Air leakage in buildings - review of international literature and standards

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BEDP ENVIRONMENT DESIGN GUIDE

AIR LEAKAGE IN BUILDINGS – REVIEW OF INTERNATIONAL LITERATURE AND STANDARDS

Mark B Luther

This paper reviews the information available internationally on air leakage and testing of buildings, and reviews the systems and standards available. This paper and its companion paper TEC 24, originate from a Victorian study which gives an understanding of the issues and metrics of air leakage, and builds a case for further Australian research into air leakage of buildings.

Keywords
air leakage, blower door testing, building envelope, energy efficiency, exfiltration, fan pressurisation method (FPM), infiltration, tracer gas dilution method (TGDM).

1.0 INTRODUCTION

This paper and the companion paper *TEC 24: Realising Air Leakage in Australian Housing* is the result of a study that was commissioned by the Victorian Building Commission. The intention for this paper is to provide a brief literature overview of the subject of air-tightness or leakage (infiltration and exfiltration) testing in buildings, and how this might apply to Australia. Specifically two different testing methods; the **Fan Pressurisation Method** (**FPM**), for air-tightness, and the **Tracer Gas Dilution Method** (**TGDM**) are discussed for their accepted ability to measure volumetric air change rates within buildings. Practical case studies for these are discussed in TEC 24.

Overseas standards and research recognise that the sealing of air leaks in houses (tightening) is the single most cost effective method of achieving direct energy savings. It is essential that exterior construction (building envelope) tightening methods, which can ensure energy efficiency while maintaining a healthy indoor air quality environment, need to be developed to suit Australian climates and construction types.

The building Industry and consumers are sceptical of building tightening possibly due to stories of 'Sick Building Syndrome' associated with attempts to increase the energy efficiency of buildings by better sealing after the 1970's Oil Crisis. While very few buildings were actually found to be problematic, the media attention of the time caused the phenomena to become lodged in the public's minds. Uncontrolled leakage undoubtedly wastes energy by increasing heating and cooling requirements.

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 and Built Environment Laboratory (MABEL) and Air Barrier Technologies Pty Ltd that Australian buildings are on average, 2-4 times leakier than European or Northern American buildings. This suggests a tremendous opportunity for energy savings in Australia.

While the energy savings of sealed buildings can be quickly translated into the reduction of carbon dioxide and other greenhouse gases, Australia also has among 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. Solutions to an optimised, healthy residential air-conditioning design are also a result of MABEL's ongoing research. (Note: This does not imply heating and cooling but rather filtration and fresh air inputs).

A major parameter in Indoor Air Quality (IAQ) measurements is the concentration and characterisation of Volatile Organic Compounds (VOCs) in the air. These VOCs are present both in the external air, from traffic emissions etc, and released by the materials of construction of the building such as paint, MDF board products, as well as furnishings within the building.

Already several testing methods for air leakage have been established for colder climates, such as Canada, Germany, United Kingdom, Sweden, Japan and the USA, These are countries that have excelled in energy savings through improved building envelope construction. Australia needs to research construction and tightening methods to suit Australian climates.

2.0 LITERATURE REVIEW

The literature review defines two accepted testing methods, provides further insight into the parameters, the 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.

The International Energy Agency (IEA) *Annex 26, Energy Efficient Ventilation of Large Enclosures: 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 to include appropriate shading, thermal storage, etc are becoming the norm, infiltration and building pressurisation are left as the unknown variables in energy analysis. The more learnt about building infiltration and its mitigation the better we can predict, operate and control the ventilation energy requirements of our buildings.

IAQ is determined by 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, and generally applies to the known quantity supplied by 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 measure. Industry methodology and research practices provide calculations which estimate the theoretical quantity of external air added to ventilation as well as infiltration of air entering a building (ASHRAE, etc.)

The Australian standard *AS 1668.2-1991 The Use of Mechanical Ventilation and Air-Conditioning in Buildings - Mechanical Ventilation for Acceptable Indoor-Air Quality* 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 proportion of outside air to be included in the ventilation of particular building types. Conventionally the fresh air into a space is addressed through volumetric units such as L/s or **ACH (Air Changes per Hour)**. The fresh air is noted as a ration of outside air to that already in the space. These ventilation rates are provided with the intention of maintaining carbon dioxide levels (CO_2) below 1000 ppm. For example, in residential application this assumes 4-5 occupants; the air ventilation rate is 7.5 l/second/person. This equates to about 0.5 ACH for a typical house although varies with the internal volume of the dwelling. The house investigated in the accompanying TEC 24 note, had a 0.2 ACH at 7.5 l/s/person. The 'required ventilation' air in such buildings may already be exceeded by the 'infiltration' or air leakage, through the building construction envelope. Conditioning these volumes of ventilation would require significant higher capital investment in equipment, and high energy consumption in order to provide control of the indoor/outdoor pressure (Ask, 2003). It therefore stands to reason that infiltration and exfiltaration should be better managed.

For a building without a mechanical system the occupants would generally rely on operable windows, or if in a closed condition – merely on infiltration for fresh air. Infiltration 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). Defining this unknown is the purpose of this study.

Designers should not fixate on preventing air leakage, i.e. making buildings 'air tight', because even if gaps were completely sealed, buildings have doors and windows which allow the occupants to allow large volume air changes at their discretion. Instead the goal for designers should be to:

- quantify leakage
- reduce excessive leakage
- control leakage by managing air pressures with the HVAC (Heating Ventilation and Air-Conditioning) system (Ask, 2003).

The golden rule for mitigating unwanted air leakage is:

"Build tight…ventilate right !"

One of the primary research interests of the accompanying TEC 24 demonstration study is to compare the results from both testing methods, and it is therefore desirable to run tests consecutively and as close as possible to each other.

2.1 A Brief Overview of the Standards

Several standards exist for the two testing methods mentioned above, but other methods that can assist in locating images include tracer smoke, sound transmission and thermal imaging testing. Specific building component testing is not the objective 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. Testing method advantages and disadvantages are offered in the *AIVC – A Guide to Energy Efficient Ventilation publication* by Liddament (1996).

2.2 What Needs to be Investigated in Ventilation and Infiltration

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

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

Such measurements are essential for building commissioning, diagnostic analysis, design and research (Liddament, 1996).

The primary intention of the blower door testing is to report on the air-tightness of a building envelope. An extensive literature search found that extremely few explanations provide the rationale behind the studies for air-tightness. This finding is also confirmed in the seminal publication *Air Leakage Characteristics, Test Methods and Specifications for Large Buildings* by Proskiw and Phillips (2001). Reasons for researching the air-tightness of buildings include:

- improved energy savings through the reduction in volume of infiltrated and exfiltrated air
- resultant reduced energy demand for heating and cooling
- establishing better values 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 in the envelope (and thus controlling damage through improved detailing)
- better health performance through limiting external pollutants
- controlling IAQ by the avoidance of indoor pollutants concentrating beyond health levels
- reducing external noise nuisance
- improved thermal comfort through less (cold) draughts
- better construction details through quantification of air-tightness
- better control of the actual pressurisation differentials between building interior and exterior spaces.

The effects of air leakage within buildings are exacerbated by the pressure differential between the exterior and interior of the building envelope. It would be ideal to design and control building pressures with the ability to provide a small pressure differential, with generally a greater indoor pressure (i.e. < 2.5Pa).

Small pressure differentials have been shown to work well in hot humid climates, though are difficult to maintain. As wind currents change direction and intensity, so do the pressurisation differentials. In locations where wind strength and direction are more predictable, such as seaside locations, control over pressure differentials within a building may be easier to control (Ask, 2003).

3.0 AIR LEAKAGE TESTING METHODS

The two internationally accepted methods for determining air infiltration or the 'leakiness' of buildings are detailed below.

3.1 Fan Pressurisation Methods

The fan pressurisation method pressurises or depressurises the building through large fans and is measured and the volume of air required to be

Figure 1. Blower door fan installation within external door opening, and gauges

transferred is measured at prescribed pressures. This method is also known as 'blower door' testing. This instrumentation is fitted within an external doorway framing the entire opening (see Figure 1). The readings of the pressure and the volume of air loss are recorded by the instrumentation sensors through the assistance of a computer. 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 (see Equation 1 and Figure 2).

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

where

Q = air leakage (l/s)

C = flow coefficient (l/s ◦ Pn)

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

n = flow exponent (dimensionless)

Equation 1

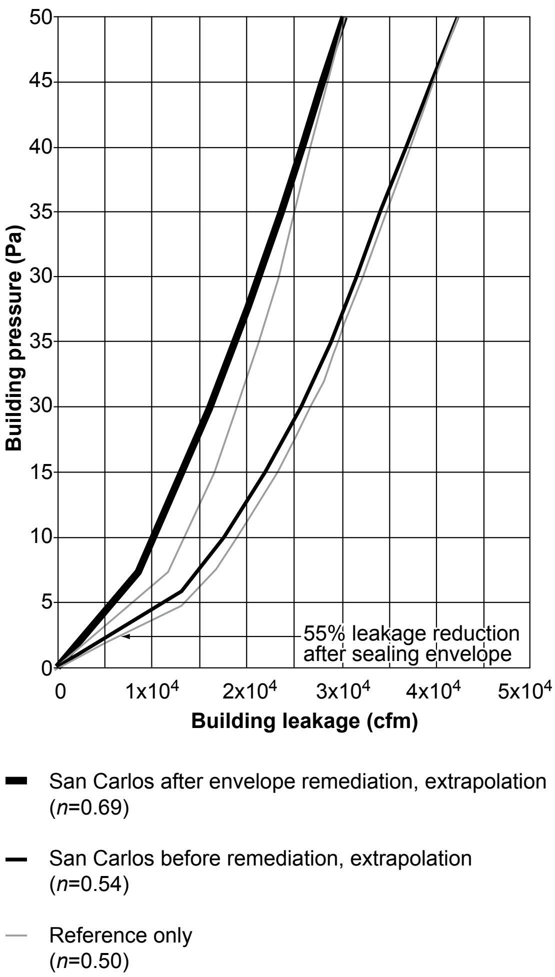

Figure 2. Air leakage to building pressure relationship: example (Ask, 2003)

Results are shown for the San Carlos Park Elementary School, in the hot humid climate of Florida, USA.

Figure 2 is an 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).

CIBSE TM23 UK Standard for Air Leakage Tests

Since 2002 all buildings in the UK with a gross floor area greater than 1000 m² had to be tested for leakage, and from 2006 this applied to buildings over 500m². The air leakage tests must be carried out in accordance with CIBSE TM23, and it is in this standard that the maximum allowable leakage of 10m³/hr at 50 Pascal per m² of envelope area is mandated. 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 natural and mechanical 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

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

- the relationship between highly pressurised blower door leakage quantities and Normalised Leakage or 'natural leakage' conditions
- the establishment of the leakage coefficient 'n' under various measured pressure levels (see Equation 1 and Figure 2)
- the ramifications between IAQ 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.

3.2 Tracer Gas Dilution Method

In the TGDM a 'tracer' gas is dispersed throughout the space to be tested at a known concentration. The concentration of this gas is monitored at regular intervals, and the amount of fresh air entering a building is inferred from the rate of change in the gas concentration as the gas is swept from the space.

3.2.1 Tracer Gas Dilution Methods

TGDM provides an accurate measurement of the accumulated airflow rate through the many unknown gaps and cracks that appear in the construction of a building. Both the American Society for Testing and Materials *ASTM E 741: Standard Test Method for Determining Air Change in a Single Zone by Means of a Tracer Gas Dilution* and the international standard *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 airflow rate or an air change rate (ACH). These are the:

- concentration decay method
- constant injection method
- the constant concentration method.

3.2.2 TGDM and Supporting Instrumentation

Much of the literature describes the measurement conditions for 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 TGDM as applied by MABEL is inclusive of these variables:

- external wind speed and direction for the test site
- external and internal air temperature difference
- internal air temperature stratification
- differential pressure difference between the outside and inside of the building envelope

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 Normalised Leakage as provided by Sherman above.

3.2.3 Concentration Decay Method

Single tracer gas concentration decay method is the most common and straightforward method of leakage measurement, as well as the least disruptive. The tracer gas can be dispersed through an air distribution system or by small desk type (or similar) fans. Once the desired quantity has been released the gas is turned off and followed by an additional short period to allow for thorough air mixing. The concentration or 'decay' of tracer gas is measured over typically 15-30 minute intervals. Decay is the term used for the dilution of tracer gas concentration due to the effects of air leakage. The air change rate is directly related to the decay gradient. 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 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 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 distributed into the test zone, after which the concentration of tracer gas is measured at specific intervals. 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 condition will be reached, and thus allow a flow rate change to be calculated. It is a great method for obtaining a flow rate in a duct-like volume, where the space tends to flushed from one end to the other. 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 *constant concentration* testing below.

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 airflows between measured zones cannot be detected using this approach. A summary of these diagnostic techniques is provided in Table 1 below (Charlesworth, 1988). Table 2 implies a program of building measurement defining the purpose and use of both methods and provides additional justification of our need to conduct both tests.

3.3 The Relationship Between the Methods

The sponsors of the research project by the Victorian Building Commission, in contrast to the numerous projects identified in the literature review, requested the need for both FPM as well as TGDM. The results of each are extremely useful in interpreting the other. An assessment realising the advantages and disadvantages of each method could be identified as follows:

FPM	
Advantages:	**Disadvantages**
• This 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 data that can guide retrofitting and a process for improving leakages in a building. • The system is self-checking, affected by taking readings at different pressures and comparing the results to highlight anomalies associated with a particular test/ pressure. • Allows for the comparison of 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 for testing to be undertaken in most conditions.	• The method does not provide results under natural building pressurised conditions • The method assumes a moderate (non-windy) external condition • The correlations made for normalised leakage conditions are estimates of the measured pressure curve.
TGDM	
Advantages:	**Disadvantages**
• The method can provide continuous results under varying external conditions. • The method provides air change rates as well as airflow rates under actual conditions. • Useful data can be collected to correlate results with FPM. • Testing can be conducted with HVAC systems in operation or turned off.	• 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.

Table 2. Advantages and disadvantages of both FPM and TGDM

3.4 Previous Research Findings and Case Studies

A literature survey conducted by the Canadian Mortgage and Housing Corporation concluded that most large buildings, including those built within the last few years, have considerable air leakage and were often found to be 10-50 times those referenced by the current recommendations of the 1995 National Building Code of Canada (Proskiw, 2001). A similar conclusion was reached by the report of Emmerich (2005) for American buildings. This is despite there being design details and quantitative data available as well as standards established for air-tightness, as well as qualitative testing methods.

An American example of a Florida school building was tested for its air leakage and indicated a good result. Florida buildings represent a temperate to hot and humid climate where buildings are generally not sealed as well as those in colder climates. After sealing and insulating the building, a 55 per cent improvement on the infiltration under normalised leakage conditions was seen. A normalised leakage condition at 2.5Pa is estimated from the blower door parabola (see Figure 3). In the Florida infiltration test it is likely that tracer gas testing methods would have assisted in verifying the estimates made under normalised (natural) wind conditions and 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 pressurisation 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.

There is little data on the simultaneous or side-by-side testing of both the FPM and the TGDM, with one of the few found being 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 depressurisation (50Pa) is applied to the room below and the ratio between is given by the ratio of tracer gas concentration in the roof space and that in the room.

$$ACH_{50} / 20 = ACH_{NL}$$

Equation 2

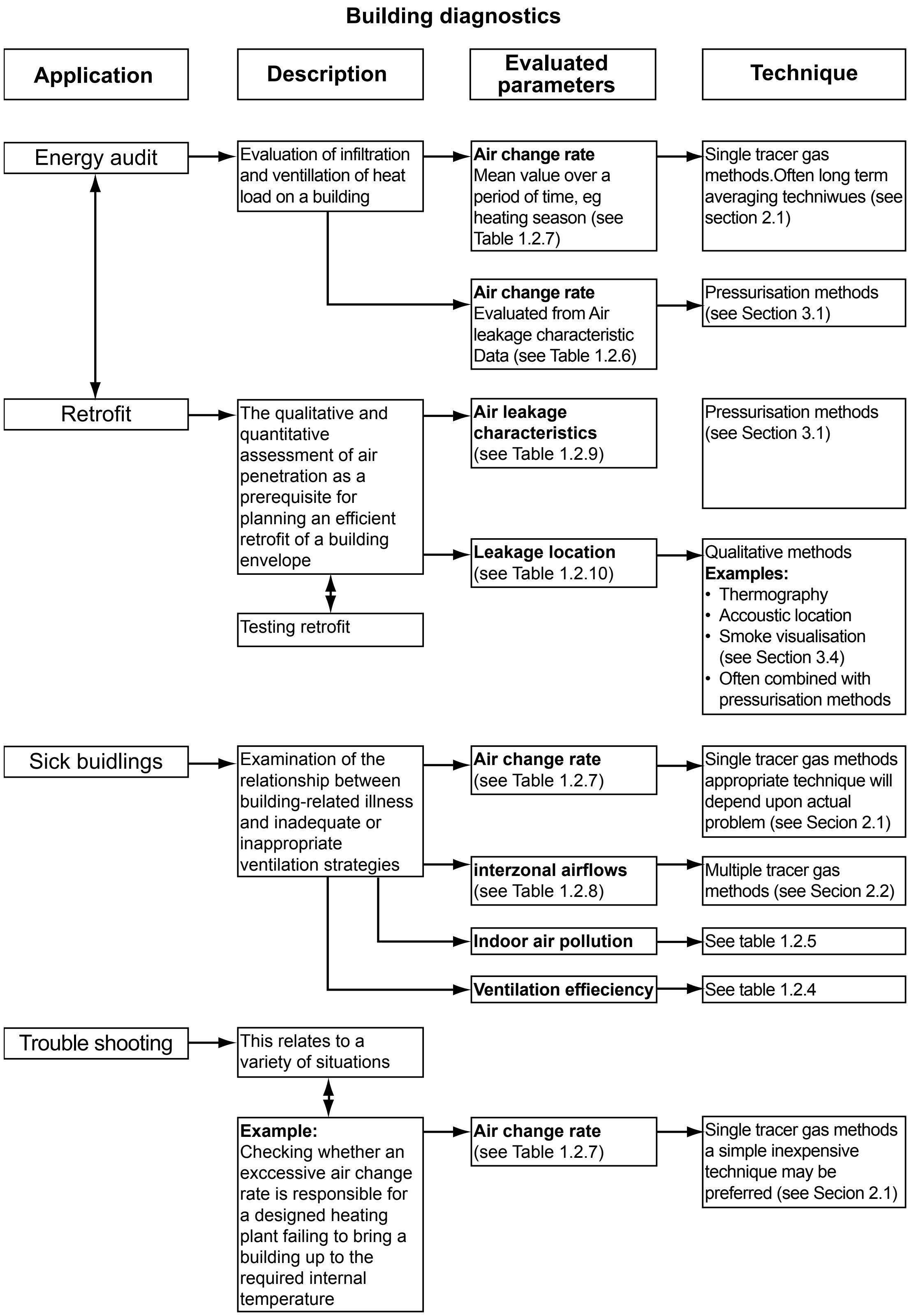

Table 3. Diagnostic testing with FPM and TGDM
(Source: Charlesworth, 1988)

Leakage class	Minimum NL	Maximum NL	Typical ACH50	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	1.6	27	Buildings in this range may be too loose and should be tightened	
J	1.60				

Table 4. Air leakage classification and ventilation requirement

(Sherman, 1998)

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

ACH50 = their change rate of the blower door testing rest under a 50 Pa condition

'Balanced' refers to the balance between internal and external pressure, where the pressurised difference is kept to a minimum.

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

4.0 FUTURE RESEARCH FOR AUSTRALIA

The present energy house rating programs concern themselves only with the building envelope. This energy evaluation is heavily reliant on *assumed* figures of air leakage, many of which have been sourced from overseas. This suggests that there is substantial room for improvement within Australian rating systems and actual performance testing.

In the companion TEC 24 note, a 5-Star building is observed with a blower door test ACH50 = 20 . This implies a leaky building between 0.8-1.13 ACH according to the chart. MABEL and Air Barrier Technology have encountered much higher infiltration rates of buildings with this blower door leakage rating. In the opinion of the author, buildings that exhibit such high leakage should be prevented from being given the minimum 5-Star rating.

Based on preliminary findings of the apparent leakiness of Australian buildings, one could strongly argue that our present predictive tools for energy consumption are not representative of the behaviour of actual construction methods in Australia. The specific objectives of future research would be to:

- conduct combined testing (FPM and TGDM) on a significant sample of dwellings to inform action of government and industry
- determine actual excessive energy consumption, CO_2 emissions and associated implications of house infiltration/air losses (leakage)
- determine the IAQ and associated health implications of leaky as compared to tight buildings
- inform inputs for simulation by home energy modelling software, which are the software engines used in all current home energy rating systems in Australia
- educate practitioners and industry on the impact of leakage on energy performance
- promote better construction practices to mitigate leakage
- mandate/specify these methods (most homes by project home market)
- develop a standard procedure to ensure that builders' efforts in achieving air tightness have been met and that building owners are assured that they are getting value for money.
- promote blower door testing on all buildings as it is a simple and quick test for understanding air tightness.

Additionally, the outputs of a larger study should be scientifically suitable for defining the acceptable standard or 'deemed to satisfy' construction detailing required by the Building Code of Australia, in terms of the leakage rate and its effect on energy consumption as well as IAQ. The air leakage can be related to indoor air quality control, draughtiness, and discomfort.

5.0 CONCLUSION

An urgent research question remaining to be answered is: How 'tight' can Australian buildings be before indoor air quality is compromised?

The report and its findings provide support for further work and analysis, applying both testing methods to several building types such as residential, commercial, industrial, schools, office buildings, etc. The intention of this paper is to raise awareness of air leakage and to outline the information needed for developing a knowledge base on Australian building envelopes. As well, it highlights the need for guidelines to aid improved ventilation performance and a method by which the degree of air tightness of a building can be tested and verified.

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 that extends the existing research of other countries. Researching both the FPM and TGDM approaches side-by-side provides a better research study of the air-leakage as well as the infiltration air change rates, compared to that of other research programs. It is therefore strongly recommended that Australian regulators and industry understand this, and move toward producing a coordinated programme of research and the establishment of a national database for air leakage.

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 categorise commercial buildings into shopping facilities, schools, office buildings, etc as well as document the type of envelope construction used.

For the many reasons discussed above, Canada, the USA, and United Kingdom have benefited greatly from a research program on building air-tightness. As Australian construction appears to be 'leakier' than that of most of these countries, such a programme in Australia would be expected to bring even greater benefit. This knowledge is critical in the further refinement of building simulation programs and ventilation assessment in Australia.

APPENDIX

TABLE OF INTERNATIONAL STANDARDS ON AIR LEAKAGE AND TESTING

CIBSE TM23 UK Standard for Air Leakage Tests
In the UK air leakage tests must be carried out in accordance with *CIBSE TM23 Testing buildings for air leakage* 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 $10m^3$/hr at 50 Pascal per m^2 of envelope area.
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 with the measuring of ACH relative to the surface area of the building envelope providing 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 which is applied primarily in the USA was developed by the American Society for Testing and Materials standards authority and permits a pressurisation or depressurisation of the building for which the results can be slightly different. . 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). The test pressure range is between 12.5Pa – 75Pa in increments of 12.5Pa.
ASTM E 1827 – Determining Air tightness 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 that of E779 above.
ISO 9972 – Thermal Insulation, Determination of Building Air tightness – Fan Pressurisation 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 pressurised or depressurised 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 or at least 5 points of measurement.
Other fan pressurisation methods exist focusing on individual components or compartments of the building such as curtain walls, windows, doors etc. These methods are outside the scope of this report.

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