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Air tightness of new Australian residential buildings

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Abstract

To achieve the energy efficiency standards in the National Construction Code, houses generally need to use insulation and weather sealing. However, if poorly installed this can lead to houses that have lower energy efficiency performance than expected. There has been little data collected on newly built houses to quantify air-tightness and assess the quality of insulation. This paper reports on a study that investigated new house construction around Australia to gain insight into the quality of house construction with regard to air-tightness and quality of insulation. Twenty houses in each capital city, except Darwin, were recruited for the project. The houses in most cities were up to 3 years old and assumed to be at the 6 star NatHERS standard.
Blower door testing was carried out on 125 of the volunteer homes and the resulting air changes per hour at 50 Pascals pressure (ACH@50Pa) for each house was then determined. In addition, an inspection of each house was undertaken by a qualified energy assessor to assess the quality of the insulation installed. A thermal inspection of the walls and ceiling was undertaken as well as a visual inspection of the ceiling insulation (if accessible). Weather sealing around windows and doors was also inspected for any gaps and damage.
A broad range of results was achieved and found that well sealed houses are being constructed, but equally poorly performing houses are also still being built. To maximise value for energy in our houses, it is critical that we determine why these differences occur and how we can consistently build well sealed houses.

Peer-review under responsibility of the organizing committee iHBE 2016.

Keywords: air infiltration;insulation;residential buildings;weather sealing

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1. Introduction

Air tightness of Australian houses has for many years not been considered an area of concern by the building industry. Our relatively mild climates and historically cheap energy has resulted in housing stock that performs poorly in terms of air tightness when compared to many other countries. Introduction of energy efficiency provisions into the Australian building code over a decade ago were aimed at improving the thermal efficiency of building envelopes, but air infiltration is still only vaguely handled with the current requirement being that residential buildings be constructed to “minimise air leakage”, but not quantifying what this means [1].

The majority of new houses that are constructed in Australia utilise the Nationwide House Energy Rating Scheme (NatHERS) software model to determine their compliance with the energy efficiency provisions of the National Construction Code (NCC). The NatHERS software does not specifically define a level of air-tightness to be achieved, instead the infiltration rate is specified as A+B.v, where A and B are the stack and wind infiltration factors respectively, and v is the local wind speed [2]. A rate of 15 air changes per hour (ACH) when the house is pressurised to 50 Pascals could be considered a rough average value that would result from the use of the NatHERS software. If the windows and doors are properly weather stripped, the value may be closer to 10 ACH@50Pa. Houses achieving results above 20 ACH@50Pa would be considered poorly sealed and have higher levels of air leakage than would be expected of newly constructed houses. Very few studies of air tightness of Australian houses have been done, but a small study of 10 houses found an average air change rate of 26.3 ACH@50Pa [3]. Another study found that infiltration rates in houses located in Melbourne, Australia could be reduced by 52% through sealing major air leakage pathways and this would result in an average reduction of 7% in annual space heating and cooling requirements [4].

Concerns have been raised in various forums that the energy efficiency features of houses that are required to achieve the minimum energy efficiency standards in the NCC, e.g. insulation and weather sealing, are often poorly installed, thus leading to houses that have lower energy efficiency performance than expected. There has been little data collected on newly built houses to quantify air-tightness and assess the quality of installation of insulation and consequently a study was undertaken to inspect and test a series of newly constructed houses across Australia to determine their actual performance. The study involved testing 20 new houses (up to three years old) in Adelaide, Brisbane, Canberra, Hobart, Perth and Sydney. Twenty houses in Melbourne tested and inspected as part of an earlier study [5] are included for the purpose of comparison. The houses recruited in these cities were assumed to have been built to the current NCC energy efficiency standard. Blower door testing was performed on each house in the study to quantify air-tightness. A visual inspection of ceilings and thermal imaging of ceilings and walls was carried out to check whether insulation had been installed correctly. Weather sealing on windows and external doors was also inspected.

2. Air infiltration

Blower door testing was carried out on 134 volunteer homes in accordance with ATTMA Technical Standard 1. Issue 2 – Measuring Air Permeability of Building Envelopes [6]. It should be noted that the ATTMA Standard is based on the British Standard BS EN Standard 13829:2001 – Thermal Performance of Buildings – Determination of air permeability of buildings – Fan pressurisation method. One variation to the ATTMA Standard that is in common practice in Australia is that the air conditioning (cooling/heating) systems are not temporarily sealed. This requirement was incorporated in the ATTMA Standard because the Standard was designed strictly to assess the permeability of the building envelope and to exclude any leakiness in air conditioning systems that may affect the results. In practice however, houses are invariably operated with air conditioning systems open to the interior space of the house. To properly assess the air-tightness of the house as a whole in operational mode, it is common practice to not seal the air conditioning systems from the interior of the house during the pressure test.

In many of the cities tested, a wide range of air tightness results were achieved. Fig 1 shows the spread of results for each city. Most cities had at least one high outlier, with one house in Perth recording a result of 39 ACH@50Pa. Several of the cities had relatively tight clustering of results. Houses in the Canberra, Adelaide and Hobart recorded results that were relatively close together, although each city did have one outlier. Houses in Sydney, Melbourne and Perth had a much broader set of results.

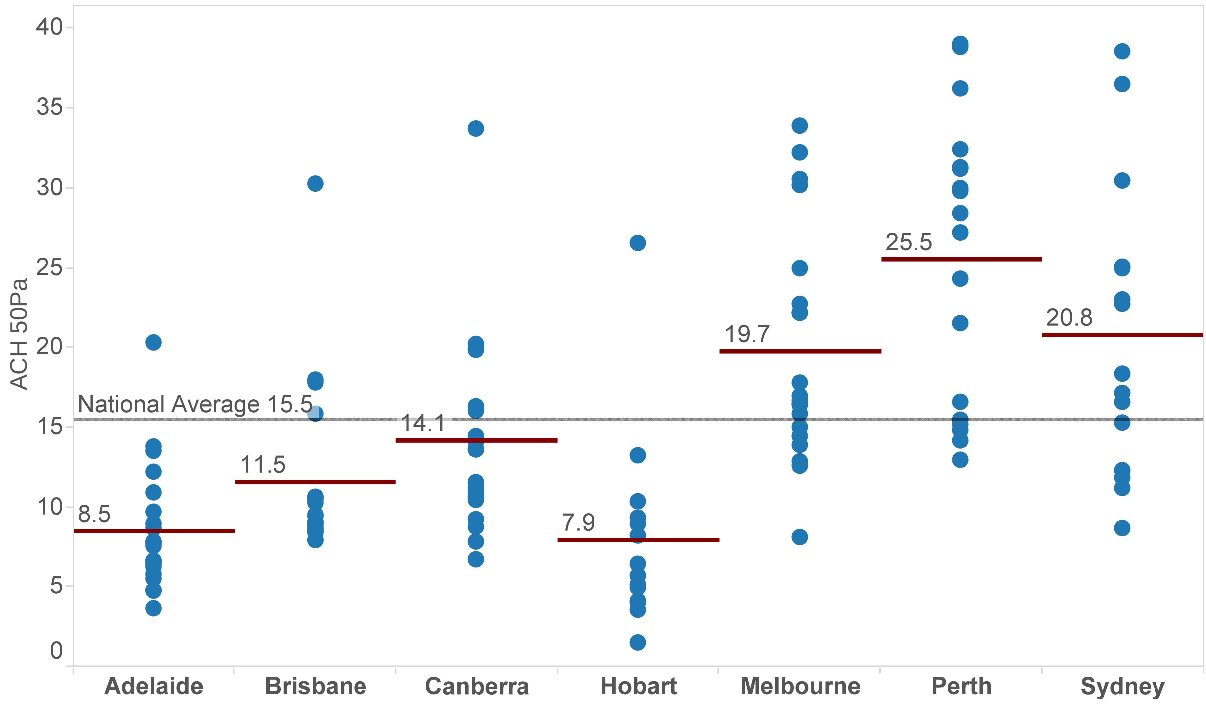

Fig. 1. Air change rates by city.

Overall, the average air change rate was 15.5 ACH@50Pa which is only slightly higher than what one would assume as average from the NatHERS software. **Error! Reference source not found.**Fig 2 shows the binned distribution of results in increments of 2 ACH@50Pa with each bin being the lower mark. So for example, houses that achieved 15 ACH@50Pa would be counted in the 14 ACH@50Pa bin as it is equal to or greater than 14, but less than 16 ACH@50Pa. The figure shows that a third of houses had results equal to or lower than 10 ACH@50Pa which demonstrates that well sealed houses are possible and occurring across Australia. However, with an overall median of 13.3 ACH@50Pa almost half the houses tested were above what could be considered as the upper mark for a newly constructed house in Australia. Several houses recorded air change rates above 30 ACH@50Pa which is common amongst old poorly sealed houses, but should be considered unacceptable for a newly constructed house. Consequently, there is reason for concern about why so many houses recorded poor results. It is clear from the results that well performing houses are achievable and in many cases air tightness was not a stated objective of the design. However, after discussion with home owners it was found that in some of the very high performing houses, air tightness was a specific objective of the design and construction of the house. Indeed, the overall top performing house, which recorded a result of 1.4 ACH@50Pa, had the specific objective of aiming for the PassivHaus standard of 0.6 ACH@50Pa.

The Australian results are much higher than those required for new residential buildings in a range of other countries including the UK, USA and Canada (Table 1). Even the best performing Australian city of Hobart with an average rate of 7.9 ACH @50Pa, was higher than maximum allowed in most countries listed.

Fig. 2. Distribution of air change results.

Table 1. Air infiltration requirements for new residential buildings by country [7].

Country	Air Tightness @ 50Pa	Country	Air Tightness @ 50Pa
UK	10	Netherlands	8
Finland	4.3	Sweden	2.9
Germany (Natural ventilation)	3.2	Spain (North)	17.1
Germany (Mechanical ventilation)	1.6	Spain (South)	31.6
France	5.5	USA (depending on climate)	3-5
Belgium	3.2	Canada (depending on climate)	3-5
Norway	4.3	*PassivHaus Standard*	*0.6*

3. Ceiling insulation

Visual and thermal inspections of ceiling insulation were carried out on all houses where possible. In all jurisdictions included in this study, ceiling insulation is mandatory for achievement of the current 6 star standard or equivalent deemed-to-satisfy requirements.

A visual inspection of the ceiling insulation found that the majority of insulation used was batts (79%) with the vast majority of these being glasswool batts. Loose fill cellulose fibre or expanded polystyrene were used in a very small number (2% for each) of cases. One Brisbane based house was found to have no ceiling insulation installed. This is concerning, but it is not known whether this is a breach of the NCC without knowing the building standard that applied at time of building and the compliance path chosen. Sixteen percent of ceiling spaces were not accessible, so no visual inspection could be made.

Overall, the quality of the installation of insulation was assessed to be average (39%), while a further 33% was considered good. A surprisingly high 10% was rated as poor, although part of this was in the older houses located in Melbourne. Good condition was considered to be where the coverage was consistent across the whole ceiling area with only minimal gaps for items such as downlights. Average condition was considered to be where the majority of the ceiling had consistent coverage with gaps only to ceiling perimeter, around down lights, under heater platforms and tight corners. Poor condition was considered to be where insulation coverage was inconsistent with lots of gaps or large gaps and/or where insulation was thin, degraded or ripped. Fig 3 shows some examples of houses that had their ceiling insulation rated as poor. The image on the left shows batts moved to place pipework, but not replaced, while the right hand image has batts still in their packaging and not installed.

The R-Value of the ceiling insulation was also estimated based on the type of insulation and its thickness. The majority of ceiling insulation was bulk insulation, so a direct linear relationship between thickness and thermal resistance was able to be made. Thermal resistance values for various insulation materials were obtained from other CSIRO research [8] and used to calculate the estimated R-Value of the insulation. Fig 4 shows the estimated R-Values (in SI units) for each city. The older houses in Melbourne have the highest proportion of insulation with lower R-Values with 63% being between R2.0 and R3.0. Overall, most ceiling insulation is in the range of R2.6 to R4.0 (66%), but Hobart has a high proportion of houses with relatively high levels of insulation with 62% of houses having insulation rated at R4.6 to R5.0. Adelaide had the highest proportion of houses with insulation in excess of R5.0 with 25% of houses estimated to have ceiling insulation at this level.

Fig. 3. Examples of ceiling insulation rated as poor.

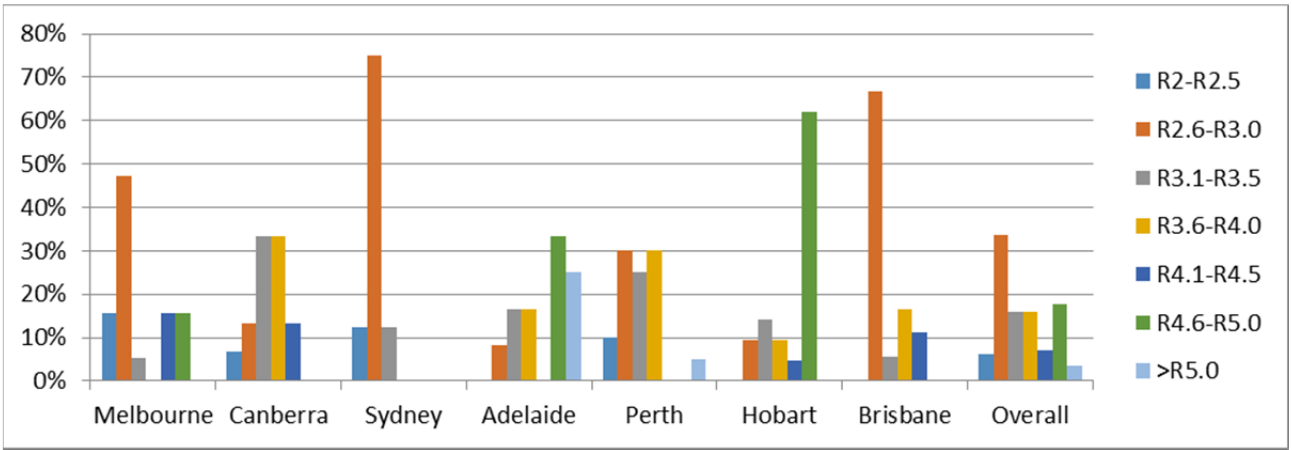

Fig. 4. Estimated ceiling insulation R-Value (SI units) by city.

Thermal imaging of ceilings helped to identify whether there was missing insulation or gaps that could allow air movement and dampness. The series of thermal images that were taken at each home were uploaded to a secure image sharing website for secure (unique password protected) viewing of the images by each volunteer. Fig 5 is a selection of thermal images from houses that shows the types of insulation gaps that can be identified through thermography. As shown in the colour bars on each image, the darker colours represent surfaces that are at a lower temperature than surfaces with lighter colours. Areas where insulation is missing will show a temperature difference from the surrounding insulated ceiling space. For example, in hot weather an uninsulated part of a ceiling will show up as being hotter than the insulated parts due to heat transmission from the roof space. The image on the left shows a large area of a ceiling that is uninsulated, while the image on the right shows a line of missing insulation close to the roof edge.

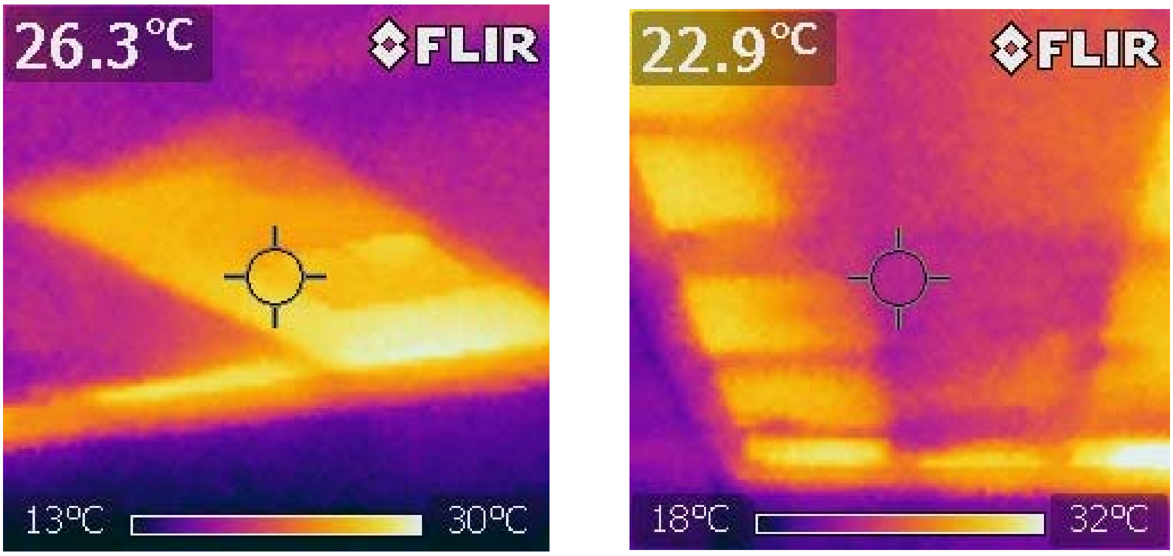

Fig. 5. Thermal images of ceilings.

Examining the rated quality of the insulation installation found that although the houses with good insulation had a lower average air change rate than those houses with average insulation (14.2 ACH@50Pa verses 17.1 ACH@50Pa), the difference was only small. Houses assessed to have an overall poor quality of insulation recorded a slightly lower average air change rate (13.7 ACH@50Pa) than those with good insulation. Ceiling insulation installation quality showed a slight correlation with air change rates, with houses with good ceiling insulation installation having better average air change rates (11.8 ACH@50Pa) than those with average (17.3 ACH@50Pa) or poor (17.4 ACH@50Pa) ceiling insulation installation.

One interesting observation was that those houses with high estimated R-Values for the ceiling insulation tended to have low air change rates. It is difficult to determine if this relationship has a causal link, but more likely is the relationship between houses with high levels of ceiling insulation being purposefully built to higher energy efficiency levels and consequently greater attention being paid to building sealing.

4. Weather sealing

Visual inspection of weather sealing of windows and external doors was undertaken to determine the condition. Overall, weather stripping on windows was found to be good (92%) with only 3.4% rated as average and 1.7% rated as poor. A further 3.4% of houses had no weather stripping present on their windows with the majority of these being in Brisbane (three houses) and one house each in Melbourne and Hobart. A high proportion of the Melbourne houses (85%) where found to have window sealing rated as average and none were rated as good. However, this may be due to the older age of the Melbourne based houses in the study. Good weather stripping was considered to be stripping that was complete with no gaps and little or no compression or degradation of the stripping. Average condition was considered to be stripping that was complete, but may have some compression and some wear due to use. Poor condition was considered to be where there were gaps in the weather stripping and where significant compression and wear and tear has occurred with the stripping.

External doors usually experience many more opening and closing events than windows and consequently weather stripping can be damaged and degraded more quickly. Overall 53% of weather sealing on external doors was found to be good, 25% average and 11% poor. Around 11% had no weather stripping present. The older Melbourne based houses again showed higher levels of missing weather stripping (25%) than most cities, although Adelaide houses actually had the highest percentage of houses with no weather stripping on their external doors (35%). Both Hobart and Brisbane houses had high percentages (75%) of their door weather stripping rated as good.

It is commonly assumed that houses that have a high air change rate as measured by a blower door test will also have poor sealing of windows and doors, thus allowing air to more easily transfer from inside to outside and vice versa. However, analysis of the data from the houses tested found no strong correlation with poor weather sealing and high air change rates. Table 2 shows the average air change rate for houses by their assessed quality of door and window weather sealing. It shows that there was little difference in the average air change rate for houses that were assessed to have either average or poor quality door weather sealing, while houses with good or no weather sealing on their doors recorded similar average air change rates.

Houses with good window weather sealing recorded better average air change rates than houses with average sealing, while the number of houses with poor or no window weather sealing were too few to make any meaningful conclusion.

Table 2. Average air change rates @50Pa for door and window weather sealing condition.

Weather seal condition	External doors		Windows	
	ACH@50Pa	Number	ACH@50Pa	Number
Good	14.0	53	14.8	97
Average	17.2	33	18.4	20
Poor	17.3	21	21.0	4
No weather sealing	14.5	18	12.8	4

These results would suggest that the quality of window sealing may have an impact on the air change rate recorded, although the improved performance is only small.

5. Conclusion

The overall results would indicate that no immediate cause for the variations in air change rates has been identified and that consequently the differences are due to factors that were not investigated during this study. This might include gaps around power points and light switches and also air return vents for heating/cooling systems. One potential cause might also be the quality of sealing between the window frame and the house frame. It is common building practice to oversize the framework to allow for the installation of the window and door frames. Chocks are then used to level and stabilise the window and door frame within the building frame before fixing the two frames together. Consequently, a large gap is often present between the window/door frame and house frame. A sealant can be used to totally fill this gap, such as expanding foam, but usually only lightweight packing is used and sometimes the gaps are not filled at all before the architraves are installed. These gaps are not obvious once the house is completed, but could potentially provide a pathway for air exchange.

It is interesting to note that six of the houses tested used uPVC window frames. These frames usually have built in sealing systems to provide a tight seal between the window frame and the house frame. Analysis found that houses with aluminium or timber frames had a broad range of results while houses with uPVC window frames recorded much lower air change rates than most other houses.

Overall the project has found that newly constructed houses in Australia have a broad range of air tightness levels ranging from world’s best practice through to much higher than the assumed average air tightness levels in the NatHERS software. The significant number of houses reporting high air change rates is cause for concern but there does not appear to be a single factor that determines the level of air tightness. Further investigation may be required to determine the precise cause of the high results. Build quality and attention to detail seem to be significant factors, but certain building elements may inherently be difficult to seal effectively, e.g. some types of windows and doors.

However, the project also found that many houses were well below the assumed average air tightness levels and this demonstrates that building houses to higher air tightness levels is possible and doable. Many of these houses had no particular common features associated with high air tightness and did not have specific goals of improved air tightness. It may have been more a result of good quality construction and building techniques.

The overall average air change rate was 15.5 ACH@50Pa. This is very close to what one would assume as and average air change rate using the NatHERS methodology. This would suggest that the average rates in NatHERS are close to what is actually being delivered, although a lower result would have been preferable, say around 10 ACH@50Pa. A target value of 10 ACH@50Pa would line up with the minimum value required for houses in the United Kingdom and as results have shown a third of the houses tested recorded a value of 10 ACH@50Pa or less.

Consequently, this could pave the way for setting specific air tightness requirements in the NCC. A value of 10 ACH@50Pa could be the recommended target with many houses already demonstrating that this is an achievable goal. An agreed methodology and/or standard would be required for ensuring compliance and this could be similar to the methodology employed in the UK, where random selections of newly built houses are tested for compliance. The exact percentage of houses that would be tested as well as how this would be funded would need to be determined. The houses selected for testing could also be inspected for other aspects of the energy efficiency provisions, including ceiling insulation and weather sealing to help improve compliance with these aspects of the NCC.

NatHERS could allow high performing houses to receive higher star ratings by incorporating certified air pressure results into NatHERS calculations. Currently, houses that have achieved good air infiltration results get no star rating benefit from this. This would require “as designed” and “as built” NatHERS certification certificates to be issued with the “as built” certificate only issued after verification of the house performance was established through testing. This could lead to the greater uptake of air pressure testing of new houses and help improve their performance and further reduce the energy requirements. Increased uptake of testing could also lead to better understanding in the broader residential construction industry about how to improve air tightness of dwellings and simple measures that can be employed during construction that could lead to tighter houses.

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