This is the published version:


Available from Deakin Research Online: http://hdl.handle.net/10536/DRO/DU:30018087

Every reasonable effort has been made to ensure that permission has been obtained for items included in DRO. If you believe that your rights have been infringed by this repository, please contact drosupport@deakin.edu.au.

Copyright: 2008, ANZAScA
Ventilation Research on Australian Residential Construction

Mark B. Luther
Deakin University, Built Environment Research Group, Geelong, VIC Australia

ABSTRACT: This paper applies established testing methods used to discover the ventilation performance of various residential building envelope construction in Australia. Under the definition of 'ventilation performance' we imply the building envelope leakage (or infiltration) the living space air change rates, the volumetric flow rates and the pathways of air flow between subfloor, room volume and roof spaces. All of the methods applied and discussed here are on-site, evidence-based performance of actual structures as tested by the Mobile Architecture & Built Environment Laboratory and Air Barrier Technologies.

The testing processes primarily involve the Tracer Gas Decay Method (TGDM) and the fan pressurisation method (FPM a.k.a 'blower door'). All the measurements are performed with respect to the external wind speed and direction as well as the typical weather parameters. This paper discusses the differences and similarities of both testing methods as well as a few other procedures that can inform the researcher on air leakage pathways. Findings of a simultaneous TGDM and FPM air leakage rate are also encountered in this paper. One of the most unique methods introduced here is the application of three different tracer gasses in different spaces (subfloor, room and roof) to discover pathways of ventilation within residential construction.

Keywords: air leakage, tracer-gas decay, building pressurisation testing.

1. INTRODUCTION

The International Energy Agency (IEA) Annex 26, Energy Efficient Ventilation of Large Enclosures: Design Principals declared building ventilation as the single most influencing component in the future of building energy consumption. This statement was made on the basis that buildings in the future would undoubtedly have solved the problems of thermal insulation, effective construction and optimised building control services. Australian building codes have acknowledged the value of thermal insulation in the building envelope improving energy consumption. In recent years, overseas standards and research recognise that the sealing of air leaks in houses (tightening) is the most cost effective method of achieving direct energy savings. These practices and testing methods have yet to be taken into account within Australian building codes.

Several reasons for researching the 'air-tightness' in buildings include:

- reducing energy savings through the reduction of infiltrated and exfiltrated air
- resultant reduced energy demand for heating and cooling
- establishing better predictability for an unknown air quantity in energy load calculations
- thus resultant reduced size of mechanical equipment
- eliminating interference with the mechanical (HVAC) system control.
- reducing moisture deposition within the building envelope.
- better health performance through limiting external pollutants; IAQ control
- the permeability (m³/hr/m²) of a particular building envelope system.
- reducing external noise nuisance
- improved thermal comfort through less (cold) draughts
- better construction details through location and quantification of air leakage
- better control of the actual pressurisation differentials between building interior & exterior spaces.

While the energy savings of sealed buildings can be quickly translated into CO₂ and other Greenhouse Gas reductions, Australia also has amongst the highest incidences of childhood asthma and allergic reactions. The health aspects of a controlled clean and sealed environment have been shown to be of benefit in achieving reductions in asthmatic attacks and allergenic reactions in children (Committee on Environmental Health, 2004). This is thought to be due in part to their ability to seek refuge in a controlled (appropriately filtered) environment.

1.1. Investigating the parameters of air leakage

The study of airflow within buildings pertains to developing an understanding of the mechanics of ventilation (Liddament, 1996). Ideally, the information required for such would be the:

- external air flow rate (m³/s) into a building (ventilation and infiltration)
- air change rate effectiveness within a particular space (room) of a building,
- maximum and minimum infiltration rates (m³/s) into a building.
Ventilation is defined as the 'wanted and known' quantity of air coming into a building and generally applies to the quantity supplied by mechanical ventilation. However, ventilation air quantities under natural conditions, such as entering through windows, are quite complex to measure. Air leakage, on the other hand, is defined as infiltration or the unknown and unwanted quantity of air entering the building (ASHRAE, 2001). Designers should not necessarily fixate on making buildings 'air tight', because even if gaps were completely sealed, buildings have doors and openings, which allow large volumes of air changes at occupants discretion. The idea instead is to quantify leakage, reduce excessive leakage and control leakage by managing air pressure with the HVAC system (Ask, 2003).

There are two different but internationally accepted testing methods for determining air leakage (infiltration) rates in buildings: the fan pressurisation method (PPM), for air-tightness, and the tracer gas dilution method (TGDM), for air change rates.

In the fan pressurisation method (a.k.a. 'blower door') the building is either pressurised or depressurised through a fan system that fits within an external door opening (see Figure 1). The unit is equipped with a calibrated pressure gauge, which is associated with a computer program to calculate the air leakage rate per hour (ACH), and the building envelope permeability (m$^3$/hr/m$^2$). Permeability is the calculation of leakage (m$^3$/hr) per m$^2$ of envelope. The testing method is performed according to a standard that requires the leakage to be observed at several pressure levels (Figure 2). The standard reported leakage is at 50Pa (pressure) where the air change rate of the building volume and/or envelope is reported. Recently, it has been of interest to know what the leakage under normal outdoor conditions might be (ie. 2.5Pa or 4.0Pa). Such results are for non-windy external periods and more closely represent 'natural' infiltration conditions.

The tracer gas dilution method (TGDM) provides an accurate measure of the air exchange rate within a particular building volume. This air change rate (ACH) can be observed under various conditions, such as the mechanical system operation, natural ventilation or the closed building (infiltration) condition. There are three different tracer-gas testing techniques to determine either an airflow rate or an air change rate: the concentration decay method, the constant injection method and the constant concentration method. All of these are described in greater detail in Liddament, 1996 or Luther 2007. The research in this paper utilises the 'concentration decay method' which is the most common in leakage testing. In this case, the tracer is dispersed through an air distribution system (supply ducting) or through small secondary fans within the test space. Once a desired quantity is released and a balanced mixing level occurs throughout the space, the gas is turned off. Following a short period of adjustment, the 'decay' of the tracer gas is measured over 30 – 45 minute periods, yielding the air change rate result for the conditions of operation.

1.2. Standards of testing
At this point in time there is no scientific program on air leakage performance for Australian construction. It has been estimated from the results of preliminary testing by the Mobile Architecture & Built Environment Laboratory (MABEL) and Air Barrier Technologies Pty. Ltd., that Australian buildings are often, 2-4 times leakier than European or Northern American buildings. This suggests a tremendous opportunity for energy savings in Australia. This paper discusses the application of both methods as investigated on residential case studies. An interest in comparing the two methods of air leakage testing is also explored.

![Figure 1 Fan Pressurisation Unit](image1)
![Figure 2 Pressure vs. Flow Rate of a House](image2)
There are many other FPM developed standards such as the ASTM E 779 and ASTM 1827 which all appear to target the same result. These standards are all reviewed in 'Air Leakage in Buildings – Review of International Literature and Standards', (Luther, 2007).

2.0 Case Studies on Air Leakage

The first study utilising both the FPM and TGDM took place in two houses, designed by a well known residential building company, located in Point Cook, Melbourne. Figure 3 illustrates the plan, section and instrumentation location for these houses. The bower door test results were different for each of the houses. One such result is graphed in Figure 2, which contains two curves. The upper curve represents the flow pressure in the blower door apparatus. This Flow Pressure graph indicates the calibration of the orifice plate meter that is used to calculate the flow rate, which is dependent on the volume and leakiness of the house. The second (lower curve) is the relationship between the pressurisation (Pa) and the air leakage (m³/sec).

Figure 3 Floor Plan and Section Including the Instrumentation of a Point Cook House

TGDM testing is conducted after the FPM method and takes several hours of the day. The intention is to observe the leakage (infiltration condition) of this house without mechanical ventilation and under natural conditions. One of the purposes of conducting these air leakage tests in Australia, is to investigate whether we have similar findings and resulting leakage correlations as in other countries. One such example is the 'normalised' (2.5 Pa) pressure equation as provided by Sherman (1998). Equation 1 basically states that the result of FPM at 50Pa can be factored by 20 to yield a natural leakage (NL) air change rate.

\[
ACH_{50} / 20 = ACH_{NL}
\]

Equation 1 (Sherman,1998)

The research question is whether this equation applies to Australian residential construction. Another more recent use for such is with the fire brigade who anticipate non-evacuation (shelter-in-place) strategies based upon a predicted air leakage rate developed elsewhere in the world. Therefore, unless we research our own building stock, we will be reliant upon 'others' representing it for us.

The air change rates for both the FPM and the TGDM can be observed for the two test houses in Table 1. Note that a calculated ACH at 2.5 Pa from the FPM pressurisation graph is provided. A measured ACH is also provided by the TGDM. The 'shaded area' indicates the factor which would be required to obtain the tested air change rate from the FPM result. It is obvious that the result is far from the factor of 20 as provided in Equation 1. However, a much larger factor (in some cases closer to 20) would be required to convert the measured ACH_{50} to the ACH_{Tracer Gas} result. A larger testing sample would be required here to draw more conclusive results.
2.1. Realising air leakage locations

Several interesting pieces of information are gathered from the tracer gas studies. Figure 4 shows the results of air change rates for two regions (of the house floor plan not shown). This case clearly illustrates that wind pressure differences on a building (the windward vs. the leeward side) can produce variable air change rates within the space. Another interesting aspect indicating the effects of where and when leakage takes place is observed in Figure 5 where the roof cavity air changes are observed. In this case the CO₂ level from the occupants is measured in the living space as well as the roof cavity. The visitation of the researchers and visitors of the house provide the ‘tracer’ of CO₂. Initially the measured CO₂ in the house is greater than the roof cavity due to the visitation. After several hours it is realised that the CO₂ has wandered through to the roof cavity due to the multiple penetrations of down lights. Note that the wind speed is also charted on the graph. At a particular moment when the wind speed has dramatically increased for a moment (point 2) the CO₂ is flushed from the roof and both the roof cavity and the living space become equally concentrated.

Table 1 Air Change Rate Results and Calculations

<table>
<thead>
<tr>
<th>Test Site</th>
<th>ACH at 50 Pa</th>
<th>Calculated ACH at 2.5 Pa</th>
<th>Measured w/ Tracer ACH (range)</th>
<th>Factor for ( \frac{ACH_{iso}}{ACH_{x}} )</th>
<th>Factor for ( \frac{ACH_{iso}}{ACH_{tracer,iso}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lot 602</td>
<td>7.17</td>
<td>0.91</td>
<td>0.45 – 0.01</td>
<td>7.88</td>
<td>15.9 – 717</td>
</tr>
<tr>
<td>Lot 603</td>
<td>8.39</td>
<td>1.33</td>
<td>1.3 – 0.01</td>
<td>6.31</td>
<td>6.7 – 839</td>
</tr>
</tbody>
</table>

Figure 4 The Air Change Rates in two Different Regions of a House

Figure 5 The Air Exchange between the Living Space and the Roof Cavity
2.2. Realising varying air leakage due to operational differences

In another case study in Queensland near Brisbane two houses constructed by SALA Homes (Sustainable Affordable Living Australia) were investigated. These houses are designed to accommodate the climate and are responsive to various natural conditioning principles. The roof is of a cathedral type and the cavity between the sarking and the metal roof is vented by two roof cowl turbines. The builder wanted to obtain air change rates and ventilation results of various operating scenarios within the structure. The floor plans of both houses are provided in Figure 6, again indicating the instrument location as well as the dosing and sampling of the TGDM. Note that the 'Blower Door' is not indicated on the plan and is located in the main entry door of the house.

The testing was performed with House 1 being occupied over the test period while House 2 remained empty. Our results of FPM testing indicated that House 2 did not change dramatically in its result for all three different test conditions (see Table 2). It was reasoned that the interior vents either remained unchanged whether thought to be open or closed. In contrast to this the ACH differences in House 1 are dramatically noticed for the various running conditions. The ACH for House 1 completely closed are assumed to be quite reasonable for houses located in a moderately hot climate. House 2 would need to be checked for the operation of its venting systems and their retro-commissioning.

<table>
<thead>
<tr>
<th>Test</th>
<th>34 The Green (House-1)</th>
<th>19 The Green (House-2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All vents closed</td>
<td>ACH@ 4Pa 2.0</td>
<td>ACH@ 50Pa 8.3</td>
</tr>
<tr>
<td>Roof vents open (only)</td>
<td>3.45</td>
<td>13.5</td>
</tr>
<tr>
<td>Roof and Fridge vents open</td>
<td>3.60</td>
<td>15.6</td>
</tr>
</tbody>
</table>

The TGDM results are quite interesting, considering the operating conditions of the two houses. House 1 clearly indicates when occupants are adjusting the vents and windows in their house (Figure 7). The results between the two houses indicate the potential air change rates due to natural ventilation during a very low wind speed condition. It is also interesting to note that House 2, which is closed under the complete period of testing, does not appear to have an excessive ACH.

2.3. Comparing air leakages within different construction detailing

The third, and last case study, considers the FPM and TGDM of three highly energy rated houses (4 – 5 Star) in Hobart, Tasmania. Figure 8 is the 'typical' floor plan applied to all three houses and again illustrates the instrumentation and where it is located. These houses consist of different floor construction as well as window types. House 1 is a concrete slab on grade construction with double glazed windows, while House 2 and 3 are raised wooden floor (sub-floor cavity) construction. House 2 (5-Star) has double glazed windows while House 3 (4-Star) has single glazed. The floor is not insulated. The FPM results are provided for all three houses in Table 3. These air
leakage results are representative of the expectations of the rating scheme. Note that there is a reporting of both air change rate (m$^3$/hr) as well as the permeability (m$^2$/hr/m$^2$) of the building envelope. Although House 2 indicates a somewhat greater leakage while holding a 5 Star rating, this is to be expected, due to its raised and exposed sub-floor. It should be noticed that House 1 is within the limits of 'best practice' according to the UK TM23 Standard.

2.4. Comparing the two different testing methods to each other
It was decided during the testing period to try and compare the results of a FPM air change rate with that of the TGDM results. In order to provide simultaneous results a method was devised to dose the space heavily with the tracer allowing it to disperse without the operation of the FPM. Once a uniformly dosed and balanced volume with

Figure 7 The Air Change Rates of the Tracer Gas Method in both SALA Homes (with and without ventilation)

the tracer was obtained, the FPM was quickly turned on to a fixed specific pressure level while the tracer gas decay was measured over time. This resulted in both the FPM leakage rate as well as the TGDM rate being simultaneously available. This testing method was applied to 4, 8 and 20Pa fixed pressure levels. These results are provided in Table 4 and it can be seen that the results of the two totally different testing methods are remarkably in agreement with one another.

Figure 8 The Typical Floor Plan and Instrumentation of the Hobart Houses

2.5 Recognising air leakage pathways between building ‘zones’
Lastly, an observation of the air leakage between the sub-floor, the living space and the roof cavity were observed. This testing was aimed at qualitatively discovering interstitial leakages among the areas as well as inspecting the construction detailing. The chart in Figure 9 illustrates the acetone (ppm) concentration in House 2 and 3 after being dosed into the sub-floor only.

Table 3 Fan Pressurisation Results of the Hobart Houses
It is noticed that the tracer in House 2 quickly makes its way (after dosing) directly into the roof space as well as the lounge (living) area. This is due to the construction detailing in the brick veneer cavity and the floor plate. The wall cavity is very leaky and open to the sub-floor cavity in both houses. However, House 3 (4-Star Rated) has about a fifth of the leakage to the lounge space when compared to House 2 (a 5-Star) house. This illustrates the differences between a rating and actual performance. The construction detailing of House 3 is tighter at the floor sill plate than House 2.

**Acetone Tracer Gas**

![Acetone Tracer Gas Graph](image)

**Figure 9 A Comparative Testing of Air Leakage within the Lounge and Roof Cavity of House 2 & 3**

### 3.0 Predicting the Costs of Leakage

One of the unknown associated issues with building air leakage is the prediction of cost savings to a client. This of course is dependent on several factors which include the mechanical conditioning equipment type, the type of house construction (air leakage), the fuel source used, as well as the climate. An example of predicted savings as provided by Air Barrier Technologies Pty. Ltd. includes the calculations of applying a proprietary code ‘EC-128’ (software developed in Canada) and the assumptions for the calculation of a year’s savings are as follows:

- 200 – 230 m² house within a Melbourne climate
- the method applies HDD (heating degree days) and CDD (cooling) and humidity
- the fuel source is electricity at $0.12 kWh

- For a house with a blower door air change rate of 10 at 50 Pa it is calculated that there is a $300+ saving after sealing (lightening) the house to a reasonable level (5-6 ACH at 50 Pa).
- For a house with a blower door air change rate of 14 at 50 Pa the saving after sealing (lightening) the house to a reasonable level (5-6 ACH at 50 Pa) is calculated to be around $400.

Note: the leakier the house the greater the savings.
Another example considers using the ASHRAE 62 Standard. The assumptions made here are as follows:

- Melbourne HHD = 1175 (base of 18°C) note: cooling degree days not included
- House floor area = 270 m²
- House Volume = 656 m³
- Initial ACH_{natural} = 0.7
- Desired ACH_{natural} = 0.35
- Excess infiltration = 228 m³/hr

According to the ASHRAE 62 calculation, as based on the required L/s (liters per second) of ventilation air per person, the unwanted (excess infiltration) would be 228 m³/hr. The energy put into this excess infiltration based on HDD (only) is 13.87 kWh per day based on an annual average HDD-18 of 1175. This equates to a yearly total of 5063 kWh excess conditioning of air.

- An electric heat pump with a COP (coefficient of performance) of 3 would use 1687 kWh/year costing $270 @ $0.16/kWh
- Gas heating with a COP of 0.9 would use 20250 MJ/year costing $243 @ $0.012/MJ
- CO2 emissions would be 2.2 tonnes with electricity or 1.1 tonnes with gas

As stated earlier in this paper, there are many other reasons including increased occupant comfort as well as interstitial condensation prevention of the envelope construction, to be considered when tightening buildings.

CONCLUSION

This paper presented the results of several houses located throughout Australia on air leakage. The findings quantified the amount of air leakage utilising two test methods: the Fan Pressurisation Method (FPM) and the Tracer Gas Decay Method (TGDM) as well as providing qualitative approaches to air leakage within the building itself. Not all the results of ventilation testing, such as the air change rates between the sarking and a metal roof sheet, could be reported in this paper. The intention here was to indicate to the reader the huge amount of research potential for ventilation testing of houses in Australia. The findings here are only a sample of the housing and construction types in Australia. Further research is required to develop a better understanding of a construction type (weatherboard, brick veneer, etc.) and its leakage rate as well as where leakages occur and how we can improve our detailing and execution.

REFERENCES


ASTM E741-00, 2006, Standard Test Method for Determining Air Change in a Single Zone by Means of a Tracer Gas Dilution


Chartered Institution of Building Service Engineers (CIBSE), 2002, CIBSE TM23 UK, Testing Buildings for Air Leakage, London


