressure difference called the Q(50). This allows for easy comparison with New Zealand house airtightness data (Bassett[2]) which is also referenced to 50 Pa. The units used are litres/second (l/s) or litres/second/square meter(l/s.m^2).

Because cavity walls are quite inhomogeneous assemblies of materials, large variations in air flow characteristics should be expected at discontinuities, such as near corners, windows and doors etc. There are also wide variations in building practice and choice of cladding and lining material. For these reasons it is unlikely that a complete set of air leakage resistances can be provided for all situations. The information in the following pages makes a start, by summarising air flow resistances (sometimes with a resolution no better than one order of magnitude) that have been measured in recent years.

3 CLADDINGS

Air leakage characteristics of claddings were measured in the course of rain leakage tests (Bishop[3]) on a wide range of new and traditional systems. The method used for these measurements is described by Bassett[4].

3.1 Cladding Airtightness results

Air flow characteristics for 16 distinct claddings types have been measured. Four were traditional timber and fibre reinforced cement weatherboards and the others were lightweight PVC, or coated aluminium or galvanised steel weatherboards new to the New Zealand market. Air flow characteristics through the cladding in the vicinity of four cavities A - D in Fig 2 were measured for each cladding.

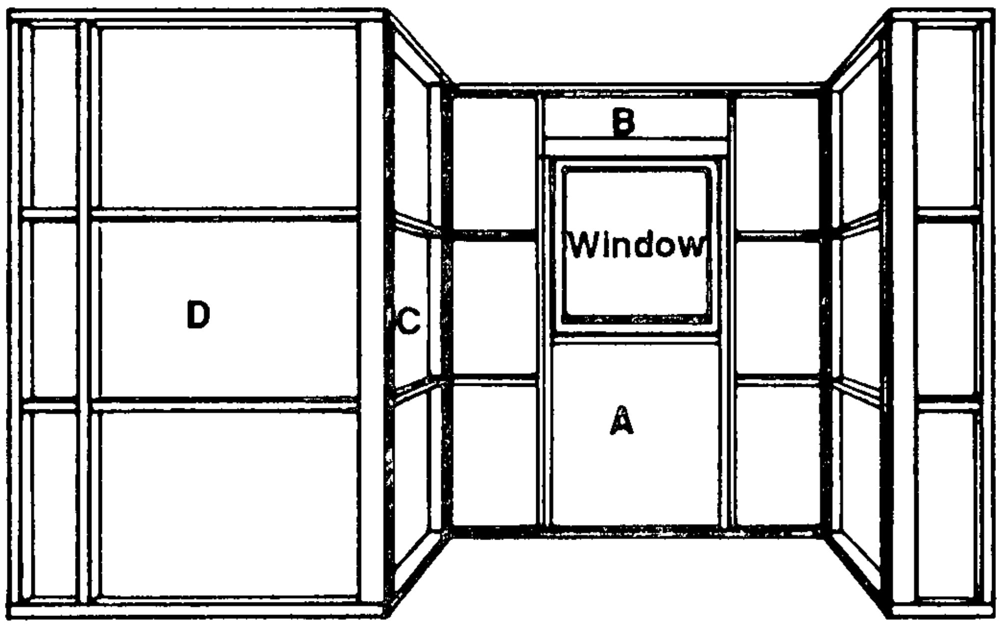


Fig.2: Experimental stud cavity arrangement

Although this arrangement gives a useful comparison of claddings, it does present some difficulty if an average leakage resistance is required for a particular section of wall. This difficulty arrises because leaks at corners and around doors and windows are a large fraction of the total leakage, and the proportions of these vary considerably from one section of wall to the next. Furthermore, the extent of leakage at edges and corners varies from one cladding to the next, which means there is little scope for a simple model of cladding airtightness in terms of wall area and building geometry. Table 1 gives Q(50) flow rates for new and traditional claddings averaged over all four cavity types. The area averaged flow rate given in Table 1 is based on the mean cavity area and should only be taken as a guide because they will include a component of intercavity flow.

Table 1 Cladding leakage rates

Cladding type	Q(50) Flow rates at 50 Pa	
	l/s.cavity	$l/s.m^2$
Wood or fibre reinforced cement weatherboards	26	42
PVC, coated metal	80	130

A histogram of Q(50) flow rates is given in Fig 3 for two classes of cladding and all cavities lumped together. It shows the traditional types to be, on average three times as airtight as the new claddings. Differences in air flow rates through the cavities were generally smaller than the differences between claddings.

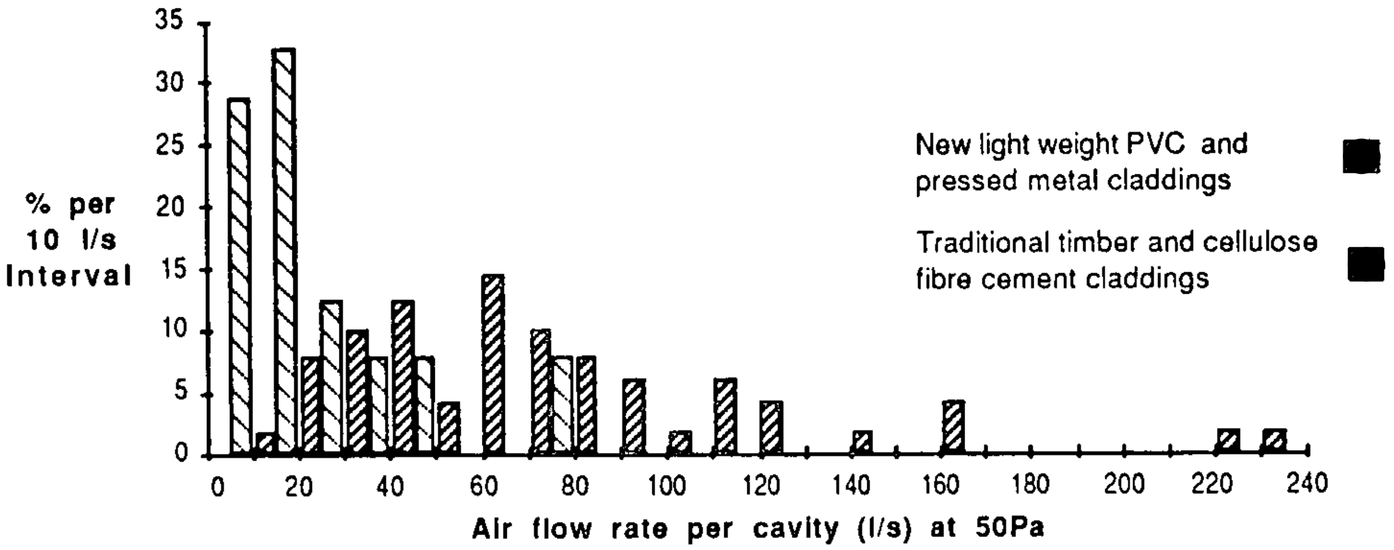


Fig 3 Cladding Airtightness

Traditional claddings are painted in situ and this could make the joints more airtight than on the unpainted laboratory examples. One rusticated timber weatherboard sample was finished with a three coat paint system and this reduced the average Q(50) flow rate by 30%.

3.2 Underlayers

A building paper underlayer must be fixed between cladding and framing in New Zealand houses. This has a large influence on wind driven airflow rates through the cladding into cavities and is seen as a second line of defence against rain leaks. New Zealand Standard 2295[5] requires building papers to have a water vapour flow resistance less than 5.8 MNs/g but the air flow resistance is not specified. A survey of building material air flow characteristics reported by Bassett[6] gives air flow resistances for several "breather papers" available in New Zealand. These appear in Table 2 expressed as Q(50) flow rates for $1m^2$ area of paper and as resistances.

Air flow rates were measured through three claddings with a building paper underlayer in place. The last entry in Table 2 gives the average Q(50) flow rate approximately corrected for $1m^2$ area. As with the diffusion resistance measurements, there were no overlap joints in the test area.

Table 2 Underlayer Airtightness

Underlayer	R MNs/m^3	Q(50) $l/s.m^2$
	Previous air flow resistance measurements	
Building paper - lightweight $0.22\ kg/m^2$ bitumen impregnated	0.03	2
Building paper - same sample as above but soaked in water	0.1	0.5
Building paper - another sample of lightweight bitumen impregnated paper	0.8	0.06
Roofing felt heavy weight $0.63\ kg/m^2$ bitumen impregnated paper	4	0.01
	Measured during cavity wall tests	
Building paper - lightweight $0.19\ kg/m^2$ bitumen impregnated		6

4 INTERCAVITY AIR LEAKAGE

Lateral air leaks between cavities could play a significant role in both dispersion of airborne moisture and the air leaks that can drive rain entry through claddings. Fig 4 identifies two cavities, one formed by the framing and the other between cladding and building paper. It also identifies two types of intercavity air flow labeled type 1 and type 2.

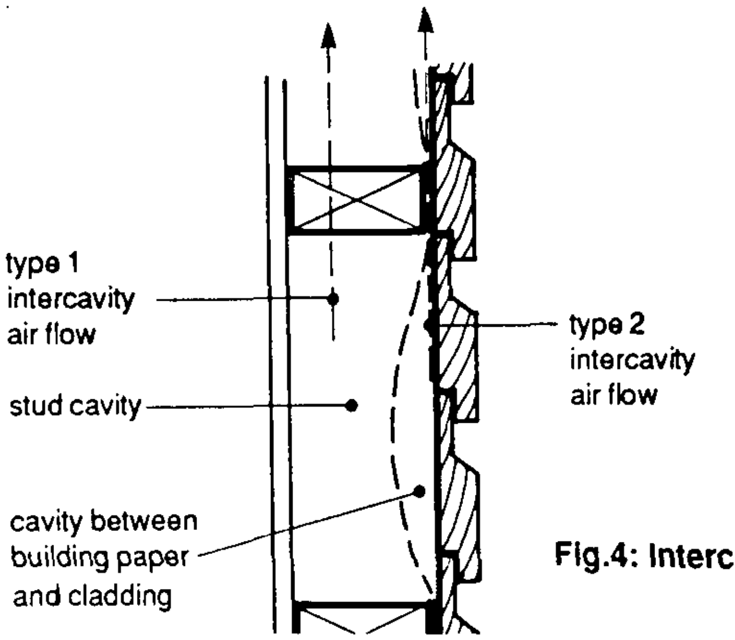


Fig.4: Intercavity air flows

Type 2 air leakage rates between the cavities labelled A-D in Fig 2 were estimated by a method given by Bassett[3]. They are approximate values, being based on an assumed exponent of n = 0.6 which is similar to the exponent found to apply to complete house air leakage[2]. Airflow resistances between these cavities were found to be higher than for leakage through the cladding itself. While cavities A and B in Fig 2 are only one cavity apart in the same wall, the other cavities were separated from each other by a corner. The arrangement of test cavities was chosen this way because there are large differences in wind pressure coefficient near corners of buildings and therefore potentially large intercavity air flows that could drive rain entry. Table 3 gives the pattern of type 2 intercavity air flow rates. These were measured as cavity leakage rates without building paper in place. Because the linings were well sealed on the framing and because the type 1 flow rates are so low, (see Table 4) this should model the cladding/building paper cavity flow rates.

Table 3 Type 2 intercavity flow rates (l/s at 50 Pa)
For cavities formed between building paper and cladding

Cavities	PVC or metal weatherboards Q(50) l/s	Timber or cement based weatherboard Q(50) l/s
In same wall separated by one cavity	36	3.7
Separated by 1 corner	7	2.5
Separated by 2 corners	7	0.4

Table 4 Type 2 and 1 Intercavity flow rates (l/s at 50 Pa) Illustrating effect of adding building paper on air flows between stud cavities

	Type 1+2 A PVC weatherboard cladding without building paper	Type 1 with building paper
Cavities	Q(50) l/s	Q(50) l/s
In same wall separated by one cavity	25	0.03
Separated by 1 corner	16	0.37
Separated by 2 corners	10	0.31

Three significant effects emerge. The first is that type 2 air flows around corners are rather more restricted than between cavities in the same wall. The second is that type 2 intercavity air flows in PVC and pressed metal weatherboard systems were higher than for timber or cement based weatherboards. Finally, with building paper in place as a measure of type 1 air flows, much higher intercavity resistances were encountered.

5 LININGS

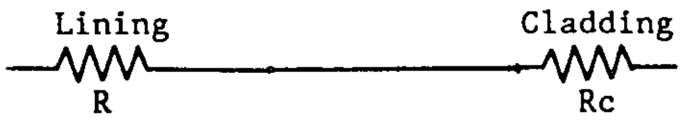
A variety of evidence is given below, in support of interior linings forming the plane of highest leakage resistance in walls and therefore determining the air infiltration rate through walls. This is perhaps to be expected as linings are generally sheet materials with a standard of finish that has to be free from cracks to be visually acceptable. Claddings, on the other hand, are generally interlocking or overlapping boards with therefore greater potential for air leaks.

5.1 Air Tightness Tests

The suggestion that linings might contribute most to wall airtightness came first from an airtightness survey of houses in three major cities in New Zealand[7]. Houses were classified into two categories: "masonry" or "other" according to the materials used for cladding. In the sample of 90 randomly selected houses "other" turned out to be mostly timber or fibre reinforced cement weatherboards and all the "masonry" types were brick or concrete block veneer over timber frame. There was no statistically significant difference in airtightness between the two classes of building, indicating that if claddings contribute to house airtightness, the difference between the two classes is less than a 10% effect. It was considered more likely that the results were similar because claddings play a minor role in wall airtightness.

5.2 Cavity Pressures During Airtightness Tests

A direct way of measuring an average ratio of air flow resistance connecting wall cavities to indoors and outdoors involves simply measuring cavity air pressures while the house is under air tightness test pressurisation. If the network of resistances in Fig 1 can reduced to an equivalent series combination as in Fig 5 then, with assumed flow exponents, a resistance ratio can be calculated from pressure differences measured across cladding and lining.



flow equality → $Cc\Delta Pc^{n_c} = C\,\Delta P^{n_L}$

$$\frac{Cc}{C_L} = \frac{\Delta P_L^{\,n_L}}{\Delta Pc^{\,n_c}} \quad . \; . \; . \; (4)$$

if $R(\Delta P) = \Delta P/Q \qquad R(\Delta P) = \dfrac{\Delta P^{(1-n)}}{C}$

then $\dfrac{Rc}{R_L} = \dfrac{C_L \Delta Pc^{(1-n_c)}}{Cc\Delta P_L^{(1-n_L)}}$

if $n_c = n_L = 0.6$ and both $Rc = R_L$ are at the same reference pressure ie $\Delta P'_c = \Delta P'_L$

then $\dfrac{Rc}{R_L} = \dfrac{C_L}{Cc}$

substituting in 4 $\qquad \dfrac{Rc}{R_L} = \left(\dfrac{\Delta Pc}{\Delta P_L}\right)^{0.6}$

Fig 5 Simplified wall resistance network

Five houses in Lower Hutt were equipped with wall cavity pressure taps before the wall linings were fitted. These taps consisted of 5mm diameter plastic tubes running from the cavities to an accessible termination in the ceiling space. All houses were clad in fibre reinforced cement weatherboards and lined with gypsum plasterboard. A set of cavities of 6 types given in Table 5 were selected in each house and pressure ratios recorded while an indoor/outdoor pressure difference of 50 Pa was maintained with an airtightness test fan mounted in an external door. Pressures were measured with an MKS electronic manometer datalogged and switched between the two pressures at 5 Hz. The margin for experimental error in $\Delta P_c / \Delta P_L$ is considered to be ± 0.02.

Table 5 Cavity Pressure Ratios

Cavity description	Mean $\Delta P_C / \Delta P_L$	Range $\Delta P_C / \Delta P_L$	Mean R_C/R_L
1 Cavity - at least one cavity distant from any joint or protrusion in the lining or external corner.	0.07	0.02 - 0.18	0.2
2 Corner - As above but with one edge on an external corner.	0.03	0.01 - 0.07	0.1
3 Window - As 1 but bordering a window.	0.07	0.01 - 0.17	0.2
4 Top plate - Bordering on the top plate.	0.03	0.01 - 0.08	0.1
5 Bottom plate - A floor level cavity	0.18	0.09 - 0.24	0.4
6 Electric outlet - Containing an electrical outlet	0.05	0.01 - 0.08	0.2
7 Roof space cavity	0.02	0.01 - 0.05	0.1
8 Subfloor crawl space	0.01	0.00 - 0.01	0.1

Cavities bordering on the bottom plate had significantly higher resistance ratios. These could result from air leaks between the lining and bottom plate at a joint which is not stopped because it is covered by a skirting board. More important than this, however, is the low overall value of the resistance ratio, indicating the lining represents the plane of highest leakage resistance in this type of cavity wall construction. Another point of interest was the difference in $\Delta P_c/\Delta P_L$ between adjacent cavities, indicating that significant resistance separates the stud cavities.

5.4 Air Flow Resistances of Materials

Diffusion of air through the solid components of a building (such as its wall lining materials) has the potential to contribute to air leakage rates because the areas involved are orders of magnitude larger than the size of cracks and joints. Air diffusion resistance measurements were made in the laboratory for a range of interior and exterior lining materials and reported by Bassett[6]. A selection of the data relevant to walls is given in Table 6 together with a brief description of each material. The resolution of the data was limited to one order of magnitude by variation between materials of the same description but different batch. The airflow resistance is defined in[7] by equation 5.

$$R = \frac{A\ \Delta P\ 10^{-6}}{Q} \quad \text{MNs/m}^3 \quad . \quad . \quad (5)$$

Where

R = leakage resistance, MNs/m^3,
A = area of material, m^2,
Q = volume flow rate of air, $\text{m}^3\text{/s}$, and
ΔP = air pressure difference across the material, N/m^2

TABLE 6 Bulk air flow resistances of wall lining materials

Material	Coating	Density kg/m^3	Thickness mm	Resistance MNs/m^3
Paper-coated gypsum plasterboard	none	750	9.5	10
	alkyd paint system	"	"	$>10^7$
	acrylic paint system			10^5
	vinyl wallpaper	"	"	10^3
Wood fibreboard low density	prepainted	330	13	1
Wood fibreboard high density	none	1130	5	10
	alkyd paint system	"	"	$>10^7$
	acrylic paint system	"	"	10^4
	varnish	"	"	10^6
Building papers see Table 2				

5.5 Wall lining leakage data from air tightness tests

Many other leakage resistances have been gleaned from house airtightness tests. Mostly the data was obtained by selectively taping over air leaks and remeasuring the whole house leakage characteristics[2]. Table 7 is a summary of leakage resistances measured in wall linings. The data is expressed as Q(50) leakage rates at 50 Pa applied pressure.

Table 7 Leakage Openings in Wall Linings

Leakage at 50 Pa in l/s

Location	Q(50)	Units
Bottom plate: Wood prelaid chipboard floor, Gypsum plaster board wall - Two houses.	0.08	l/s.m
Top plate: Gypsum plaster wall board, wood fibre board ceiling. Mean of two houses (unpainted).	0.3	l/s.m
Window architraves: gypsum plaster wall board overlapped by wooden architrave	0.7	l/s.m
Electrical wall outlet - average	1.0	l/s
Electrical switchboard	10	l/s
Unfinished wall lining behind kitchen joinery (most serious wall lining leak encountered)	12	l/s

On three occasions it was attempted to isolate all detectable leakage openings in a house and arrive at a background leakage rate attributed to invisible cracks and the porosity of materials used in floors, ceilings and wall linings. Table 8 summarises total and background leakage at 50 Pa achieved in 3 houses.

Table 8 Background Airtightness Characteristics of 3 Houses

Characteristic	House A	House B	House C
Total house leakage at 50 Pa in ac/h	5.05	4.64	10.0
House leakage with all locatable leaks blocked	2.47	2.12	1.62
Building enclosed volume m^3	227	210	377
Building shell area m^2	298	288	410
Shell area averaged Q(50) $l/s.m^2$	0.52	0.43	0.41

Although the buildings concerned were quite different sizes, styles and of different cladding materials, the background leakage was similar in each case.

6 SUMMARY OF WALL AIR FLOW RESISTANCES

A picture of air flow resistances in walls has emerged which can be summarised with the help of Fig 6 as follows:

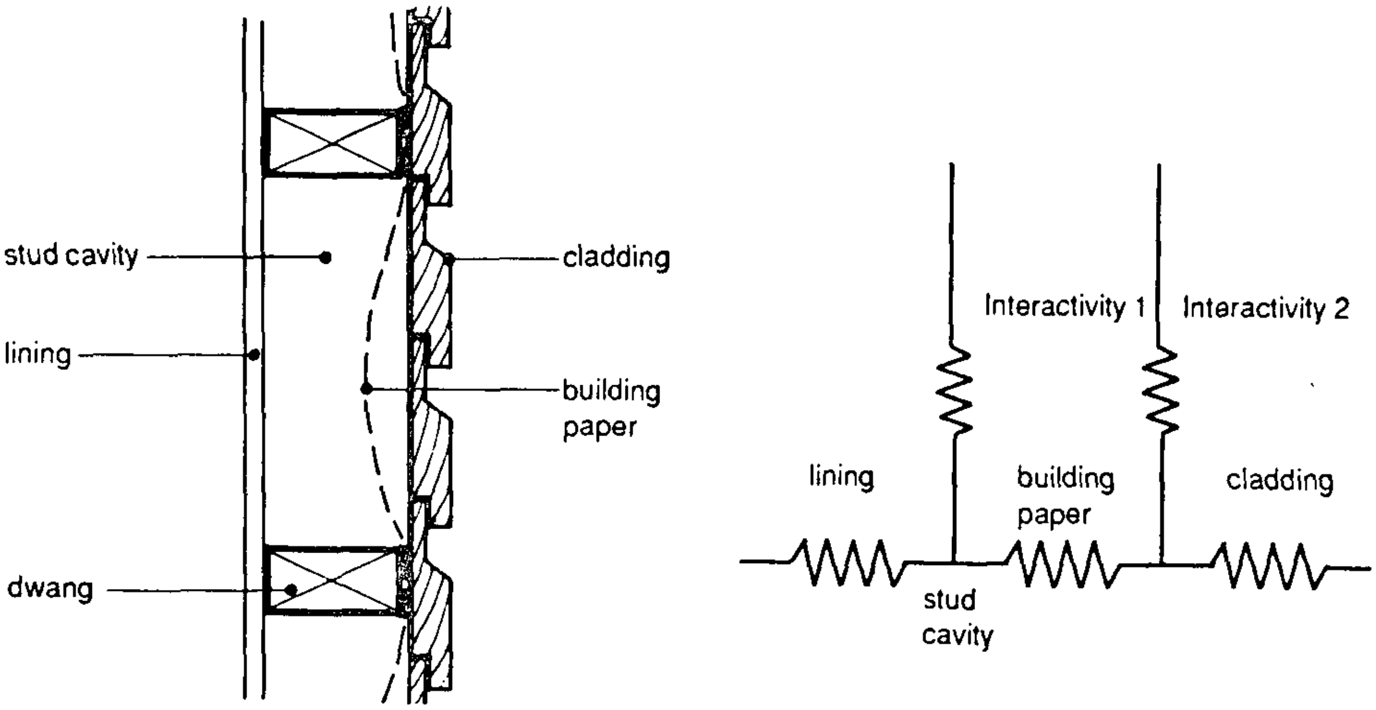


Fig.6: Arrangement of air flow resistances in timber framed wall

Table 9 gives the best estimates for components of the network of airflow resistances in walls. The units are l/s per m^2 wall area driven by 50 Pa air pressure unless otherwise indicated.

Table 9 Summary of Air Flow Path Magnitudes

Air flow path	Origin	Q(50) l/s.m^2 Max	 Best estimate	 Min
Wall linings	cracks	1.0	0.6	0.2
	background		0.5	
	diffusion	0.005		
	total		1.1	
Intercavity 1 (frame cavity)	adjacent		0.03 l/s	
	around corner		0.4 l/s	
Building paper (BP)	no joints	6	6	0.5
Intercavity 2 PVC or metal (BP to cladding)	adjacent		40 l/s	
	around corner		7 l/s	
Intercavity 2 timber or cement (BP to cladding)	adjacent		4 l/s	
	around corner		2 l/s	
Wall claddings	Timber, Fibre reinforced cement		42	
	PVC Metal		130	

Notes relating to Table 9

Wall linings - In the "Max" case, the area averaged Q(50) flow rates are based on all air leaks at top and bottom plate passing through the cavity. In the "best estimate" case the fraction is 50% and in the "Min" case it is 0%.

Intercavity 1 - This intercavity air leakage path has a high resistance with building paper in place and air pressure holding it against the studs. For pressure applied the other way or, with overlap joint present in the paper, the resistance could be lower.

Building paper - With heavier papers than normal, the resistance at this plane in the wall could exceed the lining resistance by orders of magnitude. More information is needed on the effect of joints and sensitivity to workmanship detail.

Intercavity 2 - These resistances depend very much on cladding type - in particular, on how tight a seal the weatherboards make against the framing.

Claddings - The air leakage resistance is more a factor of cladding type and proximity to corner and edge details than on surface area. Traditional weatherboards nailed in tight contact and with scribers at door and windows were more airtight than newer claddings in PVC or pressed metal which clip together.

7 CONCLUSIONS

First order estimates of flow characteristics have been provided for many of the air flow paths in timber framed walls. In spite of there being a wide range of building material combinations the following observations can be made.

1 The plane of highest leakage resistance for walls with weatherboard claddings, building paper, and gypsum plaster linings is the linings.

2 Building paper is the next most significant air barrier provided it can be made airtight at the joints.

3 New PVC and pressed metal weatherboards are less airtight than more traditional timber or cement based weatherboards. This need not mean the former are more prone to rain leaks.

4 Intercavity air leaks (about which comparatively little is known) tend to be blocked at corners. The resistance between stud cavities can be high enough to support appreciable pressure differences.

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