AIR TIGHTNESS OF AUSTRALIAN OFFICES BUILDINGS: REALITY VERSUS TYPICAL ASSUMPTIONS USED IN ENERGY PERFORMANCE SIMULATION.

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ABSTRACT

This study investigates the impact of air tightness assumptions on the accuracy of energy performance predictions generated by building simulation of Australian office buildings.

The first part of this paper will present the results of air leakage testing of a number of Australian office buildings performed by the author in conjunction with a commercial air leakage testing company.

The second part of the paper utilises the values from the air leakage testing in a sensitivity analysis of the impact of assumed air leakage on the predicted energy performance of office buildings in Australian climates.

INTRODUCTION

This paper explores air leakage in Australian office buildings and its impact on building energy performance.

The outcome of recent air leakage testing of a number of Canberra buildings is presented in the first part of the paper. The aim of this part of the study was to determine typical air leakage rates for Australian office buildings.

The results of this testing was used to inform the levels of air leakage in simulation studies to determine the impact of air leakage on energy efficiency of office buildings. The simulations were performed for the climates of Darwin, Melbourne and Sydney, which are located as shown on the map in Figure 1 below.

Air leakage is defined by ISO 9972:2006 as the airflow rate across a building envelope including flow through joints, cracks and porous surfaces. The driving forces for this airflow are mechanical pressurisation and depressurisation, natural wind pressure, air temperature differential and combinations of these forces (American Society for Testing and Materials, 2010).

Currently the Building Code of Australia (BCA) has no requirement for verification of a building's air tightness (Australian Building Codes Board, 2010). In the UK, the UK Building Regulation L specifies requirements for air tightness of any

building with a floor area over 1000 m² and stipulates a limiting air permeability of 10 $m^3/hr/m^2$, with air permeability defined as the flow rate at 50 Pa induced pressure divided by the surface area(UK Government, 2010). The UK Air Tightness Testing and Measurement Association (ATTMA) provides suggested maximum values for air permeability in air conditioned offices of 2 $m^3/hr/m^2$ for best practice and 5 $m^3/hr/m^2$ for normal practice (ATTMA, 2006).
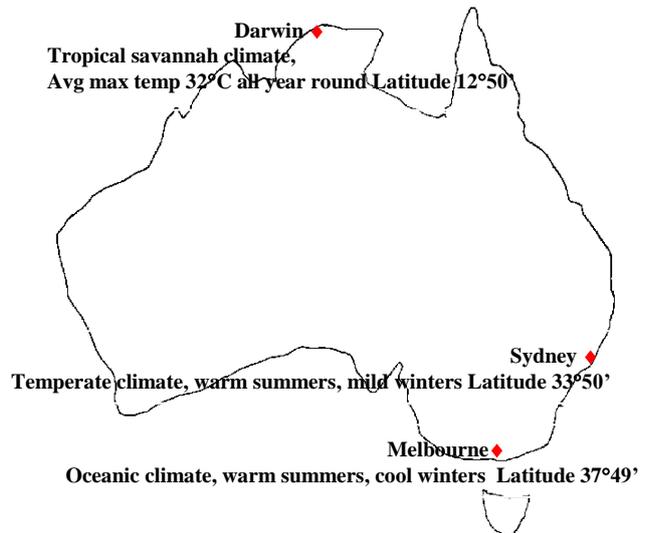

Figure 1: Locations modelled in this paper.

To measure the air leakage of a building by fan pressurisation, a pressure difference across the building envelope of 50 Pa is created and the flow rate across the building envelope recorded. The flow rate at this test pressure in air changes per hour is reported as ACH_{50}. The average annual air leakage per hour (or infiltration) is simply described as ACH. In dwellings, ACH_{50} can be converted to ACH by dividing by 20 (CIBSE, 2000).

There are few published studies of air tightness in Australian buildings. One study of Australian houses (Bigg et al, 1986) tested two groups of houses, one group of 33 selected to include a variety of construction types and a second group of 12 built for a solar village project. These groups had air leakage rates of 26.3 ACH_{50} and 12.2 ACH_{50} respectively. The authors concluded that these levels were well above international standards.

Studies of US houses and apartments found air leakage rates of between 0.5 and 2.0 ACH for 50% of the time with rates below 0.5 ACH for the remaining time (Persily et al, 2010). European housing studies have reported 6 ACH_{50} for Swedish houses and 2.3 ACH_{50} for Swedish flats (Blomsterberg et al, 1999), 3.9 ACH_{50} for Finnish houses (Jokisalul et al, 2007) and 1.5 ACH for Lithuanian apartments (Juodis, 2009).

Testing of air leakage of non-residential buildings tends to be reported as single case studies. In the US ASHRAE's office headquarters was found to have air leakage of 2.4 ACH_{50} (Brennan et al, 2007). Investigating a radiantly heated and cooled office, another study found considerable variation between summer, 0.74 ACH and winter 1.5 ACH (Gong et al 2010l).

The impact of air leakage on the energy use of a building has also been reported in a variety of countries. One study over 13 European countries concluded that across these 53% of heating energy is loss to air leakage (Orme, 2001). In the US similar studies (Emmerich et al, 2007) concluded that savings of 9-36% of total heating and cooling energy usage could be achieved by reducing air leakage depending on the climate, with the lowest savings being achievable in cooling dominated climates. The authors concluded that air leakage is the most significant factor in small building energy consumption. Modelling of an 1860 m² building in Minneapolis showed a 51% increase in HVAC costs when air leakage costs increase from 0.5 to 1.5 ACH (Yuill et al, 1999). The same building modelled in New Orleans showed a 26% increase in HVAC energy use with the same change in air leakage.

One impact of modelling with an inaccurate level of air leakage will clearly be an inaccuracy in the calculated energy required to heat infiltrating air. Inaccurate assumptions of air leakage level in energy performance modelling have also been found to have the following impacts:

- incorrect assessment of whether a system, for example, radiant cooling in a hot humid climate, is viable (Gong et al, 2010);

- misrepresentation of the effectiveness of heat recovery systems (Manz et al, 2007);

- errors in the assumed need for fresh air intake and night-time flushing (Bearg, 2000); and

- errors in modelling conduction through the building envelope due to changes in the temperature profile of the envelope caused by air leakage (Qui et al, 2007).

The selection of the air leakage rate for modelling is not covered by the NABERS Energy Guide to Building Energy Estimation (NSW Department of Environment, Climate Change and Water, 2011). The BCA (Australian Building Codes Board, 2010) gives some guidance for modelling reference buildings

suggesting 1 ACH for perimeter zones when plant is operating and 1.5 ACH for the whole building when plant is not operating. (A reference building is a BCA Deemed-to-Satisfy compliant building used for comparison with an actual design that may not be compliant with the codes checklist of Deemed-to-Satisfy inclusions). The level of air leakage assumed for modelling purposes are generally left to the discretion of the simulator.

METHODOLOGY

Air leakage testing

Six Canberra office buildings were tested in accordance with ASTM E779-10 (American Society for Testing and Materials, 2010). In each case either a single door or two doors were replaced with the blower fan apparatus shown in Figure 2 below.

The tested buildings were prepared in accordance with the standard, for example, outdoor air intakes were sealed off. Some buildings were untenanted while others were tested outside of normal working hours which avoided problems with occupants opening doors and windows during testing.

As the testing of building involved some disruption to normal operations of a buildings, it was difficult to find building owners willing to allow testing. The sole basis for including buildings in this study was that owners allowed access to them. The buildings tested for air leakage are described in Table 3. One of the limitations of this study was that only office buildings in Canberra were tested.

Figure 2: Blower door used for air leakage testing

Simulations

Figure 3 to Figure 8 shows the models of the six buildings simulated in this study. Buildings One, Two and Three are recently built Canberra office buildings, which have been designed to achieve an

NABERS rating of approximately 4 stars. Some of these building had substantial shading from nearby buildings and all had non-uniform shapes typical of real buildings.

Building Two was the only building available for both air leakage testing and modelling and is referred to as Building A in Table 3 below. As the purpose of this paper is to present a broadly applicable sensitivity analysis based on the air leakage testing of a range of buildings rather than a narrow case study, the inclusion of this building in both testing and modelling is not central to the experimental design of this study.
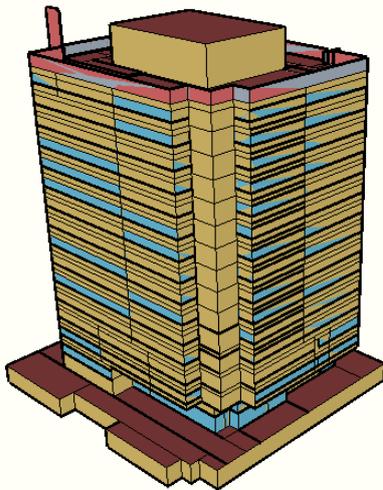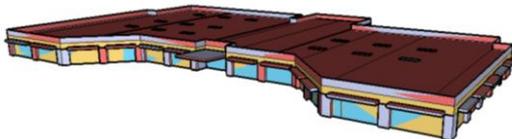
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Figure 3: Building One
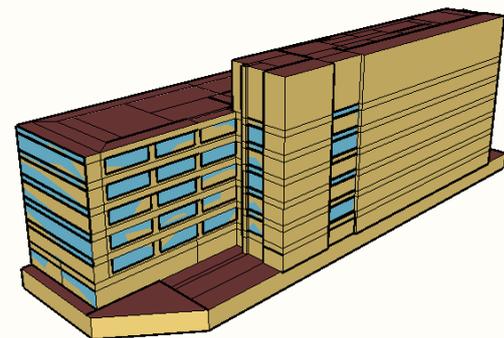

Figure 4: Building Two
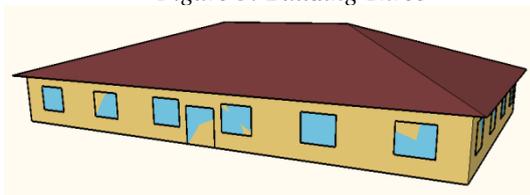

Figure 5: Building Three
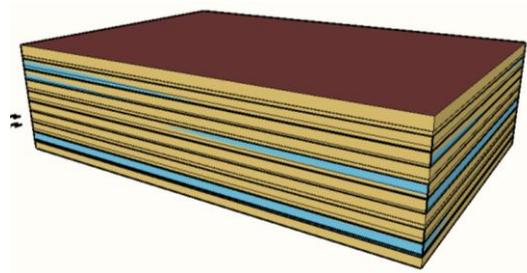

Figure 6: Building Four
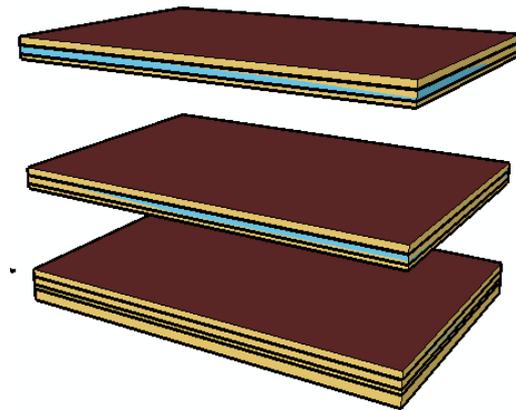

Figure 7: Building Five

Figure 8: Building Six - Note this model simulates a multiple of the central floor

Buildings Four, Five and Six are the San Francisco versions of benchmark offices developed by the US Department of Energy for use with EnergyPlus (Deru et al, 2008). These three offices are simple four-sided models. They have no adjacent buildings or complex geometry.

The characteristics of the buildings are summarised in Table 2 below. In changing the location of the buildings, no attempt was made to adapt the building to the climate.

The buildings were modelled using EnergyPlus, the US Department of Energy's building simulation package. The modelling was done in accordance with NABERS Energy Guide to Building Energy Estimation (NSW Department of Environment, Climate Change and Water, 2011), which provides default values for occupancy, lighting, equipment and air conditioning operation.

The modelling was performed for the climates of Darwin, Melbourne and Sydney. These climates cover the largest population centres in Australia as well as the most common climates.

As no standard assumption for air leakage exists a datum case of 1 ACH when the plant is operating and 0.5 ACH when the plant is off was selected. The buildings using this level of air leakage will be referred to as the datum case. As the simulations

were performed over a range of air leakage values, the results will allow comparison of all values so selection of the datum case is not crucial to the interpretation of the results.

RESULTS AND DISCUSSION

Air leakage testing results

Table 3 below shows the outcomes of each of the air leakage tests performed. The summarised testing of 68 residences in Canberra is shown as Item G of Table 3 for comparison purposes.

The average air leakage for the six offices was 8.69 ACH_{50} and 0.46 ACH with standard deviations of 3.87 for ACH_{50} and 0.23 for ACH. The range of ACH_{50} for the six offices was 5.23 to 16.19 and the range of ACH 0.26 to 0.81. The air leakage in the offices was significantly lower and less variable than for the houses.

The measured air permeability levels of all six offices tested were above the ATTMA air permeability maximum for normal practice of 5 m³/h/m². Three of the offices tested had measured air permeability above the UK Regulation L limiting air permeability of 10 m³/h/m².

All of the tested office buildings had much higher leakage values than the European and US office buildings mentioned in the introduction to this paper. Similarly, the values of air leakage in the Canberra houses were significantly higher than those mentioned in the Introduction as typical in Europe or US.

Based on these results the air leakage range with plant operating of 0.25 ACH to 1.5 ACH was chosen for the simulation part of this study. The air leakage level with plant operating was assumed to be half that of the air leakage with plant operating. The simulations were performed for air leakage increments of 0.25 ACH.

Outcomes of Simulations

The base building energy for each of the datum case building models is summarised in Table 1 below. The range of performance shown here is approximately between NABERS energy ratings of 0 and 5 stars.

The base building energy is all energy used in the building excluding tenant light and plugin power. Base building energy includes all energy used for heating and cooling as well as for lifts and common area lighting. The range of values in Table 1 may in part reflect the unsuitability of the building for the climate in which it was modelled.

Table 1: Base building energy consumptions of modelled buildings with datum 1 ACH air leakage assumption.

BUILDING	BASE BUILDING ENERGY CONSUMPTION (MJ/m²)		
	DARWIN	MELBOURNE	SYDNEY
One	161	80	82
Two	182	82	92
Three	434	292	303
Four	402	270	276
Five	474	454	379
Six	412	418	336

Figure 9 to Figure 14 shows the impact of varying the air leakage across different climates.

The benchmark models provided by the US Department of Energy had an approximately straight-line increase in energy consumption in response to air leakage increase as shown in Figure 12 to Figure 14. This straight line response could be attributed to the absence of shading and the simple geometry of the building models. These models all indicated that halving the air leakage relative to the datum case reduced the energy consumption to approximately 85-95% of it's previous value, depending on the climate.
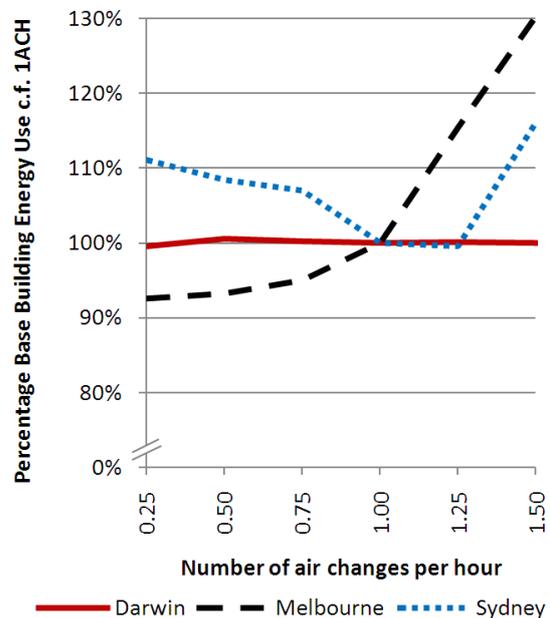

Figure 9: Building One –Simulated percentage change in Base Building Energy use with variation of air leakage

Figure 12 shows a slight deviation from a straight-line response with the smallest of the US Department of Energy benchmark models in the Melbourne

climate. In this modelling in increasing the air leakage range of 0.25 ACH to 0.5 ACH, there was a decrease in cooling requirement which was offset by an increase in heating needed. The cooling load did

not change significantly with further increases in air leakage though heating increased.
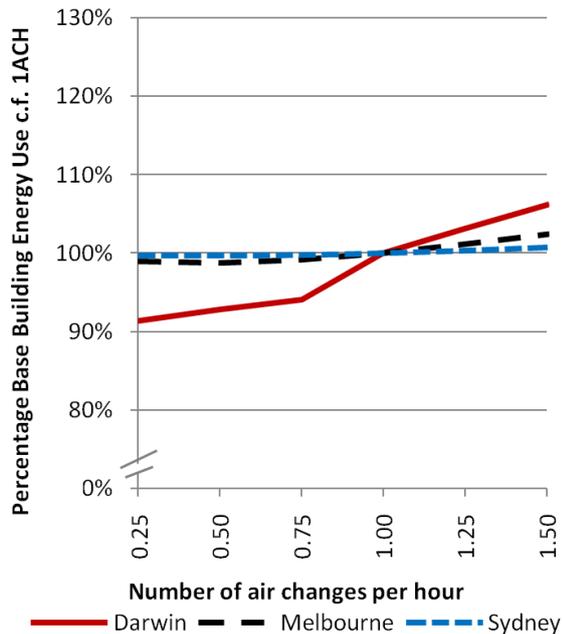

Figure 10: Building Two –Simulated percentage change in Base Building Energy use with variation of air leakage
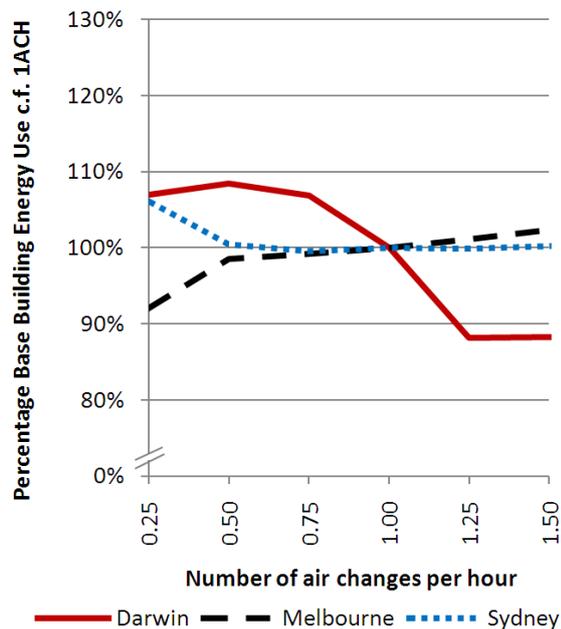

Figure 11: Building Three – Simulated percentage change in Base Building Energy use with variation of air leakage

Another deviation from the straight-line response in the benchmark models occurred with Building Five in Sydney as shown in Figure 13. The combined effects of increased heating and increased cooling caused a sharp increase in energy use as the air leakage increases from 0.75 ACH and 1.0 ACH in Sydney modelling.

In the models of recently constructed buildings, the change in base building energy usage, shown in Figure 9 to Figure 11, due to the variation of air leakage was less of straight line response than it was with the benchmark models. The energy performance of Building One in Sydney and Building Three in Sydney and Darwin benefited from the increase in air leakage over some ranges.
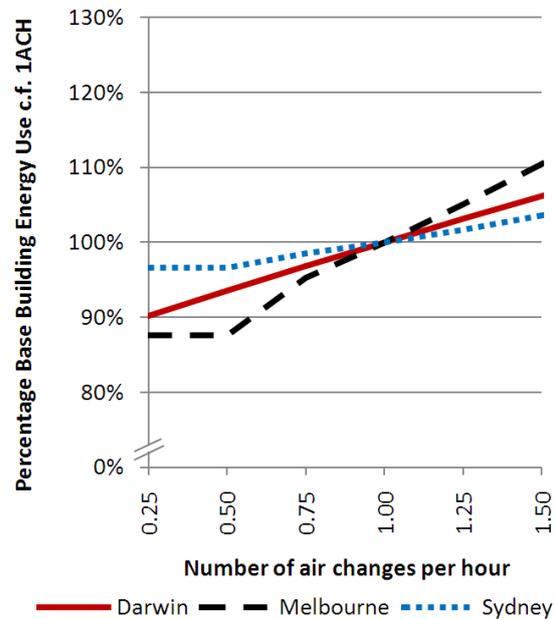

Figure 12: Building Four –Simulated percentage change in Base Building Energy use with variation of air leakage
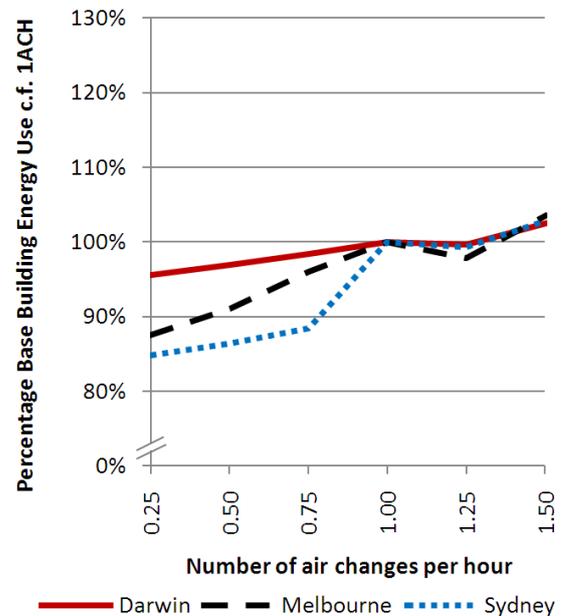

Figure 13: Building Five –Simulated percentage change in Base Building Energy use with variation of air leakage
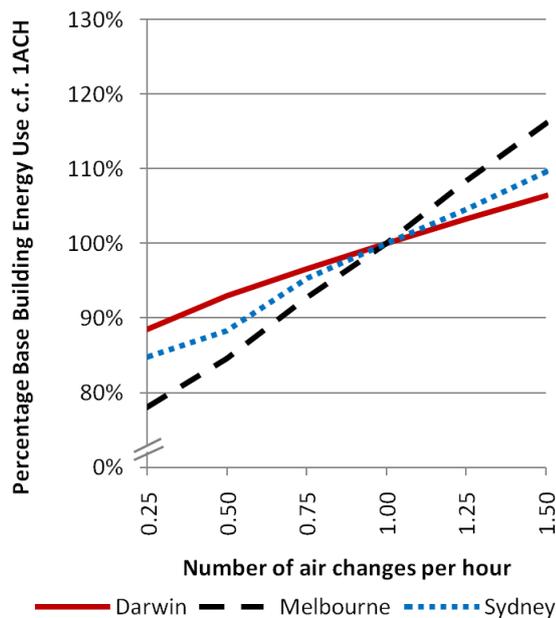
Figure 14: Building Six –Simulated percentage change in Base Building Energy use with variation of air leakage

Building One and Three both had significant ammounts of eastern shading so reduction in air leakage increased the need for morning heating in cool weather. Building Three also had this effect which was intensified due to adjacent buildings on the northern side. The impacts of this shading on increasing the need for heating were exacerbated by the high levels of insulation and the use of double glazing in both Buildings One and Three.

In Figure 9, the unchanged energy performance with increased air leakage between 1.00 ACH and 1.25 ACH in Sydney is not, as in other examples described here, a trade-off between changes in cooling, heating and reheat as between these two air leakage rates most modelled HVAC components used similar ammounts of energy. Above 1.25 ACH the modelled heating and cooling increased sharply.

Similarly the unchanged energy performance with increasing air leakage shown in Figure 11, between 1.25 ACH and 1.5 ACH, for the Darwin modelling is simply a situation where most HVAC compnonts used similar amounts of energy at the two leakages values with small increases in fan energy being offset by small decreases in gas usage.

The energy performance for Darwin for Building Three shown in Figure 11 may also be partially explained by the reduced need for reheat with increased infiultration in this very humid climate. Building One which used no reheat showed little variation in energy use with air leakage in the Darwin climate as shown in Figure 9. Provision of controlled adjustment of outside air levels which flushed early morning cold air on warm mornings would achieved the same benefits as the increased air leakage in these

unusual situations. Again some of the energy performance variation described may be due to buildings being modelled in climates for which the were not designed

Building Two, shown in Figure 10, of all the modelled buildings seemed to be the least sensitive to changes in air leakage. The building had a highly efficient HVAC system utilising VRV and heat recovery. It also had little shading from adjacent buildings.

In Darwin, the modelled energy use of the heavily insulated and shaded buildings, Building One and Three shown in Figure 9 and Figure 11, increased with a reduction in air leakage from 1 ACH to 0.5 ACH due to greater morning heating discussed above though this effect for Building One was trivial. For the other four modelled buildings, the reduction of air leakage from 1 ACH to 0.5 ACH reduced the energy consumption by between 3.1 and 8.5%.

In the Melbourne climate, increased air leakage increased the base building energy used for all buildings across the range of air leakage considered. Reducing the air leakage from 1 ACH to 0.5 ACH reduced the base building energy consumption by 1.2 to 15.4% depending on the building modelled.

The modelled energy consumption in the Sydney climate of the two highly insulated and shaded buildings, Building One and Building Three, increased when the air leakage was decreased from 1 ACH to 0.5 ACH. This increase was 8.4% for Building One was and 0.5% for Building Three. The other four building had reductions in energy use between 0.3% and 13.6% for this air leakage change.

The modelled changes in energy consumption in response to air leakage rates appear to be of smaller magnitude than the results discussed in the Introduction from European and US studies. This may be attributable to the cooling dominated climates in Australia consistent with the US findings discussed in the Introduction (Emmerich et al, 2007). However, the slight improvement in energy performance with increased air leakage with a few building/climate combinations differs from the European and US experience.

CONCLUSION

The results of air leakage testing presented in this paper indicate that air leakage rates in Australia are much higher than those reported in Europe and USA. All six office buildings tested had air permeability levels higher than ATTMA recommendation for normal practice.

The impact of altering modelled air leakage on energy performance varied significantly with climate and building. Generally, energy performance was better with less air leakage over the range modelled but there were a variety of exceptions.

These results imply that the consequence of inaccurate air leakage assumptions on modelled energy performance may be unpredictable and not all buildings or climates are affected equally by inaccuracies in air leakage assumptions. There is a need for further study of air leakage typical in Australian office buildings so this can be accurately incorporated into building simulation.

ACKNOWLEDGEMENTS

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Table 2: Building models used for simulation.

BUILDING	COVERED AREA (m²)	NET LETTABLE AREA (m²)	NO OF FLOORS	TYPE OF HVAC INSTALLED	GLAZING	INSULATION (m²K/W)
One	21,360	16,500	15	VAV with perimeter CV heating	DG 6/12/6 Evergreen Low-e	R2 wall R4 roof
Two	2,960	2,610	1	VRF with heat recovery	SG Solar E	R1.75 wall R3.5 roof
Three	18,450	12,380	6 + basement	VAV	DG Argon filled reflective outer pane	R2.5 wall R6 roof
Four	510	-	1	DX with gas heating coil	SG SHGC 0.34	R0.8 wall R4.5 roof
Five	4,982	-	3	DX with gas heating coil	SG SHGC 0.34	R1.2 wall R2.5 roof
Six	42,757	-	12 + basement	VAV with gas reheat	SG SHGC 0.34	R1.2 wall R2.5 roof

Table 3: Air leakage testing - building descriptions and results.

	DESCRIPTION	FLOOR AREA (m²)	VOLUME (m³)	AIR PERMEABILITY (m³/h/m²)	ACH_{50}	ACH
A	Small single floored office building built ~2004	2,960	7,965	6.78	5.69	0.28
B	Converted and extended house used for office space - 1950s	403	1,140	16.9	16.19	0.81
C	Small office – part floor of offices around an atrium	1,084	3.902	9.07	6.23	0.31
D	Ground floor – new office building	1,233	4,661	11.71	7.92	0.40
E	First floor new office building	3,223	11,539	7.71	5.23	0.26
F	Free standing office/library building, large vaulted ceiling ~1984	925	4315	17.7	13.9	0.70
G Sample of 68 Canberra houses	Mean	-	-	-	17.96	0.90
	Std dev	-	-	-	7.87	0.39
	Max	-	-	-	39.59	1.98
	Min	-	-	-	1.196	0.21