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Air Permeability of some Australian Houses

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The paper reports the first air permeability measurements carried out on Australian houses. Permeability was measured by the fan pressurization method. Comparison is made with results obtained in other countries. Variation between types of houses is discussed on the basis of measured leakage of components in an experimental building. Methods of predicting the permeability of houses are considered and an empirical approach is adopted. The cost effectiveness of house-tightening measures is discussed.

1. INTRODUCTION

A CONSEQUENCE of the mildness of the climate in the regions containing the majority of the population in Australia is that little attention has been paid in this country to infiltration of air into houses, i.e. the leakage of air, by natural means, beyond the control of the occupant. However, in recent years, rising energy costs have focused attention on energy losses due to air infiltration, and have stimulated interest in the infiltration rates prevailing in Australian houses.

Infiltration rates are usually determined by tracer gas techniques. Values for single rooms in some Australian houses were reported nearly twenty years ago [1]. More recently, we have measured whole-house infiltration rates, to be used for energy and indoor air quality studies. A paper on this work is being prepared by the authors. Determining the air infiltration characteristics of a house is a time-consuming process, since measurements are needed for many wind speeds and directions. For a given set of climatic and shelter conditions, air infiltration rates of houses with controllable openings closed depend on the fundamental permeability to air flow of the house envelopes. Envelope permeability can be readily measured by applying artificial conditions such as a constant internal net pressure using the fan pressurization technique (see, for example, refs [2, 3]).

We have measured the permeability of the houses for which air infiltration rates were determined, and for others covering a range of types. These measurements were carried out in order to gain an appreciation of how 'leaky' Australian houses are, compared with those built in other countries, and to consider the potential value, in the Australian context, of 'house-tightening measures' for reducing air infiltration.

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2. DESCRIPTION OF HOUSES

The 33 houses included in this study were made available through the cooperation of three building firms, the Ministry of Housing, Victoria, the Housing Commission of New South Wales, and five private householders. The set of houses comprised four houses more than 30 years old and 11 contemporary houses representative of those built in the temperate south-eastern part of Australia where over 50% of the population lives: three passive solar houses; a group of 12 houses constructed for an experimental solar village development together with two houses serving as experimental controls; and an experimental, one-room 'house'. Brief details of these houses are given in Table 1.

The most common type of house currently being built in south-eastern Australia is a detached, single-storey dwelling of brick-veneer construction, which consists of a timber frame lined on the inside with plasterboard and clad on the outside with a single leaf of brickwork. The ceiling is of plasterboard while the floor may be concrete slab-on-ground or suspended timber. These houses incorporate fixed ventilation in 'wet areas' and, in the State of Victoria, until very recently it was mandatory that there be fixed ventilation in all habitable rooms as well. The latter requirement was usually met by installing in each room one or more fixed wall vents each typically having an open area of about 0.01 m^2. Twelve of the houses in the present study were of this kind.

Some houses of full brick or concrete masonry construction were included in the study. The external walls consisted of two leaves of brickwork 50 mm apart, while the internal walls were of single leaf brickwork. In some houses the wall cavities were filled with urea formaldehyde foam. In houses 14, 15 and 16 ventilation was provided by slots above every window, while in house 17 ventilation openings in the form of unfilled vertical mortar joints were provided in the bedrooms and the living room.

Two of the older houses were of full brick construc-

Table 1. Details of houses and values of $Q(50)$, the flow rate for a pressure difference of 50 Pa, and the flow exponent

House No.	Type of house	No. of vents	Floor area (m^2)	Surface area (m^2)*	Volume (m^3)	$Q(50)$ ($m^3\ h^{-1}$)	Exponent, n
1	Cavity brick, timber floor, insulated ceiling	12	136	469	399	5170	0.61
2	Cavity brick, timber floor	12	116	381	331	6230	0.65
3	Timber frame clad with 'weatherboards', timber floor	12	83	273	221	5940	0.64
4	Brick veneer, timber floor	14	113	345	292	8640	0.62
5	Brick veneer, timber floor	12	105	319	252	7390	0.61
6	Brick veneer, timber floor	12	105	319	252	6080	0.59
7	Brick veneer, timber floor	12	105	319	252	6320	0.59
8	Brick veneer, timber floor	12	105	319	252	6760	0.62
9	Brick veneer, timber floor (split level)	12	135	374	315	7920	0.58
10	Brick veneer, timber floor	12	112	338	270	6600	0.58
11	Brick veneer, timber floor	14	135	396	324	10,200	0.63
12	Brick veneer, timber floor	12	107	325	253	6990	0.60
13	Brick veneer, timber floor	11	110	226	264	6080	0.61
14	Cavity concrete masonry, concrete floor, flat roof, ventilation slots above windows	†	157	297	360	23,300	0.76
15	Cavity brick, concrete floor, flat roof, ventilation slots above windows	†	144	311	329	8520	0.57
16	Double brick (urea formaldehyde in cavity), concrete floor, flat roof, ventilation slots above windows	†	144	253	329	7270	0.63
17	Double brick (urea formaldehyde in cavity), concrete floor, fixed ventilation via unfilled mortar joints, doors and windows weatherstripped	12	95	190	217	5920	0.62
18	Brick veneer with glass fibre insulation in walls and over ceiling, concrete floor	0	105	209	252	4390	0.63
19	Timber frame with fibre-cement sheeting, particle-board floor	18	95	295	228	5000	0.59
20	Brick veneer, particleboard floor	4	72	266	172	3900	0.57
21	Double brick (urea formaldehyde in cavity), particle-board floor	2	72	251	163	3380	0.57
22	Brick veneer, concrete floor	1	72	179	172	2430	0.57
23	Timber frame with fibre-cement sheeting, concrete floor	1	95	295	228	1800	0.57
24	Timber frame with fibre-cement sheeting, concrete floor	3	84	202	226	2550	0.63
25	Timber frame with fibre-cement sheeting, concrete floor	1	84	202	226	2190	0.59
26	Double brick (urea formaldehyde in cavity), concrete floor	3	92	214	251	2800	0.68
27	Double brick (urea formaldehyde in cavity), concrete floor	2	92	214	251	2370	0.67
28	Timber frame with fibre-cement sheeting, concrete floor	3	102	282	269	3380	0.55
29	Mixed brick veneer and timber with fibre-cement sheeting, concrete floor	1	89	228	258	1930	0.75
30	Timber frame with fibre-cement sheeting, concrete floor	2	90	225	239	3710	0.59
31	Mixed brick veneer and timber frame with fibre-cement sheeting, concrete floor	1	82	172	196	1710	0.67
32	Double brick (urea formaldehyde in cavity), particle-board floor (split level)	3	97	341	284	5180	0.60
33	Single room of brick-veneer construction, timber floor, insulated ceiling	4	36	131	87	750	0.59

*Excludes floor area when floor is concrete.
†Non-standard fixed ventilation.

tion, one was of brick-veneer and the fourth was of 'weatherboard' construction in which the outer cladding consists of overlapped horizontal timber planking. All these houses had the conventional wall vents already mentioned.

The houses of the solar village were built in a variety of styles and materials. Important differences between these houses and most of the other houses in the study were the absence of wall vents, the use of well-fitting aluminium framed windows, and the provision of weatherstripping on the two exterior doors. The brick-veneer houses which served as 'controls' for the village were typical of two standard types of houses built for the Housing Commission of New South Wales. They had wall vents and unweatherstripped exterior doors.

House 33, an experimental facility built in the grounds of the Division of Building Research for ventilation studies, was of conventional brick-veneer construction but consisted of a single room with dimensions approximately $7.5 \times 4.7 \times 2.4$ m. It had four typical wall vents of open area 0.01 m^2 each, one door, and four different types of window each about 1.5 m^2 in area. The windows re double wooden awning, double wooden sash, double :minium sash, and horizontally sliding aluminium.

3. APPARATUS AND EXPERIMENTAL PROCEDURE

In the fan pressurization method of determining per- :ability, the air flow rates required to maintain given :ssure differences between indoors and outdoors are :asured, and from these data the flow rate for a stan- :rd pressure difference can be found. To allow com- :rison of houses of different sizes, the flow rate at the ndard pressure difference is normalized by dividing by her the volume of the house or by the surface area of : building envelope.

The apparatus used in this study, described by Michell d Biggs [4] and shown schematically in Fig. 1, incor- rated a three-quarter radius flow meter [5], which indi- ed mean velocity head, a variable speed axial fan, d pressure transducers for measuring the velocity head :icated by the flowmeter and the pressure difference :ween indoors and outdoors. The flowmeter and the : were mounted in a duct which was coupled to the use by means of an adjustable door panel.

From Bernoulli's theorem, the relationship between ocity head, P_v, and air speed, V, is $P_v = 0.5\,\rho V^2$, where s the density of the air. This can be written as

$$V = 2.40(P_v T/B)^{0.5},$$

:ere V = mean air speed (m s^{-1})
P_v = mean velocity head (Pa)
T = mean air temperature (K)
B = atmospheric pressure (mbar).

Multiplying by the cross-sectional area of the duct in : and by 3600 gives the flow rate, Q, in m^3 h^{-1}.

The experimental procedure involved determining the :an velocity head for five positive and five negative lues of the pressure difference, equally spaced to the :it of the fan. The pressure difference was taken as sitive when the pressure indoors exceeded that itdoors. The flow rate at a standard pressure difference 50 Pa was then calculated as described in Section 4.

In order that the measurements yield information out the building envelope in its least permeable con- :ion compatible with building regulation require- ments concerning fixed ventilation, houses were prepared for testing by masking, or otherwise sealing, any chimneys, vents on heating appliances, and ceiling vents in laundries, bathrooms, and kitchens, but leaving wall vents unmasked. All windows were closed and all plumbing water traps sealed. All internal doors were open during the tests with the exception of toilet doors. This is the standard procedure adopted by other workers in this field and facilitates comparison of results.

4. CALCULATION OF PERMEABILITY PARAMETERS

Volume flow rate and pressure difference can be related by the empirical expression

$$Q = C(\Delta P)^n,$$

where Q = flow rate
ΔP = pressure difference
C, n = constants.

The values of C and n for each house were determined from a linear regression of log Q against log ΔP, which yielded log C as its intercept and n as its gradient.

When the data for positive and negative pressure differences were treated separately for a given house, it was often found that the constant C differed significantly between the two conditions. This finding is commonly attributed to leakage paths such as window cracks opening or closing according to the sense of the applied pressure differences (see, for example, ref. [3]).

However, to characterize a house simply, a single expression was desired. Consequently, for each house, a multiple linear regression was carried out of log Q against both log ΔP and a dummy variable which took the value +1 for positive and −1 for negative pressure differences. This procedure assumed that the exponent n was the same for both positive and negative pressure differences, which was generally true. By selecting the median value of the dummy variable, representative expressions for the volume flow rate as a function of the pressure difference were obtained for each house.

To enable comparison between houses, the volume flow rates at a common pressure difference were divided by either the volume enclosed by the building envelope or by the surface area of the envelope. The former quo-

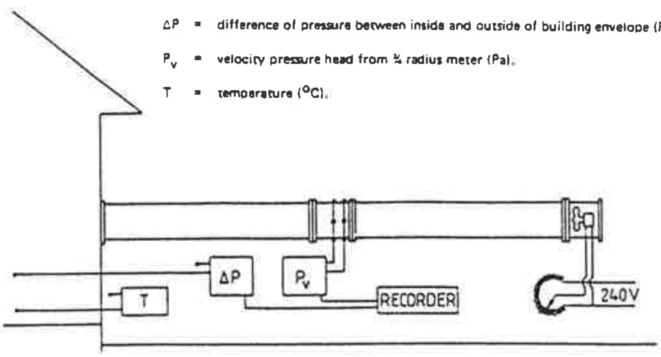

Fig. 1. Schematic arrangement of apparatus used for permeability measurements.

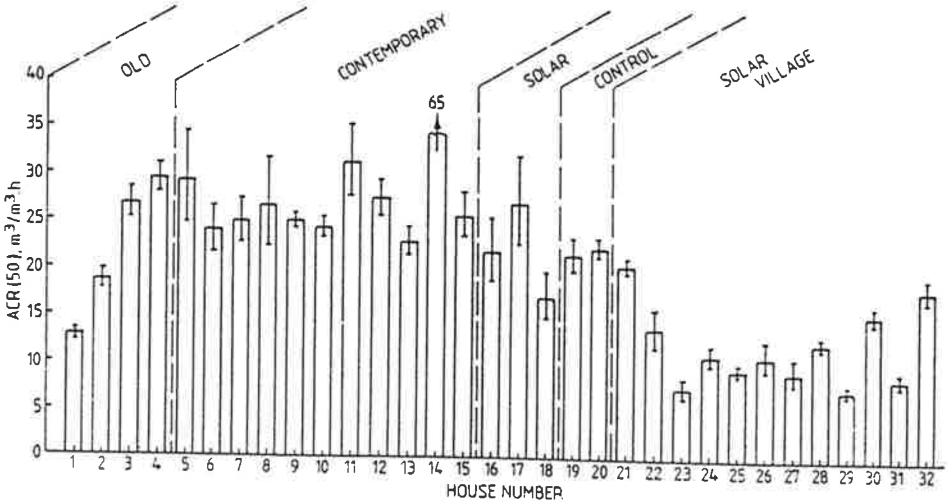

Fig. 2. Estimated values and 95% confidence intervals of the permeability parameter ACR(50) for the houses tested.

tient is called the Air Change Rate (ACR). It is expressed in cubic metres of air per hour per cubic metre of house volume ($m^3\ m^{-3}\ h^{-1}$), and yields information relevant to energy consumption and indoor pollution. The latter quotient is called Specific Air Leakage (SAL). It is expressed in cubic metres per hour per square metre of permeable surface area of the building envelope ($m^3\ m^{-2}\ h^{-1}$), and gives information about the lack of integrity of the envelope. In accordance with common international practice, the pressure difference adopted here was 50 Pa. The values at 50 Pa of the two parameters defined above are indicated by the terms ACR(50) and SAL(50).

The volume of the house was taken as the volume between the indoor surfaces of floor, ceiling, and internal perimeter walls, with deduction for those volumes such as solid internal partition walls and water closets which are isolated, but with no deduction for hollow (frame and plasterboard) internal partition walls and built-in fittings such as kitchen cupboards.

The surface area of the building envelope was taken to be the sum of the areas of the surfaces defining the indoors, namely the gross floor area, the gross ceiling area and the area of the internal surfaces of the perimeter walls between floor and ceiling. However, for houses in which the floor was a continuous concrete slab, the floor area was not included since it could be regarded as impermeable.

5. RESULTS AND DISCUSSION

5.1 *Whole house results and international comparison*

For each house, the flow rate at a pressure difference of 50 Pa, $Q(50)$, was calculated from the expression obtained by multiple regression. This value, and the flow exponent, n, are given in Table 1 along with dimensional data for each house. From these data the values of the permeability parameters ACR(50) were calculated. The estimates and 95% confidence intervals for the values of ACR(50) are shown in Fig. 2. The estimates of the values of SAL(50) are plotted in Fig. 3. For the more permeable

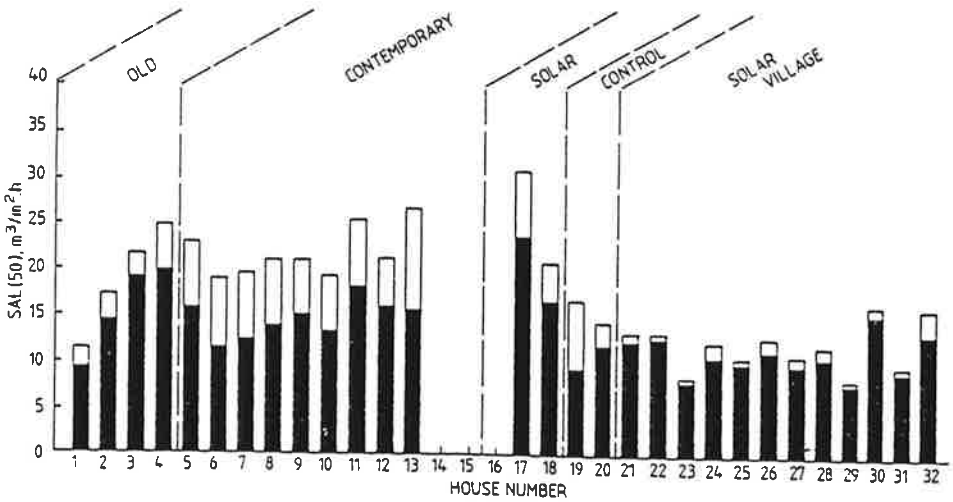

Fig. 3. Measured SAL(50) values and corresponding reduced values following deductions to simulate the effect of changing to standard construction features, namely concrete floor, aluminium-framed windows, weatherstripped doors and no fixed vents. (Excludes houses 14–16: see text.)

ｓ. where the fan lacked the capacity to generate the ıtes needed to establish a 50 Pa pressure difference, necessary to extrapolate from as low as 20 Pa in to obtain estimates of $Q(50)$. It was found, contrary rmal expectations, that the ratio of the 95% con- e intervals to the estimated value of $Q(50)$ was only y greater in these cases than in those for which olation was unnecessary.

houses have been grouped as indicated in Fig. 2. 33, the one-room experimental facility, will be sed only in relation to component leakage.

ıse 14 was exceptionally leaky and the data ıed for this house have not been included in analysis nodelling calculations. It is considered that its ıely high permeability is due to unusual and very forms of fixed ventilation and ceiling construction. xed ventilation openings take the form of wide, tructed slots above each window. Measurements ıted that the leakage due to this cause alone was than the total leakage of any other house in the The ceiling construction was also potentially very It consisted of plasterboard sheets fixed to battens en exposed ceiling beams. The length of cracks cting to the roof space arising from this form of uction was of the same order as the sum of all other cracks in the house envelope.

average values of the air change rate at 50 Pa (50)] for the two major groups were 26.3 $m^3 m^{-3}$ S.E.M. 0.9) for the contemporary houses excluding ypical house 14, and 12.2 $m^3 m^{-3} h^{-1}$ (S.E.M. 1.2) houses of the solar village.

s interesting to compare these results with those ıed from studies in other countries (Table 2). The permeability value for the contemporary houses d was approximately double the values quoted for Zealand [6], the Netherlands [7], and the U.K. [8]. atter values are themselves approximately treble quoted for Canada [8] and Sweden [3]. This ranking s the fact that, in the countries with more severe climates, greater attention is paid to reducing air ation.

solar village houses, which were designed and ructed to be less permeable than comparable con- orary housing, demonstrated ACR(50) values simi- those cited for New Zealand, the Netherlands, and K., i.e. they were on average only half as permeable se of the contemporary group. This was achieved y by the elimination of fixed wall vents, the use of sliding aluminium windows and in most houses a concrete floor slab, and by the weatherstripping of exterior doors.

The other solar houses, which were not part of the solar village, were more permeable than similar houses in the village, due mainly to the presence of numerous fixed vents in houses 16 and 17, and to the use of unweatherstripped windows in house 18.

Of the older group, the weatherboard and brick-veneer houses (3 and 4) had permeability values similar to those of the contemporary houses, but the cavity-brick houses (1 and 2) were substantially less permeable. In the latter houses the standard of maintenance was such that visible construction cracks were effectively sealed, and the windows were tight fitting when closed.

The permeability values of the two typical non-solar houses serving as controls for the solar village were similar to but slightly lower than the mean permeability for the contemporary houses. It is considered that this was due to the windows being of the low leakage, aluminium type.

Before proceeding further with comparisons between houses and groups of houses, it is useful to examine the results of the measurements on the air leakage of house components.

2. Comparison between mean ACR(50) values for Australia and those for other countries

ountry	Ref.	No. of houses	Mean ACR(50) ($m^3 m^{-3} h^{-1}$)
ılia:			
ıtemporary	—	10	26.3
ır village	—	12	12.2
Zealand	[6]	40	11
rlands	[7]	130	12
	[8]	19	13.9
ıa	[8]	60	4.4
n	[3]	205	3.7

5.2 *Component leakage*

An indication of the contribution to the total leakage made by individual components was obtained through measurements on house 33, the experimental facility. The building was first thoroughly sealed and the leakage through individual components was determined by noting the increase in flow rate when the sealing was removed from only that component. The results, summarized in Fig. 4, are expressed as air flow rates ($m^3 h^{-1}$) and as percentages of the total flow rate, for groups of components, at a positive pressure difference of 50 Pa. The wall vents, and to a lesser extent the closed windows with their attendant architraves, are the major breaches in the integrity of this envelope, but the door, which was

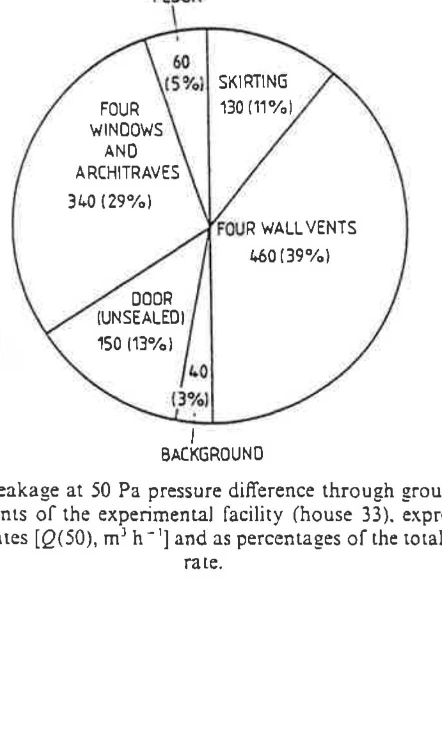

Fig. 4. Leakage at 50 Pa pressure difference through groups of components of the experimental facility (house 33), expressed as flow rates [$Q(50)$, $m^3 h^{-1}$] and as percentages of the total flow rate.

fitted with a rain screen at the bottom, and the wall-to-floor (skirting) junction also provided paths for air leakage under pressurization. Leakage through the suspended timber floor itself, as distinct from the leakage through the skirting junction, was relatively small, being comparable with the background leakage persisting when all obvious leakage paths had been sealed. Covering the floor with closely fitting carpet tiles manufactured with an impermeable backing effectively sealed it.

The average air leakage through each of the four wall vents was 115 $m^3 h^{-1}$. This is likely to be an overestimate for older houses since the insect screens incorporated in the vents tend to be gradually blocked with dust, and by paint if the screen is close to the indoor surface of the vent.

The leakage rates for the separate windows and their architraves were wooden awning 190, wooden sash 70, aluminium sash 60, and horizontally sliding aluminium 20 $m^3 h^{-1}$. Obviously these figures, based on only one example of each type, can give only an indication of the order of performance of a given window type.

The effect of weatherstripping the door was investigated. A nylon-pile strip around the door stop reduced the air leakage from 150 to 25 $m^3 h^{-1}$ at 50 Pa pressure difference.

The leakage data obtained from these measurements were analysed in terms of air flow per unit crack length for skirtings, architraves, and opening cracks of doors and windows, both weatherstripped and unweatherstripped. It was found that the values of the leakage parameter fell into two distinct classes. The cracks whose leakage values fell into the higher class comprised unweatherstripped door and wooden awning window opening cracks. Although the two classes were broad, representative values of 24 $m^3 h^{-1} m^{-1}$ and 4 $m^3 h^{-1} m^{-1}$ were adopted for use in subsequent crack modelling.

5.3 *Variation between groups of houses*

The component leakage data discussed in Section 5.2 were used to account for the observed differences in the envelope permeability values [SAL(50)] for the several groups of houses. To estimate the leakage flow rate after elimination of the wall vents in a given house, the observed flow rate at 50 Pa pressure difference was reduced by 115 $m^3 h^{-1}$ for each wall vent except for the four old houses where the allowance was halved to account for partial blocking of the vents. Similarly, the difference in leakage between unweatherstripped wooden awning and weatherstripped sliding aluminium windows, and between unweatherstripped and weatherstripped doors was allowed for by reducing the air flow at 50 Pa by 20 $m^3 h^{-1}$ per metre of door and window opening crack. These adjustments were made for all houses except houses 14, 15 and 16, which incorporated unusual types of fixed ventilation for which no component leakage data were available.

The SAL(50) values calculated from the reduced flow rates are given in Fig. 3. The values were averaged for the five groups of houses and the results compared. Differences between the solar village and the other groups still remain, but they are much reduced. The mean SAL(50) for the solar village, 12.2 $m^3 m^{-2} h^{-1}$, was reduced to 11.1, a relatively small change since most of these houses already incorporated the constructional features for which allowance was made. The reductions were greater for the other groups of houses, namely, old houses, 18.5 to 15.8; contemporary, 22.0 to 14.8; solar, 26.1 to 20.4; control, 15.8 to 10.8. The average value of SAL(50) for all houses except the solar village was reduced from 21.0 to 15.2 $m^3 m^{-2} h^{-1}$, while the average for the houses of the solar village decreased from 12.2 to 11.1 $m^3 m^{-2} h^{-1}$, as stated. Thus the leakage data of the components considered account for a substantial portion of the spread of the SAL(50) values obtained.

Other differences in construction, such as the presence of extensive wall and ceiling insulation in the solar village and the quality of the workmanship involved (the builder took unusual pains over the detailing of the houses of the solar village), would be expected to account for a further portion of the difference in means, but data were not available to evaluate these effects.

5.4 *Prediction of total leakage*

In an attempt to predict the total leakage of a house, the number of fixed vents, the type and opening crack length of windows and doors, and the length of architrave, skirting, and cornice cracks were estimated from the plans. Weatherstripping was also taken into account. For the 24 houses for which crack length data were available, between 44 and 95% of the total leakage could be accounted for, the mean value being 64%.

Reported values of the percentage of the total leakage that could be ascribed to identifiable leakage paths vary widely. Etheridge and Phillips [9] accounted for 80% of the leakage in 10 separate rooms. Warren and Webb [10] found an average value for 19 houses of 40%, and Ward [11], studying two different types of houses, could account for only 30% of the leakage. The average of 64% in the present work is higher than the values cited for houses, but lower than the figure for single rooms.

The component leakage factors used above were derived from measurements on only one building (house 33). It was thought that by using the data for all the houses in the study better estimates of the leakage factors might be derived. Accordingly, a multiple regression analysis was undertaken, but no meaningful fit was obtained. This was attributed to the small sample size, confounding of the floor type with the two main groups of houses, and limited variation within each housing group of the number of fixed vents.

5.5 *Empirical model*

In view of the above lack of success in predicting the total leakage of the houses, it was decided to use an empirical approach to model the leakage of the 15 non-solar houses for which the relevant crack data were available. The reduced SAL(50) values determined in Section 5.3 were estimates of the SAL(50) of a nominal 'low leakage envelope' incorporating low leakage windows and weatherstripped doors but no fixed vents. The mean of the reduced SAL(50) values for the non-solar houses for which crack data were available, was 14.5 $m^3 m^{-2} h^{-1}$.

The model predicts the SAL(50) value of a house on the basis of the extra leakage due to features of its envelhich differ from those of the 'low leakage envelope'. the data from Section 5.2. extra leakage at 50 Pa ıre difference of 115 $m^3\ h^{-1}$ per vent is allowed for fixed vent. and 20 $m^3\ h^{-1}$ per metre of opening for unweatherstripped doors and wooden awning ›ws. Thus.

$$SAL(50) = 14.5-(115N+20L)/S$$

SAL(50) is expressed in $m^3\ m^{-2}\ h^{-1}$.

= number of standard fixed vents
= length. in m. of unweatherstripped door and wooden awning opening cracks
= permeable surface area of the house envelope. m^2.

confidence limits for the estimated value ol ·0) for a given house would be derived from the ility of the estimate of the value of SAL(50) for the akage envelope plus the variability in the allow- for the extra leakage attributed to the components ered. If no account is taken of the variability in the :e through wall vents. weatherstripped and un- erstripped doors and windows. the 95% confi- interval for the SAL(50) value for a particular would be $\pm 2.4\ m^3\ m^{-2}\ h^{-1}$. or $\pm 12\%$ when the ·0) value is 20.3 $m^3\ m^{-2}\ h^{-1}$ (the mean value for n-solar houses). The confidence interval would be if the variability of the leakage through com- ts were taken into account. but more work would ded to estimate that variability.

ıuse tightening—retrofitting and new construction

permeability values reported here are high by itional standards. which indicates that much envelopes could be achieved. either by 'retrofit' res for existing houses or by modifications to build- actices for new houses. However. measures to permeability are unlikely to be attractive to home s and the housing market in general unless the costs ementing them can be recouped within a few years. present Australian context of energy costs. heating ments. and costs of materials and labour. only the xpensive measures warrant consideration. Even appear marginal as the following shows.

sider a brick-veneer house. internal volume 252 th a suspended timber floor. 12 fixed wall vents -mm-thick glassfibre insulation over the ceiling. In ance with the procedure described in Section 5.5 estimated that by eliminating fixed wall vents and atherstripping doors and windows. the ACR(50) would be reduced by about 30%. By use of the l modelling program ZSTEP3 [12], Dr A. E. ite of the Division of Building Research (private ınication) calculated that for this house. built in urne and heated throughout for 24 h per day to atures between 16 and 21°C according to the time . a 30% reduction in the average air infiltration om 0.58 to 0.41 air changes per hour, would result duction of the annual heating energy requirement 2.9 to 41.2 GJ. a decrease of 4%. If the heating were supplied by electricity at 2.33 cents/MJ 0% efficiency. there would be cost savings of er year. but with natural gas at 0.48 cents/MJ and 70% efficiency. the saving would be only A$13 per year.

Since the estimated costs of materials and labour for the weatherstripping alone would be about A$45 and A$60 respectively. and sealing wall vents would entail further expense. it can be seen that only when the owner does the work himself would even this first stage of retro- fitting be attractive. Additional measures. such as sealing architraves and skirtings. and installing automatic louvres on exhaust fans. would be even less cost effec- tive.

There may be slightly greater justification for house- tightening steps at the building stage. Installing low-leak- age windows and exhaust fans with automatic louvres would achieve reduced permeability more cheaply than a retrofit operation. and fixed wall vents would simply not be inserted. Concrete floor slabs might be economically justified in otherwise marginal situations by virtue of their impermeability. When a suspended timber floor is used. platform construction. in which the whole floor is laid prior to the erection of wall frames. has the advan- tage of reduced leakage at the skirting junctions. Sheath- ing timber frames with reflective foil laminate for thermal purposes will tend to reduce permeability somewhat. further justifying its use. but there is no economic justification for adopting the stringent sealing pro- cedures recommended in some countries with severe winters (see. for example. ref. [13]).

6. CONCLUSIONS

This study has provided the first measured values of the permeability of some Australian houses. The values for houses typical of the building stock in the populous south-eastern part of Australia are high by international standards. being approximately double the values quoted for houses in the U.K.. the Netherlands. and New Zealand. and about six times those reported for houses in Sweden and Canada.

Crack and component leakage data obtained from measurements in a test building and from comparison of houses indicated that the principal sources of leakage are fixed wall vents. unweatherstripped doors and wooden awning windows. and suspended timber floors. with architrave. skirting. and other cracks contributing to a lesser extent. It was found that these data could account for the majority of variation between types of houses.

Attempts to use these data to predict permeability from house plans were not convincing and an empirical approach was adopted. An empirical model was developed for which the 95% confidence interval for SAL(50). at average permeability values. was $\pm 12\%$. when no account was taken of the variability in the leak- age through wall vents. weatherstripped and unweather- stripped doors and windows. Further work is required to determine the variability of the leakage through these components.

Cost/benefit considerations suggest that. from an energy point of view. retrofit house tightening would be only marginally worth while in the temperate parts of Australia.

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