MABEL Air Leakage & Infiltration Testing Demonstration Project

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Correspondence:
Dr. Mark B. Luther
School of Architecture and Building
Deakin University
Geelong Victoria 3217
Email: luther@deakin.edu.au
Mobile: 0437 005 918

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M A B E L

As you may know, MABEL is the most versatile and comprehensive in-situ testing facility for built internal environments throughout Australia. MABEL is a diagnostic toolkit providing multi-dimensional testing of the key performance criteria of energy, light, sound, and comfort.

The general purpose of the MABEL monitoring is to:

- Identify evidence-based best practice technologies for environmental building performance.
- Provide internal environment diagnostic performance for commercial, industrial and residential buildings.
- Establish achievable performance levels of four important criteria: power, light, sound and comfort.
- Establish a set of realistic standards that can be measured and met for ESD building performance.
- Provide data to a client or consultant that verifies compliance and/or contributes to building improvement.
- Provide data sets for building energy rating and simulation tool verification.
- Perform in situ product evaluation.

You will note that the methodology does not suggest how the performance of any criteria may be improved, but should you wish us to explore this, MABEL would be most pleased to discuss this with you and outline a separate scope of work.

Table of Contents

List of Tables

List of Figures

List of Equations

1 Project Summary

This report was sub-contracted to MABEL by Air Barrier Technologies, Inc., who was sub-sequentially funded by the Building Commission of Australia to undertake this project. Its intentions are to provide a brief literature overview and actual project demonstrated results on the subject matter of air-tightness or leakages (infiltration and exfiltration) testing in buildings for Australia. In specific, a comparison of two different testing methods; the fan pressurization method (FPM), for air-tightness, and the tracer gas dilution method (TGDM), for air change rates, are investigated on two residential case studies in the Melbourne region.

The literature review defines both of the testing methods, provides further insight into the parameters, advantages and disadvantages of each method, as well as information that can be extracted from testing. The relevance and significance of studies on air-tightness is supported through the literature review. It is evident that the two different testing methods applied side-by-side, as in this study, fulfills a valuable and much needed research requirement regarding our building envelope construction performance in Australia.

In summary, the report and its findings provide support for further work and analysis, applying both testing methods. These are proposed for several building types (ie. residential, commercial, industrial, schools, office buildings, etc.). The intentions here are to raise awareness and to outline the information needed for developing a knowledge-base on Australian building envelopes and to provide guidelines for improved ventilation performance and a method by which the degree of “air tightness” of a building can be tested and verified. The findings and demonstration project of this report have acknowledged the benefits of obtaining evidence-based knowledge on building envelopes in Australia.

2 Literature Review

The International Energy Agency (IEA)– Annex 26, Energy Efficient Ventilation of Large Encloses: Design Principals, declared that ventilation alone would become the primary energy concern of our future building control. Considering that the insulation of building envelopes, inclusion of air and moisture barriers and better passive design (shading, thermal storage, etc.) are becoming the norm, infiltration and building pressurization are basically left as an unknown variable in energy analysis. The more we know about building infiltration and its methods of reduction, the better we can predict, operate and control the ventilation energy requirements of our buildings.

2.1 Investigating the Air-tightness of Buildings

Ventilation is the transport of air to provide acceptable indoor air quality in buildings. It is inclusive of wanted fresh external air and suitably treated re-circulated air (ASHRAE Fundamentals, 2001). The literature defines ventilation as the 'wanted and known' quantity of air coming into a building. Generally, this 'known' quantity applies to mechanical ventilation systems, as the absolute quantity of 'fresh external air'. However, ventilation air quantities under natural conditions, such as entering through operable windows, are quite complex to obtain. Calculations estimate the theoretical quantity of ventilation as well as infiltration of air entering a building.

The Australian standard AS 1668.2-1991 identifies the quantities of ventilation ('fresh') air requirements for particular building types. The ANSI/ASHRAE Standard 62, Ventilation for Acceptable Indoor Air Quality mandates the amount of outside air for particular building types. These ventilation rates are provided with the intention of maintaining carbon dioxide levels (CO_2) below 1000 ppm. For example, in residential applications, assuming 4-5 occupants the air ventilation rate is 7.5 l/second/person. This equates to about 0.5 air changes per hour (ACH) for a typical house although this is highly variable depending on the size (internal volume) of the dwelling. It is noted that lot 602 at Point Cook was 0.2ACH at 7.5 l/second. Meeting these requirements of ventilation alone in terms of capital equipment cost and energy consumption is enough of a burden to the building owner. Treating the excess outside air in order to gain control of the indoor/outdoor pressure relationship can prove a costly venture (Ask, 2003) it therefore stands to reason that infiltration and exfiltaration be better managed.

For a house without a mechanical system, the occupants would rely on operable windows, or if in a closed condition – infiltration. Infiltration therefore, is often the unknown and sometimes 'unwanted' air quantity entering a building through cracks and gaps of particular construction types. ‘Leakage’ is the natural, unplanned and uncontrolled flow of air into (infiltration) and out of (exfiltration) buildings (Ask, 2003). This unknown air quantity is the purpose of the present study in regards to defining the air-tightness of our building envelopes.

Designers should not fixate on preventing air leakage, ie. making buildings ‘air tight’ because even if cracks were completely sealed, buildings have doors and windows. Instead the goal should be to A) quantify leakage, B) reduce excessive leakages, C) control leakage by managing air pressures with the HVAC system (Ask, 2003). Blower door testing has the capability to provide for this testing. Determining what ‘excessive’ quantities are and might be for Australia are discussed later in this report.

2.2 Two Different Testing Methods

This project investigates the air-tightness and the air change rate (in situ), of two residential buildings through the application of two different testing methods.

The first, and perhaps the preferred (simpler) method, is the fan pressurization method (FPM). This method uses a fan mechanism to either pressurize or depressurize the building. The flow rate of the fan required to maintain a specified (standard) pressure requirement determines the ‘tightness’ of the building. This air-tightness is then extrapolated to what the building would be like under natural ventilation conditions.

The second and more cumbersome method is performed using the tracer gas dilution method (TGDM). In this testing approach, an inert gas quantity is released into the space (internal volume) and uniformly mixed via small fans or through the mechanical system. After this dosing period is terminated, a tracer gas analyzer notes the tracer gas quantity at this initial time interval. Through subsequent sampling over time the decay of the tracer gas is noted. This concentration decay is proportional to the air change rate (combined ventilation and infiltration rate) of the space over the particular decay period.

One of the primary research interests of the demonstration study is to compare the ‘natural’ tracer gas air change rate results with that generated by those of the fan pressurization method. It is therefore of interest to run each test as close together (in time) as possible. Both of the testing methods, as defined above have been quite simply explained and more detailed variations are provided under the forthcoming Overview of the Standards chapter in this report.

2.3 What Needs to be Investigated in Ventilation and Infiltration

The study of air flow within buildings pertains to developing an understanding of the mechanics of ventilation (Liddament, 1996). We want to apply instrumentation, which will provide information on:

- the external air flow rate (m^3/s) into a building (ventilation and infiltration)
- the air change rate effectiveness within a particular space (room) of a building.
- the maximum and minimum infiltration rates (m^3/s) into a building.
- the qualitative air movement (flow visualization pattern) for a space
- the quantitative air movement in a space (flow velocity, direction, turbulence, etc.)
- the non-mechanically assisted air change rate –infiltration - ACH
- the mechanically assisted air change rate – ventilation - ACH
- the location and quantification of air leakages
- the average pressurization of the building (positive or negative)

Information to the above points will yield substantial knowledge on the ventilation, infiltration (air-tightness) and its control for a particular building. Measurements are essential for commissioning, diagnostic analysis, design and research (Liddament, 1996).

The intentions of the FPM or 'blower door' testing are primarily to report on the air-tightness of a building envelope. However, after an extensive literature search in the areas of the standards, overview of ventilation guidelines and specialized research reports within the topic, it is concluded that extremely few explanations provide the rationale behind the studies for 'air-tightness'. This finding is also confirmed in the seminal publication by Proskiw and Phillips (2001). Several reasons for researching the 'air-tightness' in buildings as implied throughout the literature, are:

- improved energy savings through the reduction of infiltrated and exfiltrated air
- reducing energy demand for heating and cooling
- establishing better values for an unknown air quantity in energy load calculations
- reducing the sizing of mechanical equipment due to lower building loads.
- eliminating interference with the mechanical (HVAC) system control.
- reducing moisture deposition in the building envelope (damage control)
- better health performance against external pollutants (unwanted air infiltration)
- controlling IAQ; avoidance of indoor pollutants concentrating beyond health levels
- reducing sound transmittance
- improved thermal comfort through less draughts of uncontrolled and non-conditioned air.
- to develop better construction envelope details for improving air-tightness
- to better control the actual pressurization differentials within buildings.

Not all of the above points will pertain to a particular project, yet, the more which do, will value add to improved building performance. Air-tightness testing has an important role to play in improving unknown quantities of infiltration / exfiltration. However, the real objective is to ensure that the job is properly done and within a reliable limit or standard (Proskiw and Phillips, 2001).

2.4 A Brief Overview of the Standards

Several standards exist for the testing of infiltration and air leakages in building envelopes. Among these are conventionally the blower door testing and tracer gas methods. It should also be stated here that other methods such as tracer smoke, sound transmission and thermal imaging testing can assist in locating the leakages. Specific building component testing is not the subject of this study and we refer only to whole building envelope assessment for leakages and air change rates.

An overview of the present standards is provided in the Canadian report by Proskiw, 2001. This particular publication does a noteworthy task in relating similar standards with one another and points out their differences. It does not highlight the testing method advantages and disadvantages as done in the AIVC – A Guide to Energy Efficient Ventilation publication by Liddament, 1996. A more detailed discussion comparing the testing methods and their instrumentation will be taken up later.

2.4.1 Fan Pressurization Methods (FPM)

The fan pressurization method (FPM) may actually implement the 'pressurization' or the 'depressurization' of the building. This method is synonymous to 'blower door' testing. All FPM testing methods revert to examining the resistance to air flow created by the porous structure of the building envelope. This yields a mathematical relationship between the air leakage and the pressure differential between the internal and external air:

Equation 1

$$Q = C\,\Delta P^{n}$$

where

Q = air leakage (l/s)

C = flow coefficient ($l/s \circ P^{n}$)

ΔP = indoor-to-outdoor pressure differential (Pa)

n = flow exponent (dimensionless)

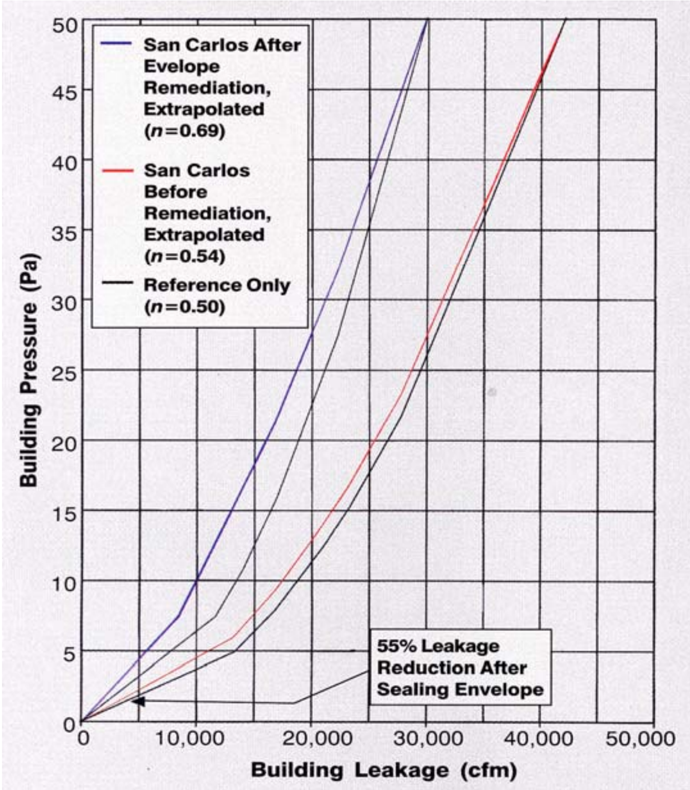

Figure 1 Air Leakage to Building Pressure Relationship: example (Ask,2003)

The above figure is a typical example of blower door testing air leakage measurements at different pressure levels. Typically, these graphed charts are used to interpolate what the Normalised Leakage (NL) or natural infiltration rate would be at a standardised pressure of 2.5Pa (Ask,2003).

The following provides a brief description of the standards for Blower Door(FPM) and

Tracer Gas (TGDM) methods.

CIBSE TM23 UK Standard for Air Leakage Tests

In the UK, air leakage tests must be carried out in accordance with CIBSE TM23 on all buildings over 500m^2 of gross floor area where construction began after April 2006 (from April 2002 all buildings over 1000 m^2 had to be tested). The TM23 standard mandates the maximum allowable leakage of 10m3/hr at 50 Pascal per m2 of envelope area. The following Table 1 is an extract from the standard:

	Air Leakage (m3/hr/m2 @50Pa)	
Building Type	**Best Practice**	**Normal**
Offices (naturally ventilated)	3.0	7.0
Offices (mixed mode)	2.5	5.0
Offices (air conditioned/ low energy)	2.0	5.0
Factories/ Warehouses	2.0	6.0
Supermarkets	1.0	5.0
Schools	3.0	9.0
Hospitals	5.0	9.0
Museums and Archival Stores	1.0	1.5
Cold Stores	0.2	0.35
Dwellings (naturally ventilated)	3.0	9.0
Dwellings (mechanically ventilated)	3.0	5.0

Table 1 CIBSE TM23 UK Standard for Allowable Air Leakages in Buildings

Although these specifications are being achieved on a number of new buildings, many other buildings built to meet these specifications are failing by significant margins, due to a combination of inadequate design and poor site construction. Such short comings are generally identified by blower door testing. Measuring ACH relative to the surface area of the building envelope provides a more meaningful measurement than some other methods as it takes in to account the size and design of the building

ASTM E 779 – Determining Air Leakage Rate by Fan Pressurization

This standard is applied primarily in the U.S.A. was developed by the American Society for Testing and Materials standards authority. This testing permits a 'pressurization' or 'depressurization' of the building which has been known to yield slightly different results between the two. The test pressure range is between 12.5Pa – 75Pa in increments of 12.5Pa. The standard describes how the flow coefficient and flow exponent are calculated. However, it recommends a reference pressure differential (indoor-outdoor) of 4 Pa, which is reasonable for low rise buildings (Proskiw, 2001).

ASTM E 1827 – Determining Airtightness of Buildings Using an Orifice Blower Door

This test is similar to ASTM E 779 yet it is directly implied for orifice blower doors (the most common FPM type testing). It describes two alternative measuring procedures: one which multiple flow measurements are made at a pressure differential of 50Pa and a flow exponent (n) equal to 0.65 is assumed, the second, where multiple flow measurements are made near each of two pressure differentials, 12.5Pa and 50Pa, thereby permitting both the flow coefficient and the flow exponent to be estimated. This is a much more detailed analysis protocol than E779.

ISO 9972 – Thermal Insulation, Determination of Building Airtightness – Fan Pressurization Method

This standard is very similar to the ASTM E 779 standard and has been primarily used in Europe. It is different in that it permits the building to be either pressurized or depressurized using a blower door, the building's mechanical system or a separate fan and duct system. There is a pressure test range requirement between 10Pa – 60Pa with no more than a 10Pa increment (at least 5 points of measurement).

Other fan pressurization methods exist focusing on individual components or compartments of the building such as curtain walls, windows, doors etc. These methods are not discussed in this report.

2.4.2 Tracer Gas Dilution Methods (TGDM)

Tracer gas methods provide an accurate measurement of the accumulated air flow rate through the many unknown gaps and cracks that appear in the construction of a building. Both the **ASTM E 741** *Standard Test Method for Determining Air Change in a Single Zone by Means of a Tracer Gas Dilution* and the **ISO 12569** *Thermal Performance of Buildings-Determination of Air Change in Buildings Tracer Gas Dilution Method* present a similar testing procedure. Each standard outlines three different tracer gas testing techniques to determine either an *air flow rate* or an *air change rate* (ACH). These are;

a) the concentration decay method
b) the constant injection method, and
c) the constant concentration method

Concentration Decay Method:

Single tracer gas concentration decay method is the most common and straightforward method as well as the least disruptive. The tracer gas can be dispersed through an air distribution system or by small desk type (or similar) mixing fans. Once the desired quantity has been released, the gas is turned off followed by an additional short period of mixing. The decay in the tracer gas concentration is measured by a tracer gas analyser over time. Periods are typically between 15 -30 minute intervals. Provided that the air in the space is well mixed and that the forces driving the air change process remain somewhat constant, the decay in the tracer gas concentration is logarithmic. The air change rate is directly related to the decay gradient.

The success of the tracer gas decay method is dependent upon the validity of several key assumptions (Liddament, 1996):

- the mixing of tracer gas into the space is uniform and instantaneous.
- the interior of the building (or measured area) is open plan
- the 'effective volume' of the enclosure is known
- factors that influence air change remain constant over the interval

One of the limitations of single measurements is that they provide a 'snapshot' of an air change rate. In fact, in leaky or naturally ventilated buildings the air change rate can vary considerably according to extreme variations in weather conditions (wind speed and direction) resulting in pressure differentials across the building envelope. Therefore, it is necessary to conduct net pressure (internal/external) differentials over several tracer decay intervals. Furthermore, information on wind speed and direction in relation to the floor plan (external openings) may prove to be useful.

Constant Injection:

This procedure injects the tracer gas at a constant rate, uniformly into the zone and then measures the tracer concentration at specific times. The difference in the concentration from its known injection quantity within a known volume of a zone is the air change flow (flow rate) at the specific interval. If ventilation conditions remain unchanged and the tracer gas is injected at a constant rate then an equilibrium conditions will be reached. This method allows a flow rate change to be detected. It is a great method for obtaining a flow rate in a duct-like volume, where there is flushing through an orifice. Difficulties in the method occur in large spaces where reaching equilibrium may not be achieved. The method is also not appropriate for short term measurement analysis, it is also a simplification of the forthcoming *constant concentration* testing.

Constant Concentration:

Another tracer gas testing approach, as controlled through instrumentation, is the constant concentration method. This approach is ideal for natural ventilation or varying conditions such as a window opening or changes in driving forces (Liddament, AIVC Guide to Ventilation, 1996). It is based upon releasing a tracer in variable amounts to maintain a near constant concentration. This is accomplished by sequentially sampling the tracer gas concentration in each zone and calculating the necessary injection rate needed to return the concentration to a 'set point' value.

The limitations should consider that the inter room air flows (between measured zones) cannot be detected using this approach.

Given that the following research is applying variable (both the FPM and the TGDM) methods of research towards air infiltration and leakage problems, a summary of these diagnostic techniques is provided in Table 1 below (Charlesworth, 1988).

Table 2 implies a program of building measurement methods regarding testing with FPM and TGDM. The purpose and use of each method is well defined in this chart and is an additional justification of our need to conduct both tests.

2.5 Previous Research Findings and Case Studies

The cause of air-leakage within buildings is directly related to the pressure differential between external and internal building envelope. We would like to design and control building pressures with small pressure differential ie. < 2.5Pa. Generally, a greater indoor pressure is to be considered. Small pressure differentials have been shown to work well in hot humid climates. Such small pressure differentials are difficult to maintain; as wind currents change and shift direction, so do the pressurization differentials. In locations where strong winds and direction are constant, such as by the sea, control over pressure differentials within a building may be easier to control (Ask, 2003).

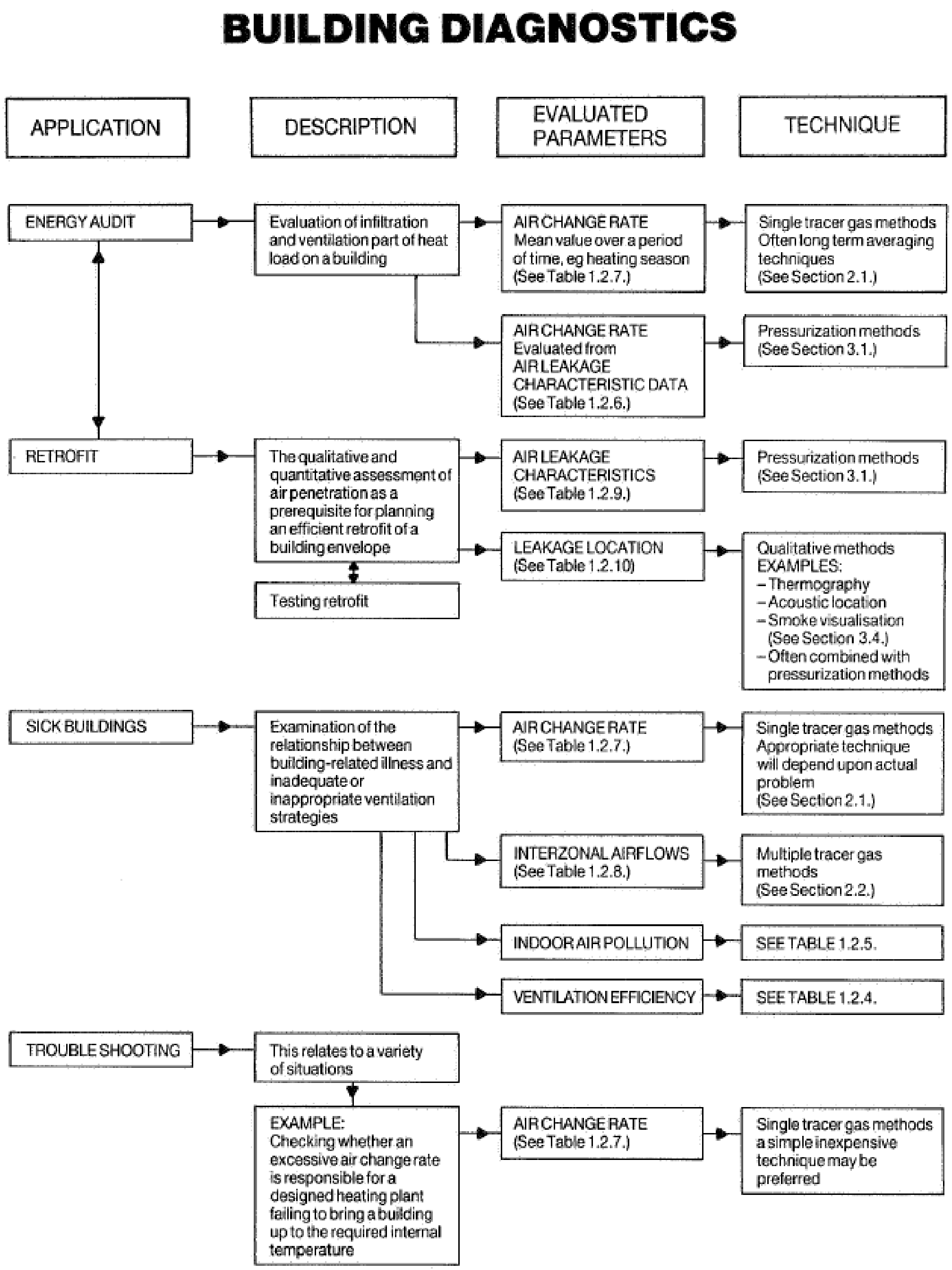

Table 2 Diagnostic Testing with FPM and TGDM (Charlesworth, 1988)

A literature survey conducted by the Canadian Mortgage and Housing Corporation concluded that virtually all large buildings, including those built within the last few years are quite leaky and would not meet the current recommendations of the 1995 National Building Code of Canada (Proskiw, 2001). Typical leakage rates were found to be 10 -50 times those referenced by the code. A similar conclusion was reached by the report of Emmerich (2005) for U.S. buildings. Nevertheless, design details for air-tightness have been developed, standards established and quantitative as well as qualitative testing methods exist.

An example of a Florida school building was tested for its air leakages and indicated a good result. Florida buildings represent a temperate to hot and humid climate where buildings are not as tightly sealed as in colder climates. After sealing and insulating the building, the results indicated a 55% improvement on the infiltration under normalized leakage conditions. A normalized leakage condition at 2.5Pa is estimated from the blower door parabola (see Figure 1).

In the Florida infiltration test it is likely that tracer gas testing methods would have assisted in verifying the estimates made under normalized (natural) wind conditions. They would have also provided air change rate (infiltration) data under various external weather conditions.

Sherman (1998) provides a chart classifying infiltration rates as well as defining the conditions for mechanical ventilation (Figure 2). Balanced conditioning requires an air-to-air energy exchanger while 'unbalanced' relates to mechanical ventilation to control the building pressurization levels. From what can be gathered by the literature, Australian buildings should target the D-F range of classification as we are not considered to be in a severe climate.

TABLE 1. CHARACTERIZATION BY BUILDING LEAKAGE

LEAKAGE CLASS	Minimum NL	Maxi-mum NL	Typi-cal ACH_{50}	Ventilation Requirement	Recommended Ventilation Type
A	0	0.10	1	Full	Balanced Only
B	0.1	0.14	2	Yes	Balanced
C	0.14	0.20	3	Yes	Either
D	0.20	0.28	5	Some	Either
E	0.28	0.40	7	Likely	Unbalanced
F	0.40	0.57	10	Possible	Unbalanced Only
G	0.57	0.80	14	Unlikely	Unbalanced Only
H	0.80	1.13	20	None	None
I	1.13	1.60	27	*Buildings in this range may be too*	*loose and should be tightened.*
J	1.60				

Figure 2 Air Leakage Classification and Ventilation Requirement (Sherman, 1998)

Note: NL = normalised leakage (air change rate) under non-windy and non-pressurised conditions.

ACH_{50} = the air change rate of the blower door testing rest under a 50 Pa condition

Sherman (1998) has conducted numerous projects for developing a relationship between the FPM air change rate (ACH) result at 50Pa and that of Normalized Leakage (natural infiltration conditions):

$$ACH_{50} / 20 = ACH_{NL} \qquad \textbf{Equation 2}$$

Very little was found (but does exist) on the simultaneous or side-by-side testing of both the FPM and the TGDM. One such example was found in the guide by Liddament (1996). A combined pressure testing and tracer gas analysis can be applied when some building components are too leaky. The leakage between the ceiling roof space and the occupied zone can be tested by providing a constant emission to the roof zone until an equilibrium is reached, at this point in time a suitable depressurization (50Pa) is applied to the room. The ratio between the occupied zone and that of the ceiling void interface is given by the ratio of roof void tracer gas concentration and the concentration in the room.

2.5.1 Reflections upon the Fan Pressurisation Method

One of the criticisms of the blower door testing is that unnatural pressurization is applied for a space. Air vents (supply and exhaust) are generally sealed off for the test; however, these openings would undoubtedly have some contribution to infiltration under natural (unsealed) conditions. Hinged dampers (flaps) may also provide very different results between pressurization and depressurization blower door testing, since building depressurization might inherently seal such. Therefore, the results of air change rates via the tracer gas dilution methods can provide a useful check to blower door estimations (calculations) for normalized leakage conditions.

Pressurization testing can be useful in determining the leakage contribution of individual components. A systematic testing approach is demonstrated where individual components are sealed off and repeating the pressurization test (Liddament, 1996). The pressure differential is a much-needed component of blower door testing and is illustrated schematically in Figure 3.

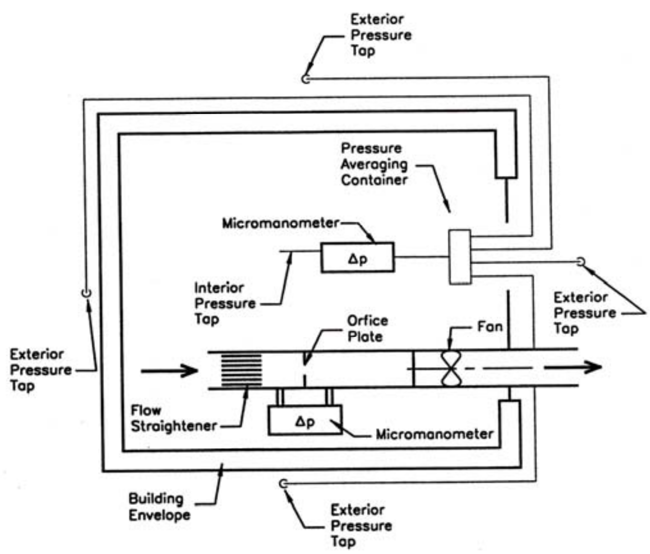

Figure 3 Pressure Measurements in Blower Door Testing (Proskiw, G. and B. Phillips, 2001)

Several deliverables from the literature review on blower door testing intend to provide:

- the relationship between highly pressurized (blower door) leakage quantities and Normalised Leakage (NL), or in other words, natural leakage conditions.
- the establishment of the leakage coefficient 'n' under various measured pressure levels (see Equ. 1 and Figure 1).
- the ramifications between IAQ (indoor air quality) improvements and infiltration energy consumption reduction.
- the energy saving estimation through infiltration reduction (Emmerich et.al., 2005)
- mechanical ventilation control and design for air-tight buildings.

2.5.2 TGDM and Supporting Instrumentation

Much of the literature describes the measurement conditions for the blower door testing. Several of these (Ask, 2003; Sherman 1998; Liddament 1996) include data variables which are important and essential to meeting the test criteria. The tracer gas testing (TGDM) as applied by MABEL is inclusive of these variables:

- External (on site) wind speed and direction
- External and internal air temperature difference
- Internal air temperature stratification
- Differential pressure difference between the outside and inside

These variables can add to the database of building use and construction types collected. They should also be considered in the correlations between FPM results and those under Normalized Leakage as provided by Sherman above.

2.6 Applied Research to Australian Buildings

The report by Proskiw and Phillips, 2001, concluded several measures, which could be taken up to improve the air-tightness in large buildings and should be considered for Australia:

1. the adoption of whole building air tightness requirements, standards and enforcement.
2. establishment of a national database on air-tightness for multiple building types
3. on-going industry training programs and educational activities for building owners and property managers.

2.6.1 A relationship between (FPM) and (TGDM) methods

The sponsors of this research project, in contrast to the numerous projects identified in the literature review, requested the need for both Fan Pressurization Methods as well as Tracer Gas Dilution Methods. The results of both are extremely useful to one another. An assessment realising the advantages and disadvantages of each method is of prime importance:

FPM - Advantages:

- the testing method is the least costly of the two.
- It provides an estimate of the leakage area or ELA (size of the hole in the building envelope).
- It provides an almost instant result.
- It provides retrofit information and a process for improving leakages in a building
- The system is self checking as tests are carried out. This is done by taking readings at different pressures and compares the results highlighting any anomalies associated with a particular test/pressure
- Compares the relationship of flows and pressures against a predetermined model built up from many test (calibration curve)
- Can test positive and negative pressure to provide an average result, therefore allowing test to be undertaken in most conditions.

FPM - Disadvantages:

- the method does not provide results under natural building pressurized conditions
- the method assumes a moderate (non-windy) external condition
- the correlations made for normalized leakage conditions are estimates of the measured pressure curve.

TGDM - Advantages:

- the method can provide continuous results under varying external conditions.
- the method provides air change rates as well as air flow rates under actual conditions.
- useful data can be collected to correlate results with FPM.
- testing can allow HVAC systems to be in operation or turned off.

TGDM - Disadvantages

- the method is costly and time consuming.
- the data analysis can be time consuming and results are not instantaneous.
- A single value (as obtained in the FPM) is not always provided.

2.6.2 Conclusions of the Literature Review

Information concerning the actual air tightness, infiltration and air change rates is probably the least known subject matter of building performance in Australia. There is room for improvement in the development of a nationwide program in Australia, from that of other countries, in producing our own database and research on the subject. Researching both the FPM and TGDM approaches side-by-side already provides a better research study of the air-leakage as well as the infiltration air change rates, compared to other research programs. It is therefore highly recommended that our building code boards, commissioning and building society panels begin to realise the importance of a nationwide research project. It is also important to contemplate and define the outcomes of such a program.

A proposed national research program would split the research of building air-tightness into climatic zones as well as residential or commercial building types. It should also separate and categorize commercial buildings into shopping facilities, schools, office buildings, etc. as well as document their envelope construction.

Considering that Canada, the U.S.A., and Great Britain have benefited greatly from a research program on building air-tightness from many of the reasons provided in this report, Australia might do the same. Australian construction would be considered leakier than most of the other countries mentioned above and therefore could receive an even greater benefit. The bottom line is to gain knowledge to define the infiltration quantities required for building simulation programs and ventilation assessment in Australia.

3 In Situ Measurement Results

3.1 External Weather Conditions

External weather was monitored by portable weather stations situated at the rear of the house (away from the street) see Figure 4. Wind speed and direction, humidity, air pressure and global solar radiation data were collected for the period of testing. Wind speed data is displayed in the relevant sections below.

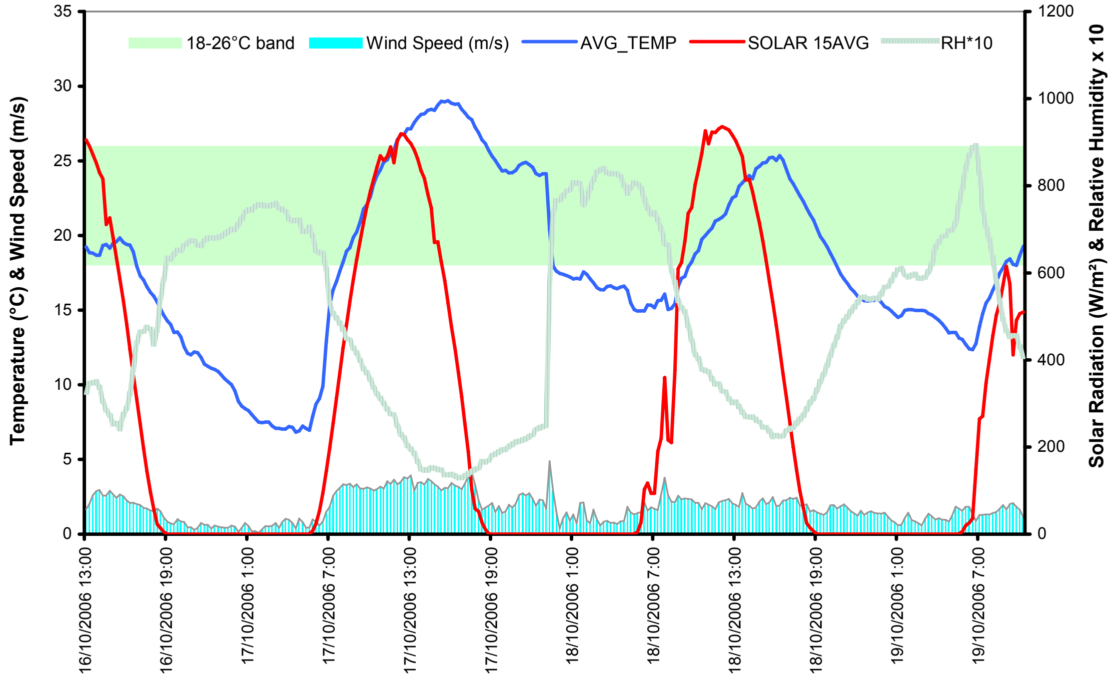

Figure 4 Weather Data Collected on Site for the Two Test Buildings

3.2 Blower Door Testing Results

Blower door Testing was conducted on the two properties by Air Barrier Technologies. The two floor plans and the location of the instrumentation are provided below in **Figure 5** and **Figure** 6**.** It is interesting to note where dosing and sampling take place in regards to the blower door testing location although the two tests are not conducted simultaneously. The first house, Lot 603 did not have any gas testing within the roof cavity.

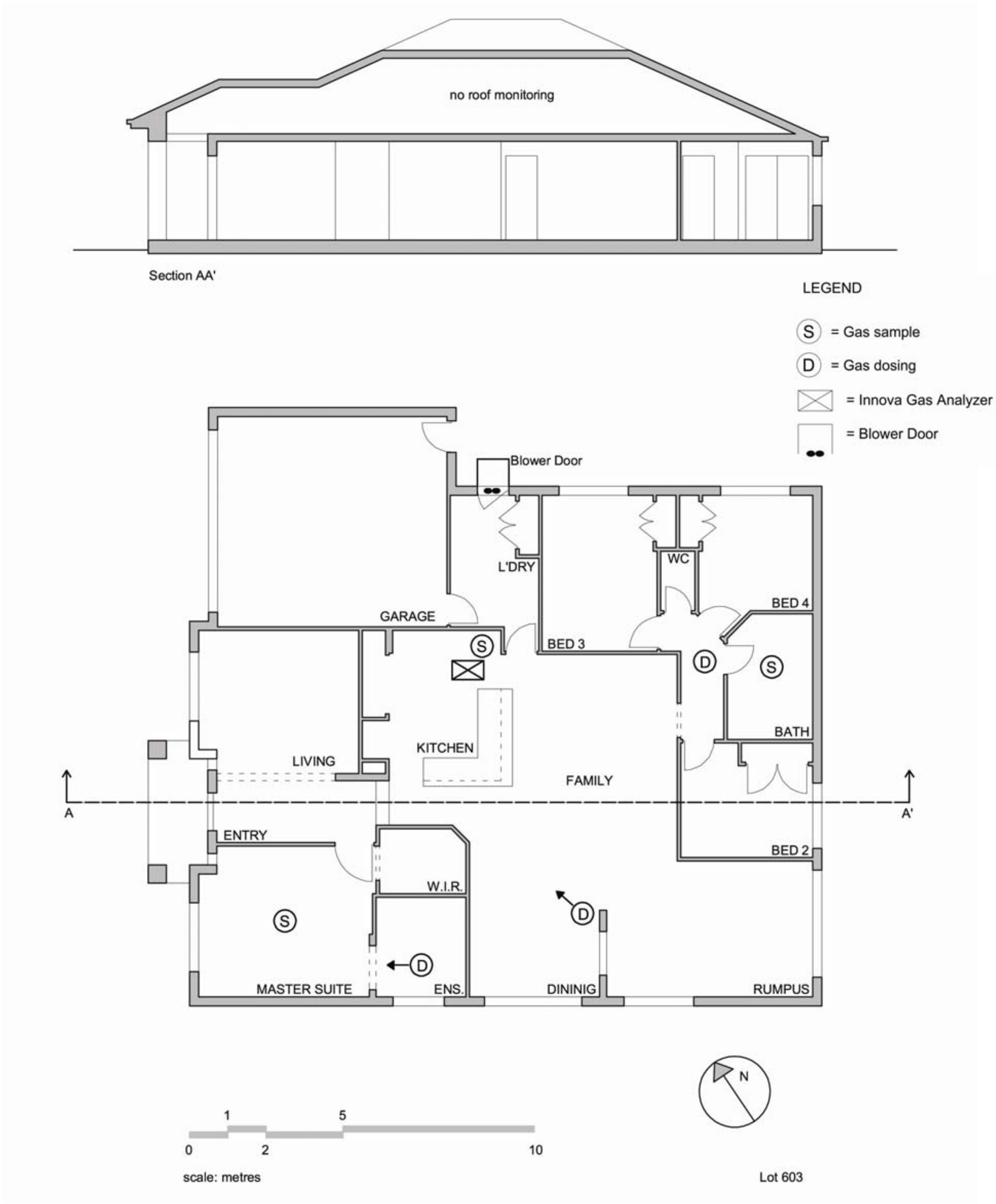

Figure 5 Section, Plan and Instrument Locations in Lot 603

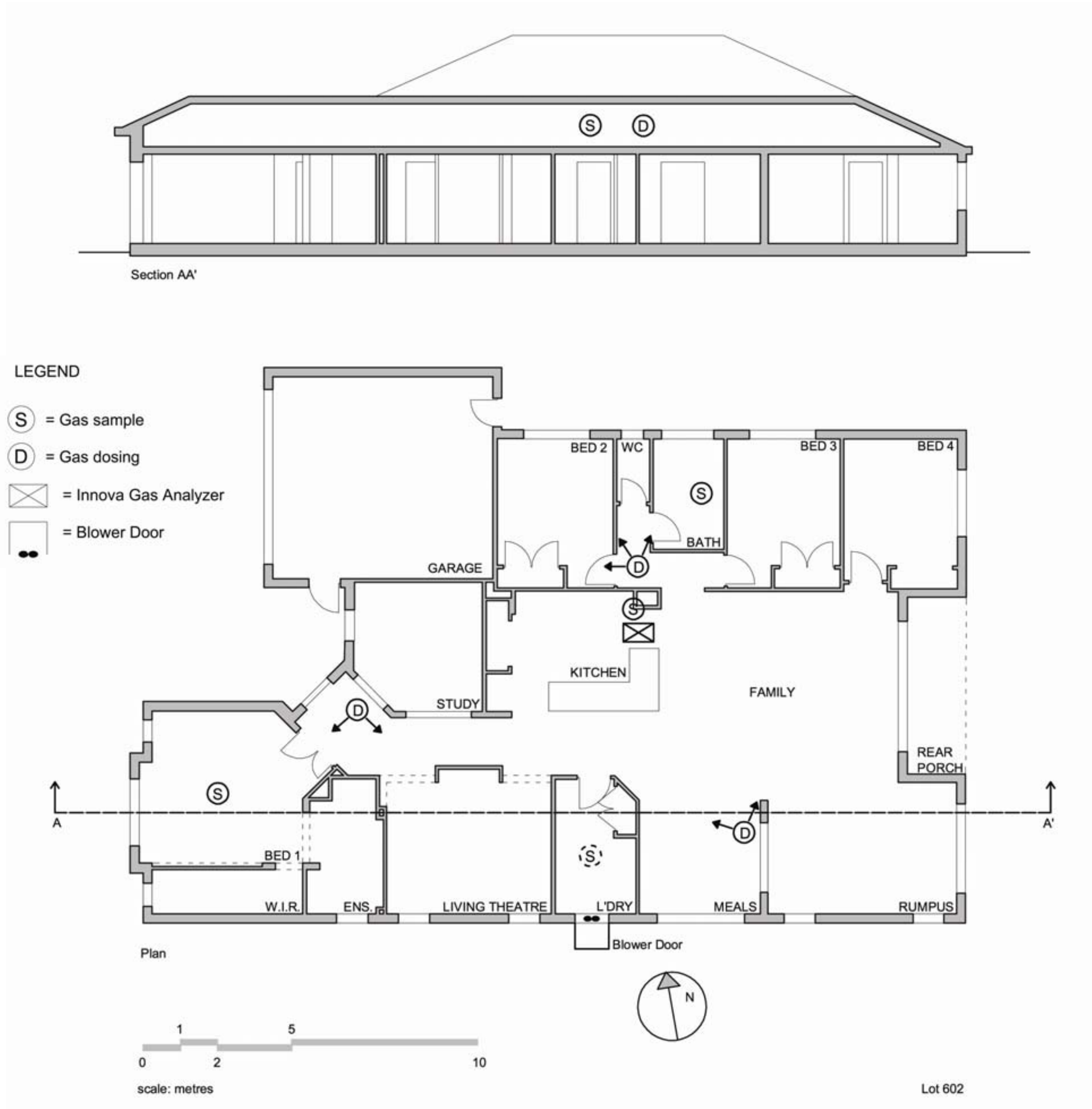

Figure 6 Section, Plan and Instrument Locations in Lot 602

The following is the data from the testing of both houses.

Figure 7 shows an upper and a lower curve. The upper curve represents Flow Pressure in the blower door apparatus. The Flow Pressure graph shows the calibration of the orifice plate meter that is used to calculate the flow rate. This curve is dependent on the orifice size that has been used for the building test. Different size plates are used depending on the volume of the building under testing.

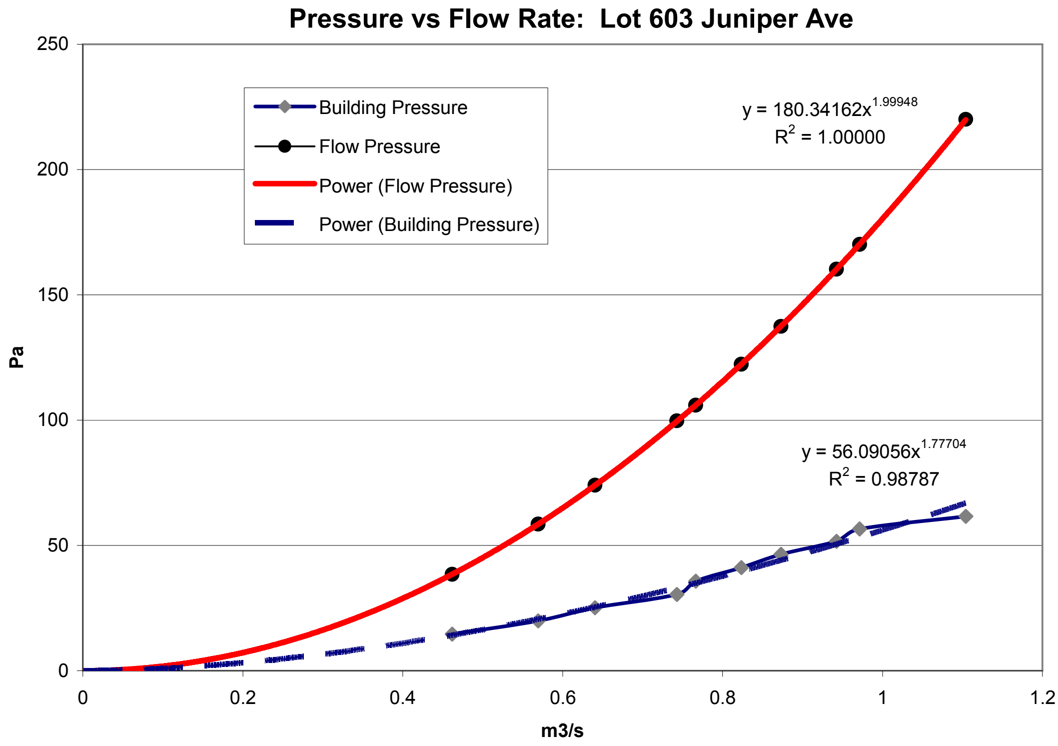

Figure 7: Pressure vs. Flow rate for Lot 603

The Flow Pressure Curve for this plate (of house 603) follows the formula of:

$$y \text{ (flow rate)} = 180.342\ x^{1.99948}$$

where x = Flow pressure (Pa).

The data for the first test of building depressurization versus leakage flow into the structure gives the lower curve in Figure 7, indicating that the flow into the building follows the formula $y = 56.09056\ x^{1.77704}$ where y = flow rate (in m^3/s) and x = the absolute value of the Building pressure (refer to Equation 1). Therefore at 2.5 Pa pressure (the target value for calculations) this gives a flow rate into the building of 0.174 m^3/s. This equates to 1.33 ACH @ 2.5 Pa (based on a building volume of 469 m^3).

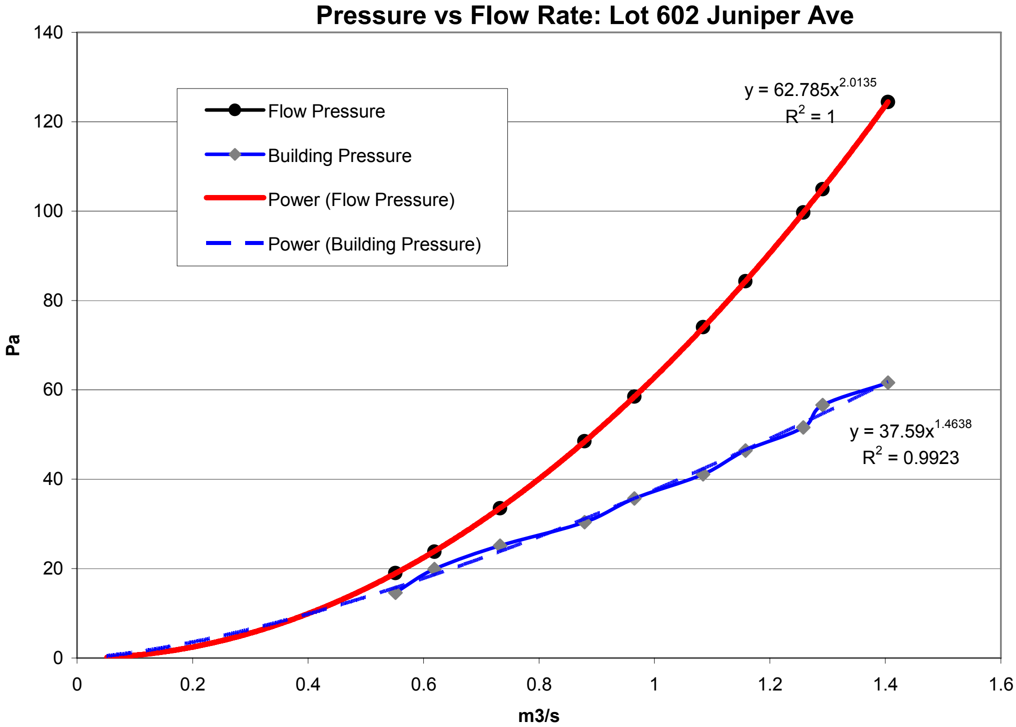

Figure 8: Pressure vs. Flow rate for Lot 602

The data for the test of building depressurization versus leakage flow into the second house (602) gives a graph shown in Figure 8 which indicates that the flow into the building follows the formula

$$y = 37.59\ x^{1.4638}$$

where y = flow rate (in m^3/s) and x = the absolute value of the building pressure (refer to Equation 1).

Therefore at 2.5 Pa pressure (the target value for calculations) this gives a flow rate into the building of 0.157 m^3/s. This equates to 0.91 ACH @ 2.5 Pa (based on a building volume of 619 m^3).

The Flow pressure graph shows the calibration of the orifice plate meter that is used to calculate the flow rate. This curve is dependent on the orifice size that has been used for the building test.

The curve for this plate follows the formula of y (flow rate) = $62.785\ x^{\mathbf{2.0135}}$

where x = Flow pressure (Pa).

Air Barrier Technologies report the results of these tests as either:

- Effective Leakage Area (ELA) at either 4 or 10 Pa (in m^2), or
- Air Changes per Hour (ACH) at 50 Pa.

3.3 Tracer Gas Study

When conducting a Tracer Gas Dilution Study with the B&K Innova equipment as used by MABEL, not only is the decay of the tracer gas monitored, but so can other indicators of Indoor Air Quality (IAQ) be simultaneously monitored.

In this study, Sulphur Hexafluoride (SF6) was the Primary Tracer, but Carbon Dioxide (CO2) was also measured. This proved beneficial in this study because the movement of CO2 from the house into the roof space was able to be tracked, which revealed this pathway as a major source of leakage for the building under study. In this study the CO2 was from expired air from the Building Commission visitors monitoring the test (see Figure 9).

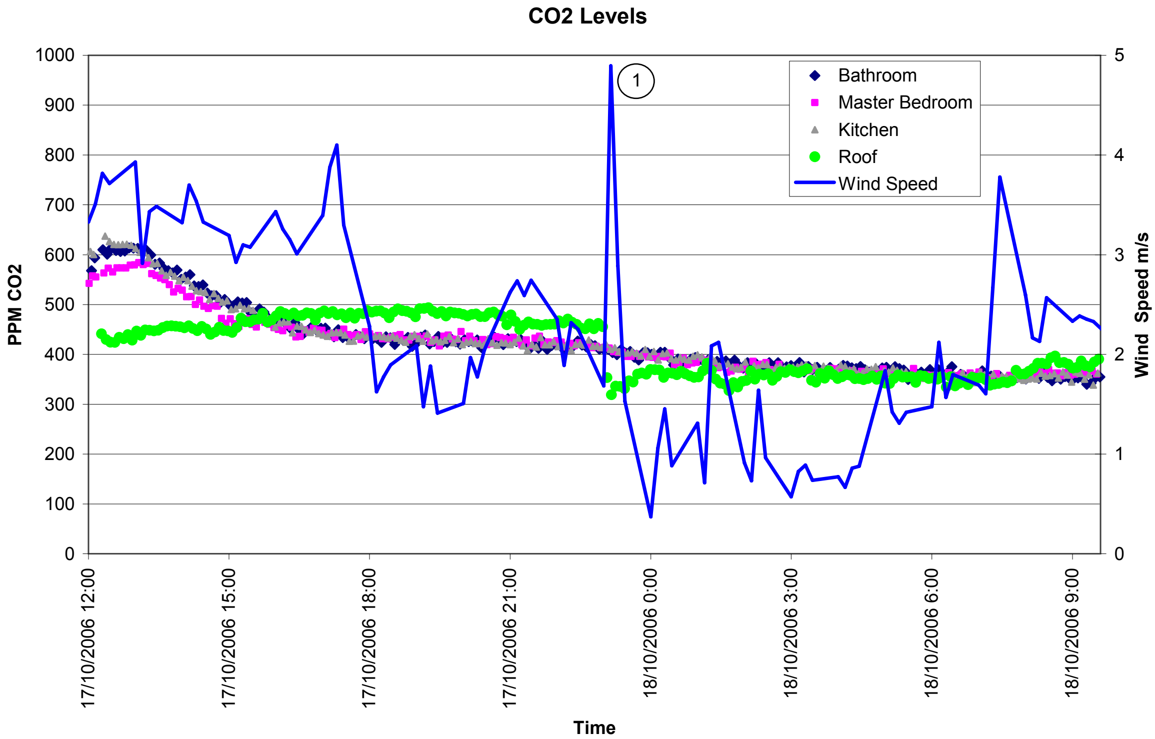

Figure 9 CO2 Levels in House Lot 602.

As can be seen in **Error! Reference source not found.**, after the initial spike in CO2 due to the group of visitors, a concentration decay takes place (note: Kitchen and Mater Bedroom curves). As CO2 diffuses into the roof space, for a period of 8 or 9 hours, the roof has a higher CO2 level than the house, until a short wind gust just before midnight of the 17th (note: Pt.-1), causes the gas to be flushed out. The gas levels then stabilize at close to background levels across the structure. This is an indication that a house to roof leakage is quite evident and suggests a need for further investigation of this type of construction.

Below is the associated ACH data as derived from the Tracer Gas Dilution Method (Figure 10).

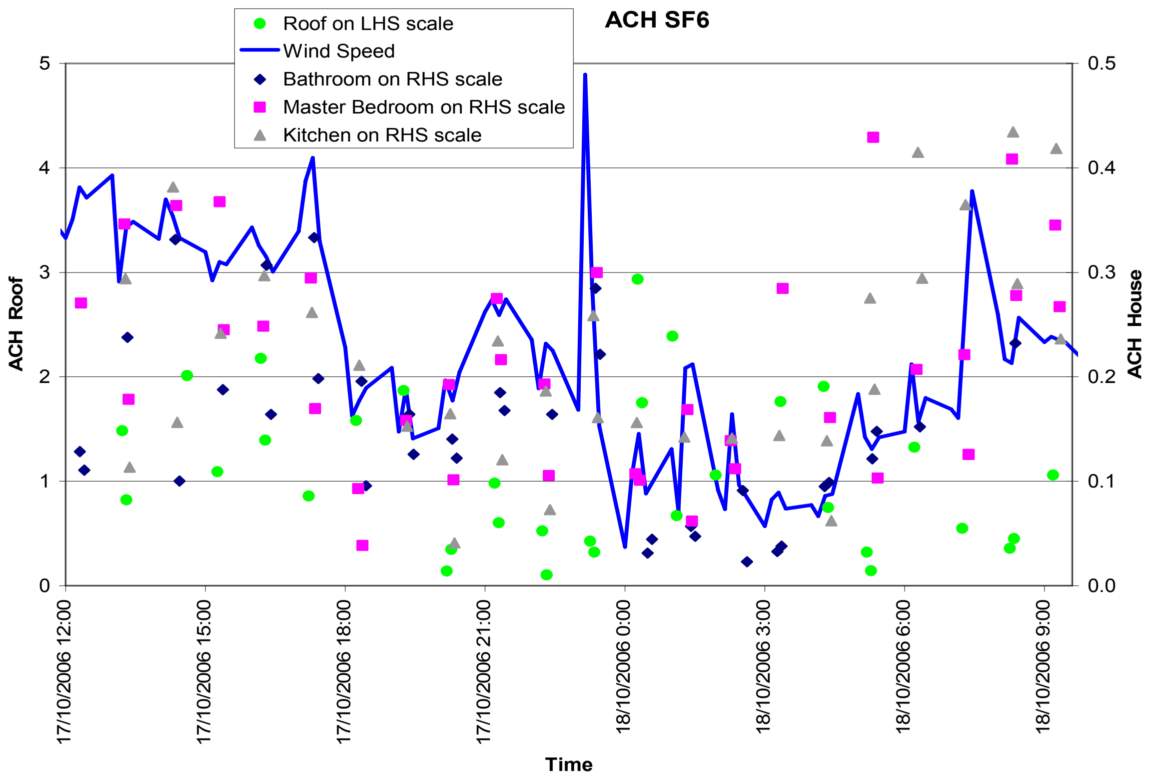

Figure 10 : Air Change Rate and Wind speed for Lot 602

The graph above shows that the ACH for the roof space varies between 0 and 3 ACH, and the rooms of the house vary between 0 and 0.45 ACH, for a wind speed of approximately 1 to 4 metres per second with one gust at 5 metres per second.

For the second building (Figure 11) the weather was much more stable with wind speeds between approximately 1 and 2.5 metres per second. The ACH for this building were noticeably non-uniform across the building with the front two rooms (lounge and bedroom) tested consistently giving results higher than the rooms tested at the rear of the house (kitchen and bath). This could be due to the influence of wind direction rather than construction and requires further study.

The ACH for this building can be split into two zones as mentioned above. The higher rate zone (front) ranged from a high of 1.3 down to 0.2 ACH. The low rate zone (rear of house) ranged from 0.4 down to 0 ACH.

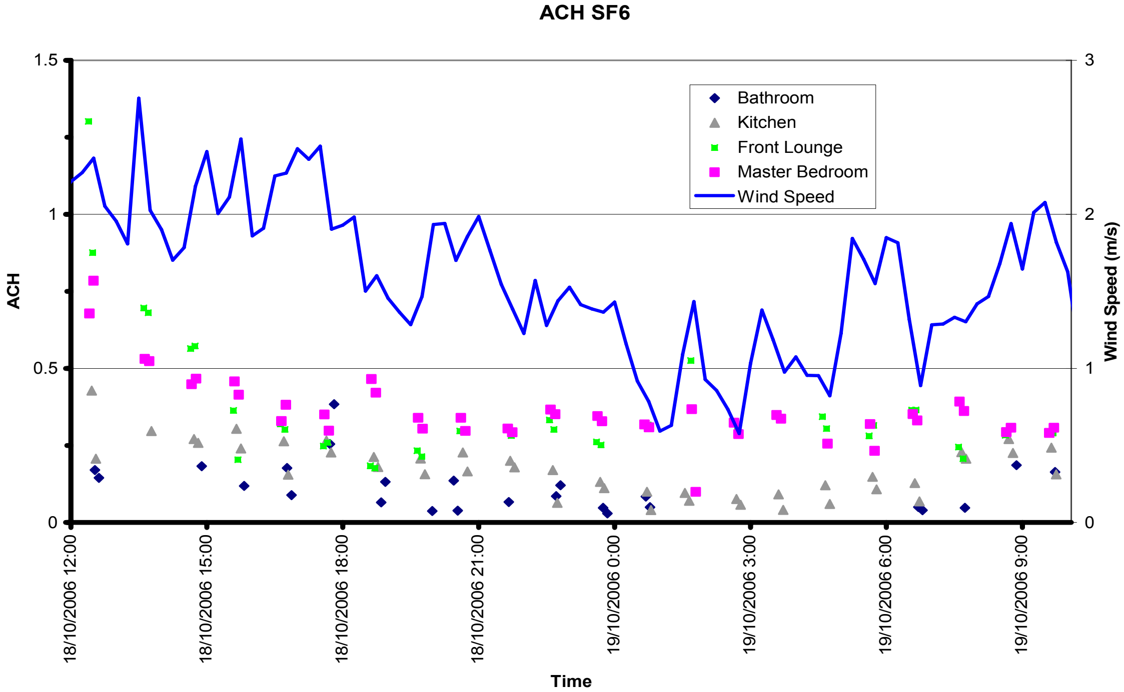

Figure 11 Air Change Rate and Wind Speed for Lot 603

For the second building the weather was much more stable with wind speeds between approximately 1 and 2.5 metres per second. The ACH for this building were noticeably non-uniform across the building with the front two rooms tested consistently giving results higher than the rooms tested at the rear of the house. This could be due to the influence of wind direction rather than construction and requires further study.

The ACH for this building can be split into two zones as mentioned above. The higher rate zone (front) ranged from a high of 1.3 down to 0.2 ACH. The low rate zone (rear of house) ranged from 0.4 down to 0 ACH.

4 Conclusion of Testing and Further Research

An initial aim of this short exploratory test was to see if the factor of 20

ACH50 / 20 = ACHNL Equation 2)

Note: 20 is the assumed Factor for converting to a ACH_{NL} rate.

is valid for Australian construction styles and climates.

At the conclusion of testing only two buildings we have the following information:

Table 3 Air Change Rate Estimation

Test Site	**ACH @ 50 Pa**	Calculated ACH @ 2.5 Pa	Measured w/ Tracer ACH (range)	Factor for ACH_{50}-$ACH_{2.5}$	Factor for ACH_{50}-$ACH_{Tracer\ Gas}$
Lot 602	7.17	0.91	0.45 – 0.01	7.88	15.9 - 717
Lot 603	8.39	1.33	1.3 – 0.01	6.31	6.7 - 839

Note that in the above Table 3 the factor for ACH_{50}- $ACH_{2.5}$ is to be compared against the factor 20 claims made by Sherman in Equation 2.

It is obviously difficult to obtain definitive answers from such a small data set. However this was never the objective of this study.

It has revealed however that even in building stock made by the same builder, in the same style and with only a change in total room numbers and floor space, significant variations in the coefficient and exponent for the equation $Q = C\ \Delta P^n$ (Equation 1) were evident.

This was unexpected. It was presumed that a more normal situation would have shown variations in the coefficient between building stock of the same builder, but with variations of the exponent only being evident between builders with different building styles and construction methods.

This greater variability only increases the need for a much larger dataset to arrive a better estimate of the Normalised Leakage Rate.

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Appendix A: MABEL Performance Measurement Table

Measurement	Standards	Deliverables / Compliance
Power		
Energy of equipment	AS 3598:2000 level 1	Excessive energy use and CO2, BASIX, NatHERS, AGBR (Greenstar)
Efficiency of equipment	AS 3598:2000 level 2 and 3	Measurement of specific appliances
System defects		Diagnostic fault finding in range of components
Flow rates in pipes		In AHU compared to performance
Building envelope	ASHRAE	Heat transfer in facade
Lighting		
Background lux	AS 1680	Over or under lighting of areas IEQ6, IEQ3 (Greenstar)
Task lighting lux	AS 1680	Work plane results IEQ6, IEQ3 (Greenstar)
Room brightness/contrast	AS 1680	Heat transfer in facade
Colour quality/ranges	CRI	Light colour variations
Glare index	DGI	Disability/ discomfort glare areas
Comfort		
Weather and solar	General practice	Defines the external conditions under which internal measured parameters are taken.
Indoor air quality	ASHRAE	Pinpoints IAQ at various points: CO_2 and VOC's
Effectiveness of air distribution	ASHRAE ADPI	Draught index at various points
Comfort levels	ASHRAE 55	PMV / PPD occupant comfort, Greenstar
Surface temperatures		Level of calculation dependant on circumstance
Sound		
Background noise	AS 2107	dB(A) for BASIX, IEQ 10 (Greenstar) and NABERS
Reverberation time	AS 2107	RT time IEQ 10 (Greenstar)
Partition and room sound transmission	AS 1469	Noise Rating (NR) in acceptable range, complies to Sound transmission class (STC)
Identification of noise sources	AS 4241, AS 1217	Identification of sound leak areas
Quality of room acoustics	AS 2107, AS 2460	Assessment of acoustics and recommendations on best applications eg music type
Speech intelligibility analysis	AS 2822	Assessment of Speech Transmission Index (STI)