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House Energy Efficiency Inspections Project

Final Report

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Executive Summary

Background

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 National Construction Code (NCC) (Australian Building Codes Board, 2015), e.g. insulation and weather sealing, are often poorly installed by builders, 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 heating/cooling ductwork. This study investigated new house construction around Australia to gain insight into the quality of house construction with regard to the energy efficiency aspects of air-tightness and quality of installation of insulation and heating/cooling ductwork and involved recruiting 20 houses in each capital city around Australia (Darwin was not included). Melbourne house results were added from the previous CSIRO Residential Building Energy Efficiency Study (RBEES) (Ambrose, James, Law, Osman, & White, 2013). The houses in most cities were up to 3 years old and assumed to be at the 6 star NatHERS standard. The Melbourne houses were up to 10 years old and of 4 and 5 star standard.

Blower door testing was carried out on 129 of the volunteer homes in accordance with ATTMA Technical Standard 1. The blower door tests were carried out by the same operator using the same equipment and operating method in order to minimise operational variation. CSIRO undertook quality assurance checks on four houses in each of Sydney and Hobart. The resulting air changes per hour at 50 Pascals pressure (ACH@50Pa) for each house was then determined.

In addition, an inspection of the house was undertaken by a qualified energy assessor to assess the quality of the installation of the insulation. Two main methods were employed to undertake this assessment. Firstly, a thermal inspection of the walls and ceiling was undertaken using a thermal camera and secondly a visual inspection was made of the ceiling insulation (if accessible). The quality of the installation of heating and cooling ductwork in the ceiling was also visually inspected (where present and accessible). Weather sealing around windows and doors was also inspected for any gaps and damage. Table 1 summarises the number of houses in each city that were inspected and tested.

Table 1 Summary of houses inspected and tested

	Melbourne	Canberra	Sydney	Adelaide	Perth	Hobart	Brisbane	Total
Energy Surveys	20	20	17	20	20	20	20	**137**
Thermal Imaging	20	20	17	20	20	20	20	**137**
Blower Test conducted	20	19	17	20	20	14	19	**129**
Test result excluded*	0	0	2	0	2	0	0	**4**
Tests included	20	19	15	20	18	14	19	**125**

*Due to factors such as unfinished house, errors in testing, etc.

Results

In many of the cities tested a wide range of air tightness results were achieved. Figure 1 shows the spread of results for each city along with the median and quartile ranges. Most cities had a 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, Brisbane, 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.

The NCC does not specifically quantify an air leakage rate, but has a performance requirement that states:

"A building must have, to the degree necessary, a level of thermal performance to facilitate the efficient use of energy for artificial heating and cooling appropriate to the sealing of the building envelope against air leakage"
NCC Volume 2 (2015) – clause P2.6.1 (Australian Building Codes Board, 2015)

Consequently, the blower door test results were compared with the level of air-tightness that is assumed within the NatHERS software that is used for the energy rating option for complying with the energy efficiency Deemed-to-Satisfy Provisions of the NCC. Overall, the average air change rate was 15.4 ACH@50Pa which is only slightly higher than the upper range assumed in the NatHERS software. A third of the houses had results 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 15 ACH@50Pa which is considered 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 is considered by the authors to be 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, 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.

A visual inspection of the ceiling insulation, where accessible, 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). Only one house (in Brisbane) was found to have no insulation. 17% of ceiling spaces were not accessible, so no visual inspection could be made. Overall, the quality of installation of the 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 (for details of the assessments see Section 3.2).

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. 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 (65%), but Hobart has a high proportion of houses with relative 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.

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 (91%) with only 3.5% rated as average and 1.8% rated as poor. A further 3.5% 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.

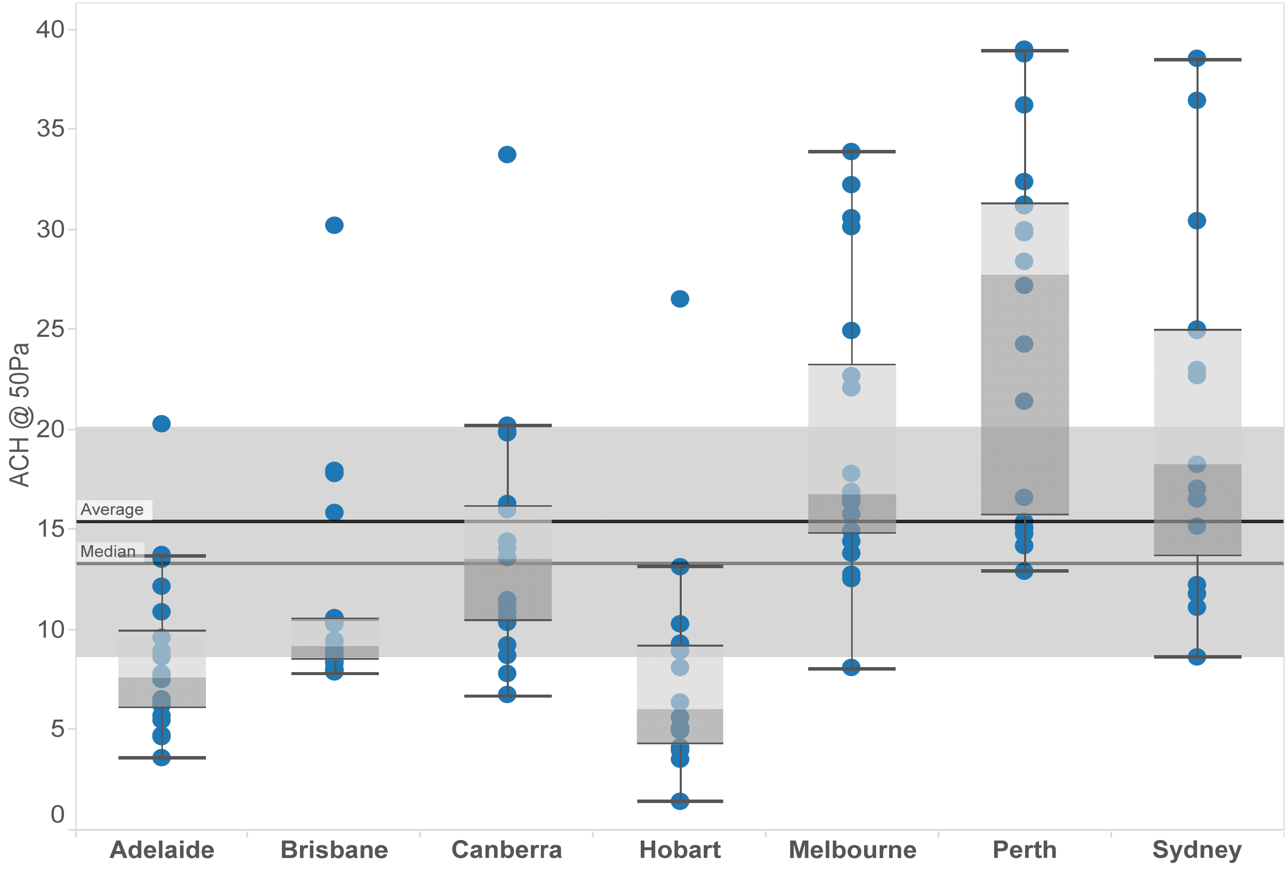

Figure 1 Air change rates by city[1]

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.

Inspection of heating and cooling ductwork was more problematic than inspection of the ceiling insulation and weather sealing. Generally, the insulation level around the ductwork was unable to be determined unless it was physically printed on the ductwork itself. Thickness of ductwork was also impossible to determine as this would have required dismantling of the ductwork. Visual inspection of ductwork was possible although limited to what could be viewed through the access hatch into the ceiling space. The Melbourne based houses did not have their ductwork inspected as these houses were inspected as part of the RBEES and ductwork was out of scope for that project.

Thermal imaging of ductwork was undertaken and this was effective in determining gaps in the insulation cover and also demonstrated significant heat loss around duct junctions which often have little if any insulation coverage. In most cases the R-Value could not be determined, however, it is important to note that with heating ductwork all ductwork was found to have insulation present, while only one house in Canberra was found to have no insulation around its cooling ductwork.

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[1] For the "box and whisker" figures in this report, the boxes describe the first and third quartiles, and the whiskers represent 1.5 times the interquartile range. The median for all houses is also shown with the first and third quartiles represented by the grey box.

Findings

- 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 air tightness levels in the NatHERS software.
- The average air change rate was 15.4 ACH@50Pa. This is very close to the upper bound of the assumed air change rate that is used in the NatHERS methodology. This would suggest that the assumed 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 third of the houses had results lower than 10 ACH@50Pa which demonstrates that well sealed houses are possible and occurring across Australia.
- Several houses recorded air change rates above 30 ACH@50Pa which is common amongst old poorly sealed houses, but is considered by the authors to be unacceptable for a newly constructed house.
- Adelaide and Hobart houses recorded results significantly lower than all of the other cities tested. On average, Adelaide and Hobart houses had an ACH@50Pa of 8.5 and 7.9 respectively.
- No immediate cause for the variations in air change rates has been identified. General build quality and attention to detail seem to be significant factors.
- Houses with uPVC window frames recorded much lower air change rates than most other houses.

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. Results showed that there was little difference in the average air change rate for houses that were assessed to have either good or average quality door weather sealing, while houses with poor or no weather sealing on their doors recorded similar average air change rate to houses with good or average door weather sealing.

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. 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. Examining the rated quality of the insulation 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 and that those houses assessed to have an overall poor quality of insulation recorded a slightly lower average air change rate (13.7 ACH@50Pa) as those with good.

Ceiling insulation quality also showed no strong correlation with air change rates, with houses with good ceiling insulation having slightly 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 standards. However, one interesting observation was that those houses with high estimated R-Values for the ceiling insulation tended to have low air change rates.

Penetrations into the roof space by downlights and exhaust fans are also often considered a potential path for air leakage, but examination of the data found no relationship between the number of unsealed downlights and air change rates, although for exhaust fans as the number of exhaust fans increased the air change rate tended to decrease, although the decrease in air change rate was only small. A few houses recorded high number of exhaust fans (more than five) and also higher air change rates, but the increased rate was not that much higher than the overall average.

Gaps in subfloor systems is also a common pathway for air leakage. Although the majority of houses in this study were on concrete slabs, several houses had suspended floor systems with a variety of subfloor insulation being used. The concrete slab on ground houses showed a wide range of results, while the suspended floor houses actually had a closer grouping of results. The highest result for a suspended floor house was 30.1 ACH@50Pa. This house had no insulation being used under the floor. This result is high, but still lower than the highest overall result.

The size of the houses was also examined and no strong relationship could be seen between house volume and air change rate, although the highest air change rates were recorded in houses with relatively small volumes.

The differences may be 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. 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 some 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. Houses with aluminium or timber frames were found to have a broad range of results, but apart from one outlier, houses with uPVC window frames recorded much lower air change rates than most other houses.

Adelaide and Hobart houses recorded results significantly lower than all of the other cities tested. On average, Adelaide and Hobart houses had an ACH@50Pa of 8.5 and 7.9 respectively, whereas the next closest average was for Canberra at 14.1 ACH@50Pa. The reason for this significant difference was not clear and additional investigation and data analysis was undertaken of the Adelaide houses as a case study to try and determine a factor or factors that may be responsible. Building materials and practices were investigated and discussions had with builders, architects and developers. Overall no specific differences from common building practice could be identified, but a higher than usual proportion of architect and custom designed houses in both the Adelaide and Hobart cohort lead to the conclusion that greater attention to build quality had occurred and this had resulted in better than average test results. In particular, the cold winter conditions in Hobart would be regarded as an important design aspect for architect designed houses and consequently it was not surprising to see some well performing houses in this climate zone. Indeed, the overall best performing house was located in Hobart and had been designed to the German PassivHaus standards.

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 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 build techniques.

Consideration should be given for setting specific air tightness requirements in the NCC. A value of 10 ACH@50Pa would be the recommended target which would line up with the minimum value required for houses in the United Kingdom. The results have shown that many houses are already achieving this goal with a third of the houses tested recording a value of 10 ACH@50Pa or less. . 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 a random selection 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.

1 Introduction

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 National Construction Code (NCC) (Australian Building Codes Board, 2010) (Australian Building Codes Board, 2015), e.g. insulation and weather sealing, are often poorly installed by builders, 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 heating/cooling ductwork.

In May 2014, the Commonwealth Department of Industry, Innovation and Science commissioned CSIRO to carry out a study of new house construction around Australia to gain insight into the quality of house construction with regard to the energy efficiency aspects of air-tightness and quality of installation of insulation and heating/cooling ductwork. This study involved testing 20 new houses (up to three years old) in each capital city around Australia. Twenty houses in Melbourne had already been blower door tested and inspected as part of the RBEES. The results obtained from the Melbourne houses are presented in the current report for the purpose of comparison. Darwin was dropped from the study because it was not possible to recruit sufficient houses in the time available. Therefore houses in the current study were recruited from Adelaide, Brisbane, Canberra, Hobart, Perth and Sydney. The houses recruited in these cities were not re-rated to confirm their star rating but given the age of the houses it is assumed that they would have been built to the current NCC standard of 6 stars or the equivalent deemed-to-satisfy elemental requirements (and noting that there are some state variations to this 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 inspected. An assessment of the quality of the ductwork was also made.

2 Selection, testing and inspection of houses

House recruitment was undertaken through several methods. Initially, recruitment was carried out through CSIRO's existing staffing base and also extended to friends and families of staff. Additional recruitment was also undertaken through print media advertising, letterbox drops and media interviews. Overall, the objective was to have a random selection of houses from a range of builders, rather than sourcing houses direct from the building industry which may have resulted in an unrepresentative sample of building practice. In some cities it was necessary to source a limited number of additional houses from a single builder due to insufficient numbers being recruited through the standard process. However, in no city were more than 50% of houses sourced from one builder. An expression of interest for participation was completed by each potential volunteer household and these were vetted to ensure the houses met the recruitment criteria.

Once the households were selected for inclusion in the study, signed consent forms were obtained and inspections organised. Each house had two inspections undertaken on different days. The first inspection was undertaken by a NatHERS accredited energy assessor who investigated the condition of insulation, weather stripping, heating/cooling appliance specifications and ductwork condition. The assessor completed a survey form for each house, a copy of which is at Appendix C. Summary tables of the information collected are at Appendix A. The second inspection was undertaken by a trained blower door operator who undertook the air infiltration test.

On completion of the inspections each household was then provided with a summary report of their house performance compared to other houses tested in their city.

The number of houses inspected was limited by the project budget and consequently the results from this study were not intended to be statistically representative of all new housing. Rather the intent was to obtain an initial understanding of the range of infiltration rates that new houses are experiencing and assess houses to see if any issues are present in relation to the delivery of the energy efficiency provisions of the NCC. Table 2 summarises the number of houses surveyed, inspected and blower door tested. A full listing of the results for each house is at Appendix B.

Table 2 Summary of houses inspected and tested

	Melbourne	Canberra	Sydney	Adelaide	Perth	Hobart	Brisbane	Total
Energy Surveys	20	20	17	20	20	20	20	**137**
Thermal Imaging	20	20	17	20	20	20	20	**137**
Blower Test conducted	20	19	17	20	20	14	19	**129**
Test result excluded*	0	0	2	0	2	0	0	**4**
Tests included	20	19	15	20	18	14	19	**125**

*Due to factors such as unfinished house, errors in testing, etc.

2.1 Selection of houses

Canberra

Twenty houses were selected in Canberra that ranged in age from 1 to 3 years old. The builders of these houses were unknown, but as the sourcing of these houses was through CSIRO staff the selection process was quite random and the chances of any of these houses being constructed by the same builder was low. Due to illness, one participant was unable to accept a visit for the blower door test just prior to the visit taking place. Therefore only 19 houses were inspected and tested in Canberra.

Hobart

Twenty houses were selected in Hobart that ranged in age from new to 3 years old. The builders of these houses were unknown, but as the sourcing of these houses was mainly through CSIRO staff the selection process was quite random and the chances of any of these houses being constructed by the same builder was low. One house was found to be a unit, while two others still had building works in progress and were not properly sealed. These houses were removed from the Hobart cohort leaving 17 houses inspected and tested in Hobart. However, after completion of the testing a fault in the equipment used was discovered resulting in the need to retest all houses. All but three of the houses were retested, resulting in 14 houses included in the study.

Perth

Twenty houses were selected in Perth that ranged in age from new to 3 years old. The builders of these houses were unknown, but as the sourcing of these houses was mainly through CSIRO staff the selection process was quite random and the chances of any of these houses being constructed by the same builder was low. Two houses were found to be attached units. They were excluded from the study so as not to affect the average for Perth. Consequently, the results from only 18 houses were used for the Perth cohort.

Sydney

Twenty houses were selected in Sydney that ranged in age from new to 3 years old. The builders of these houses were unknown, but as the sourcing of these houses was mainly through CSIRO staff the selection process was quite random and the chances of any of these houses being constructed by the same builder was low. One house was found to have a very leaky pot-belly stove flue. The construction of another house was not complete. Both houses were excluded from the study so as not to affect the average for Sydney. Two volunteers could not be contacted to make an appointment and one volunteer backed out of the study after an appointment had been made. Consequently, the results from only 15 houses were used for the Sydney cohort.

Adelaide

Twenty houses were selected in Adelaide that ranged in age from new to 3 years old. The builders of these houses were unknown, but as the sourcing of these houses was mainly through CSIRO staff the selection process was quite random and the chances of any of these houses being constructed by the same builder was low. The results from all 20 Adelaide houses were used for the Adelaide cohort.

Brisbane

Twenty houses were selected in Brisbane that ranged in age from new to 3 years old. Seven houses tested were from one builder (Plantation Homes), while the remaining houses were from a range of builders, but three were located in the same development (Fitzgibbon Chase). The results from 19 Brisbane houses were used for the Brisbane cohort.

Melbourne

It should be noted that the testing and subsequent results for the Melbourne cohort came from the earlier RBEES. There were twenty Melbourne houses built between 2003 and 2011 that were selected from the RBEES to take part in the blower door testing. Unlike the houses in the other capital cities that were between new and 3 years old, the Melbourne houses were between 3 and 11 years old. The builders of these houses were unknown, but as the sourcing of these houses was mainly through CSIRO staff the selection process was quite random and the chances of any of these houses being constructed by the same builder was low. The results from all 20 Melbourne houses were used for the Melbourne cohort.

In addition, some of the survey data that was collected for houses in the other cities was not available for the Melbourne houses as this was out of scope for the RBEES. In particular, information on ductwork is not available for the Melbourne houses and some of the window labelling information is also unavailable. Some of the Melbourne survey questions were also in a slightly different format to that used in this project and where required the responses have been modified to align with the format used in this project and allow comparison to the other cities.

2.2 House heating/cooling system profiles

The heating/cooling systems utilised in the different cities does vary. In the heating dominated cities of Melbourne and Canberra gas systems are common (especially Melbourne), while in the other cities that are either milder or don't have access to reticulated gas, reverse cycle systems dominate. A significant number of houses in Sydney and Perth had no heating system installed (Figure 2).

For those houses that used reverse cycle systems for heating, this also acted as their cooling system. In Melbourne evaporative cooling systems are very common, while in Hobart 40% of houses had no cooling system (Figure 3).

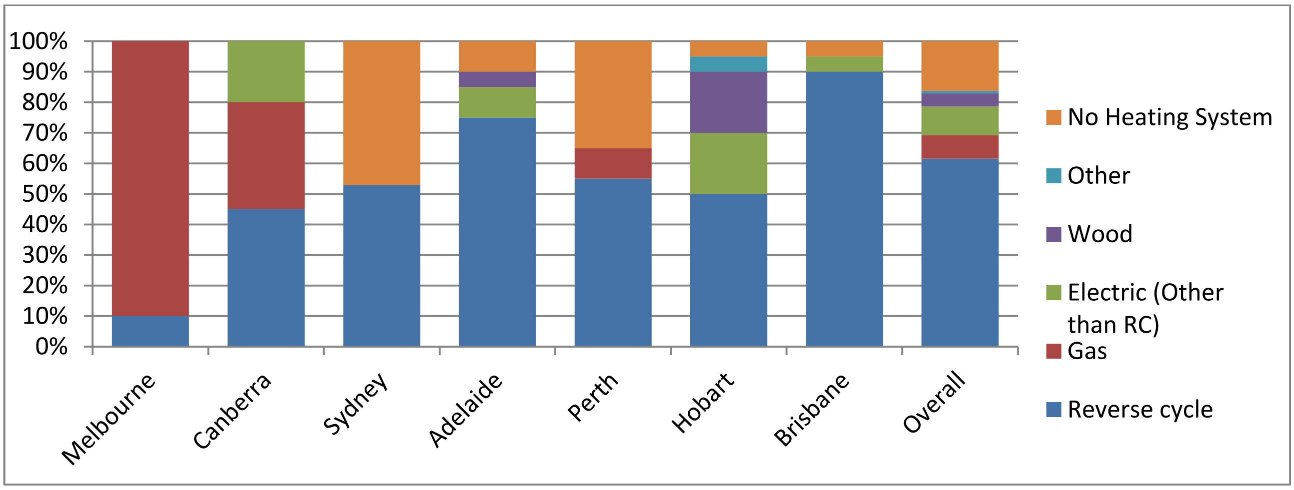


Figure 2 Heating systems by city

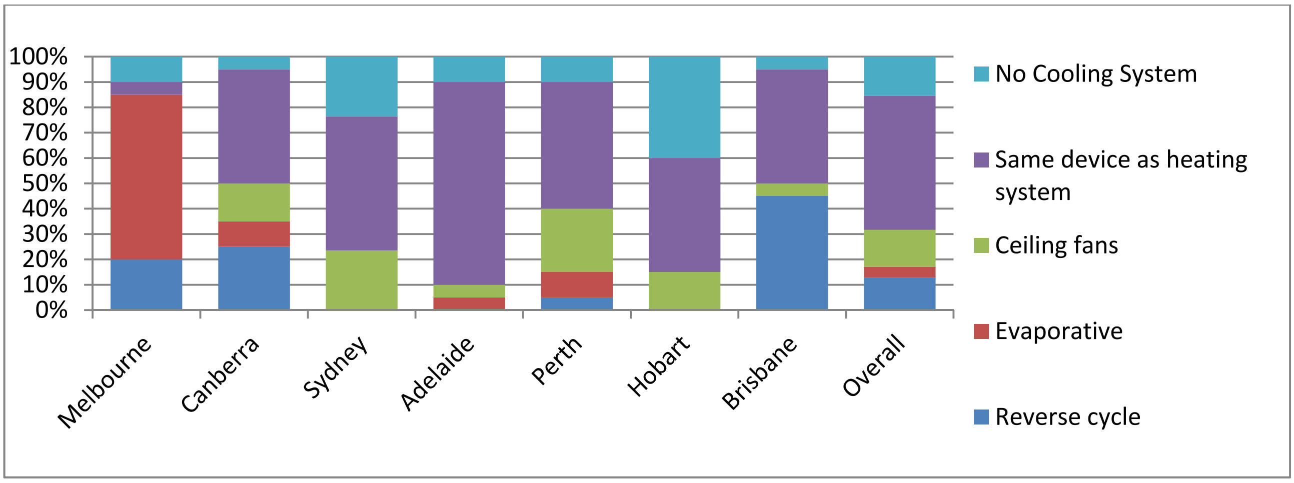


Figure 3 Cooling systems by city

One of the objectives of the project was to aim for at least 50% of houses to have a ducted heating or cooling system installed. Table 3 lists the number of ducted systems in each city and it can be seen that in

Sydney and Perth around 50% of the houses did have a ducted system, while in Canberra 90% of houses had a ducted system. In Adelaide only 15% of houses were ducted and only one house in Hobart had a ducted system. Overall, 48% of houses in the study had either a ducted system. 20% of houses in Canberra had both a separately ducted heating and cooling system installed. Ductwork inspections were not undertaken for the Melbourne houses as this was out of the scope for the RBEES project from which the Melbourne data was obtained and consequently no data is available for these houses.

Table 3 Number of ducted systems by city

	Canberra	Sydney	Adelaide	Perth	Hobart	Brisbane
Ducted reverse cycle system (for heating and cooling)	12	9	2	9	1	14
Ducted Cooling (Not reverse cycle systems)	2	0	1	2	0	0
Ducted Heating and Cooling (Separate systems)	4	0	0	0	0	0
Total ducted systems	18	9	3	11	1	14
Percentage of all houses	90%	53%	15%	55%	5%	70%

2.3 Blower door testing

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 (Air Tightness Testing and Measurement Assocciation, 2007). 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. A small series of tests on four houses in Sydney investigated what difference this variation makes. The Sydney tests along with an additional four house tests in Hobart also served as a quality assurance check of the blower door testing that was performed as part of the project.

In summary, the blower door test was performed as follows:

The size of the house (external perimeter and internal volume) was determined through onsite measurement. The blower door fan was installed in a canvas door that was sealed in an external doorway of the house (Figure 4). All exterior windows and doors of the house were closed and interior doors opened. A safety audit of the house was conducted to identify any potential problems such as unflued gas appliances, combustion stoves still warm etc. The house was then pressurized and depressurized over a range of pressures from 5-60 Pa. The flow of air required to achieve the pressure differentials was calculated from the fan calibration curve and the results were statistically validated to ensure a data correlation to the fitted line (R^2 value) was greater than 0.98. The resulting air changes per hour at 50 Pascals pressure (ACH@50Pa) for each house was then determined.

Generally, the front door of the house was used for installing the blower door unit, however, where the front door was too large to fit the blower door unit another external door was selected. This was usually a laundry door or the access door to a garage area. Effectively, the door that the blower door unit is placed in is excluded from the air infiltration test as the blower door frame forms a tight seal around the door frame. Consequently, there is a possibility that if this door was particularly poorly sealed this would not be captured by the test. However, examination of the data suggests that the impact from this, if it occurred, is only small and does not have an impact on the overall results.

Potential air inflation points such as downlights, exhaust fans and the quality of door and window weather sealing were identified in the energy assessment of each house and have been used in the analysis of the blower door results.

In all cities the blower door tests were carried out by the same operator using the same equipment and the same testing method. All equipment was recalibrated and certified before the project began to ensure consistency and accuracy of results. It should be noted that the blower door testing on the Melbourne RBEES houses was performed in the same way, by the same company and to the same standard as those of the current study.

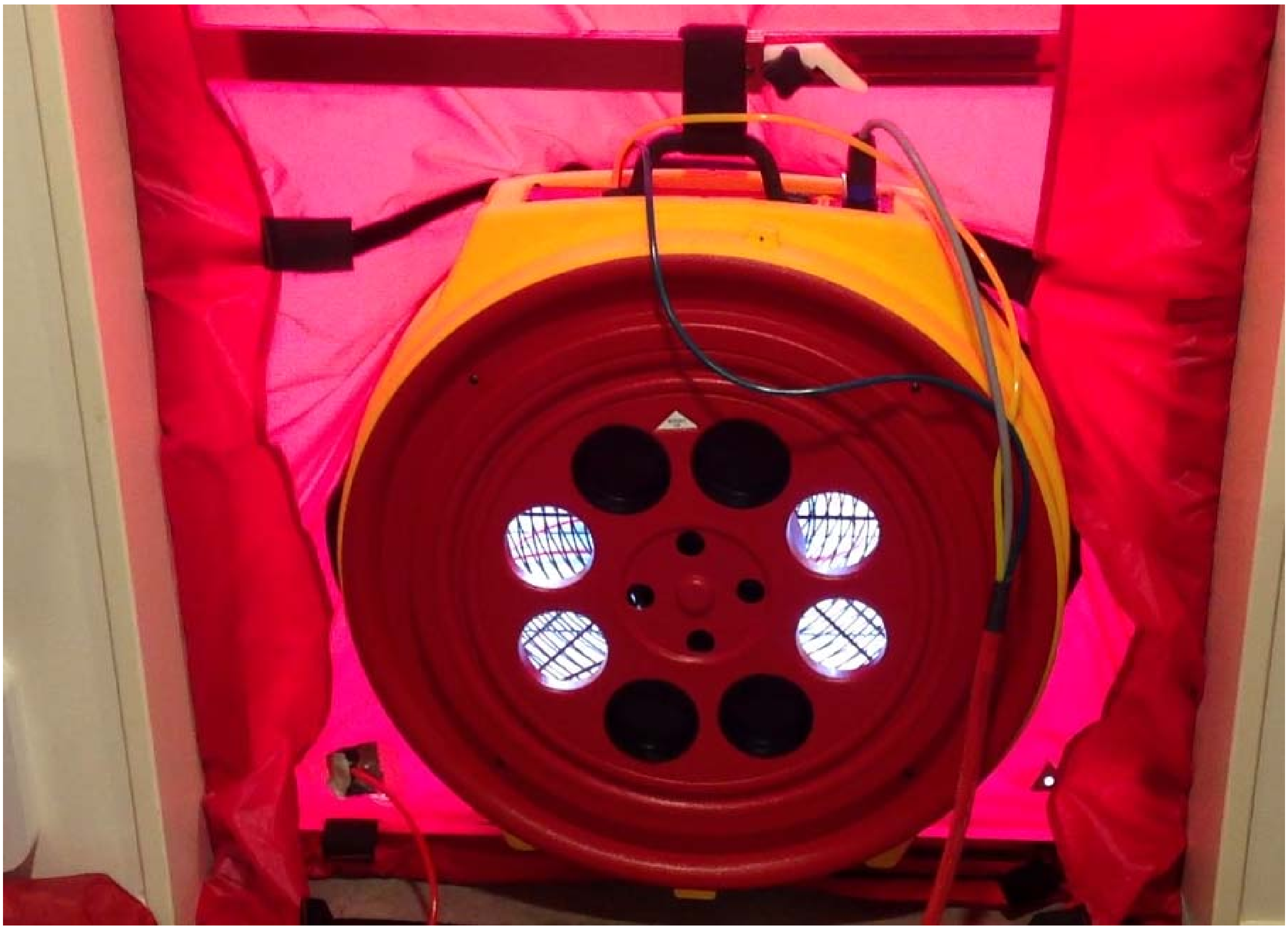


Figure 4 Typical blower door setup

2.4 Inspection of insulation

An inspection of every house was undertaken to assess the quality of the installation of insulation. Two main methods were employed to undertake this assessment. Firstly, a thermal inspection of the walls and ceiling was undertaken using a thermal camera and secondly a visual inspection was made of the ceiling insulation through the ceiling access hatch (if the roof space was accessible). Assessors did not move around the roof space for safety reasons so only insulation visible from the access hatch was inspected.

Ceiling insulation is probably one of the easiest energy efficiency aspects to inspect. A range of insulation products are available and they need to be properly installed to ensure their optimum performance. Ceiling insulation was inspected for type, thickness of coverage (if applicable) and quality of installation.

Figure 5 shows some examples of ceiling insulation that has been poorly installed or where gaps have been left in the insulation coverage.

Visual inspection of ceiling insulation showing gaps in coverage	Ceiling insulation removed to allow access and not placed correctly back into position

Figure 5 Examples of poorly installed ceiling insulation

The overall quality of the insulation install was determined through the thermal image assessment of each home using a thermal imaging camera. Thermal images or infrared photographs show the heat radiating from an object (infrared light) and under the right circumstances can give a useful indication of its temperature.

Infrared photographs can be affected by how well a material stores, conducts or radiates heat. For example concrete brick, stone and water tanks are slow to heat up but they can then store that heat for a very long time. Insulation is slow to conduct heat and reduces heat transfer. Metals such as aluminium however conduct heat away from a warm area very quickly, which is why aluminium window frames may look quite cold from inside a house and quite warm outside a house. Metal and glass can also reflect heat acting like mirrors so looking at photographs from metal or glass doesn’t necessarily tell you their temperature.

There are many other aspects that can impact a thermal images including sunlight, internal heat sources (lights, TVs, computers, kettles, etc.) and even people; so it can be hard to make a conclusive finding. Nevertheless, the assessors that inspected the participating homes made a judgment based on the thermal inspection and rated the overall standard of insulation coverage for each home.

Thermal imaging of homes can help in identifying whether there is missing insulation or gaps that 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. Figure 6 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.

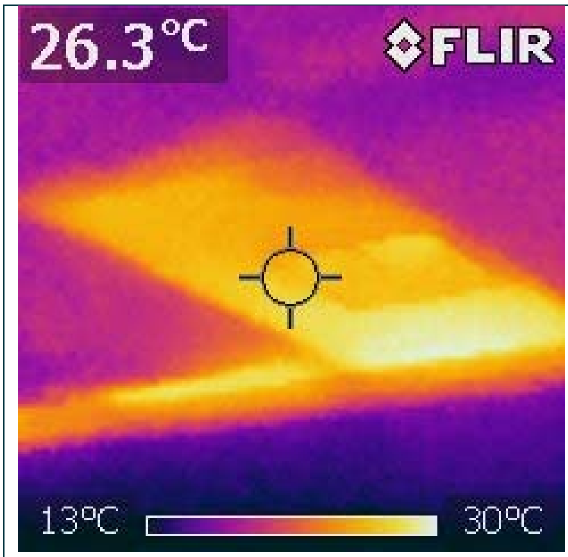
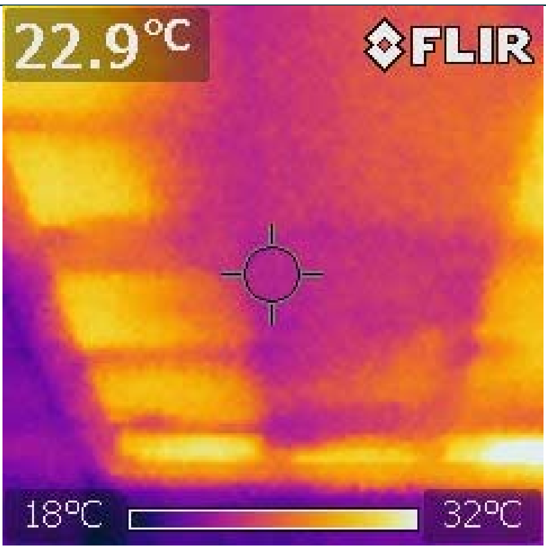
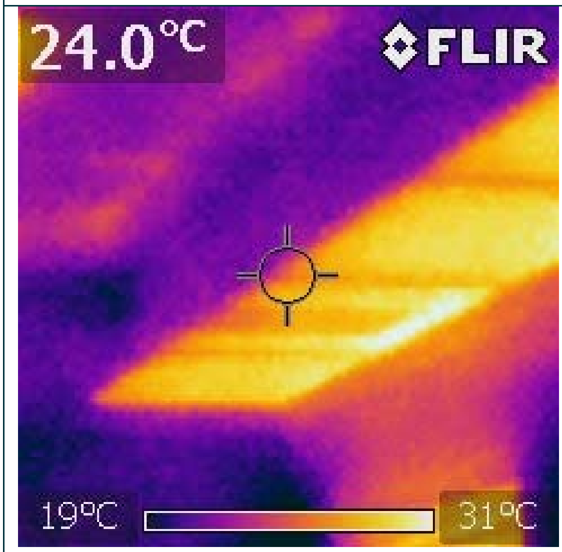
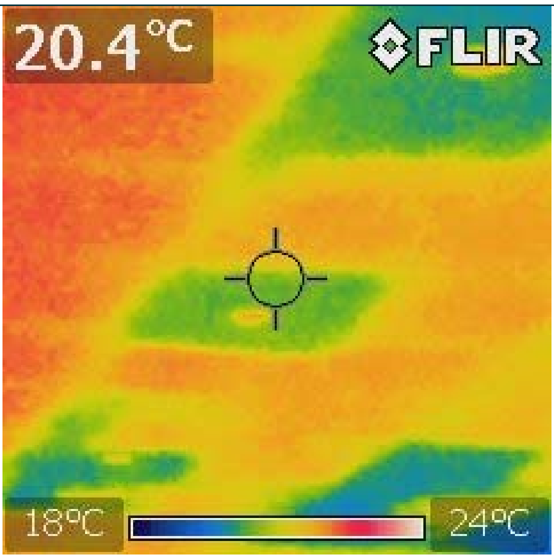
	
Living room ceiling showing gaps in the insulation layer	Living room ceiling showing a line of missing insulation batts close to the roof edge
	
Uninsulated bulkhead in bedroom	Insulation gaps around downlights

Figure 6 Selected thermal images of ceilings

2.5 Inspection of weather sealing

Good quality weather sealing is important to reduce leakage of conditioned air from the house and also to reduce external air and rain entering the house. Weather sealing around doors and windows can help to save up to 25% of heat losses and gains in many climate zones. Regulations require that windows and external doors be weather stripped. It is a fairly simple technique, but can be easily damaged over time with the opening and closing of doors and windows and its effectiveness reduced. Assessors checked for the presence and condition of weather sealing on windows and external doors. Figure 7 shows some examples of weather sealing on doors that has been damaged or poorly installed and has consequently been rated as in poor condition.

Poorly installed and damaged weather sealing around door

Door weather sealing showing gaps

Figure 7 Examples of poor weather sealing on doors

2.6 Inspection of ductwork

The NCC sets out the minimum R-value of insulation required for ductwork taking into account both the intended climate zone and the type of system to be installed (Australian Building Codes Board, 2015). AS 4254 was amended and republished in 2012 into two parts AS 4254-2012 Part 1: Flexible duct and Part 2: Rigid duct (Victorian Building Authority, 2014). By regulation, ductwork should be insulated to the minimums set out in Table 4. Generally, heating or cooling only ducted systems require ductwork to be insulated to R1.0 (R1.5 in climate zone 8), while combined reverse cycle ducted systems need ductwork insulated to R1.5 (R1.0 in climate zones 2 and 5). Fittings and junctions need to be insulated to R0.4 for all systems in all climate zones. Insulated ductwork helps reduce heat losses from heating ductwork and reduces heat gain in cooling ductwork. Visual inspection of ductwork was carried out by viewing through the access hatch into the ceiling space (Figure 8). The Melbourne based houses did not have their ductwork inspected as these houses were inspected as part of the RBEES and ductwork was out of scope for that project.

The inspections firstly tried to determine the R-Value of the ductwork. This was really only possible when the R-Value was printed and visible on the ductwork. Although this labelling is a mandatory requirement in AS 4254-2012 which is referenced by the NCC, often it was difficult to locate on the ductwork. Secondly, the inspection looked at the presence of insulation around ductwork fittings, junctions and connections and finally the overall condition of the ductwork was assessed and any defects noted.

Not all houses in this study had ducted heating and cooling installed and consequently the results presented later on ductwork are restricted to those houses where ductwork was present.

Table 4 Minimum material R-Value for ductwork and fittings in each climate zone

Ductwork Element	Minimum material R-Value for ductwork and fittings in each climate zone				
	Heating only systems or cooling only systems including an evaporative cooling system		Combined heating and refrigerated cooling system		
Climate Zone	1, 2, 3, 4, 5, 6 and 7	8	1, 2, 3, 4, 5, 6 and 7	2 and 5	8
Ductwork	1.0	1.5	1.5 (see note)	1.0	1.5
Fittings	0.4				
Note:					
The minimum material R-Value required for ductwork may be reduced by 0.5 for combined heating and refrigerated cooling systems in climate zones 1,2,3,4,6 and 7 if ducts are:					
(a)	under a suspended floor with an enclosed perimeter; or				
(b)	in a roof space that has insulation of not less than R0.5 directly beneath the roofing.				

Source: NCC Volume 2 (2015) – Table 3.12.5.2 (Australian Building Codes Board, 2015)

Figure 8 Typical ductwork inspection

3 Results and Discussion

3.1 Blower door test results

The NCC requires the external fabric of residential buildings to be constructed to minimise air leakage but does not quantify this requirement. Given that the majority of new houses are rated with NatHERS software to demonstrate compliance with the NCC's energy efficiency requirements, this study compared the blower door test results with the level of air-tightness that is assumed within the NatHERS software.

The NatHERS software does not specifically define a level of air-tightness to be achieved. In the NatHERS software, 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 (Ren & Chen, 2014). 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.

Table 5 shows the average, median, minimum, maximum and standard deviation for air-tightness for houses in each capital city.

Table 5 Descriptive statistics of air-tightness in Australian capital cities

Capital city	Air-tightness (ACH@50 Pa)				
	Average	**Median**	**Minimum**	**Maximum**	**Standard Deviation**
Canberra	14.1	13.5	6.7	33.7	6.2
Hobart	7.9	6.0	1.4	26.5	6.2
Perth	25.5	27.8	12.9	39.0	8.9
Sydney	20.8	18.3	8.6	38.5	9.1
Adelaide	8.5	7.6	3.6	20.2	4.0
Brisbane	11.3	9.2	7.9	30.2	5.4
Melbourne*	19.7	16.7	8.1	33.9	7.3
All houses	15.4	13.3	1.4	39.0	9.1

*Older houses than other capital cities – see section 2.1 of this report

In many of the cities tested a wide range of air tightness results were achieved. Figure 9 shows the spread of results for each city along with the median and quartile ranges. 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.

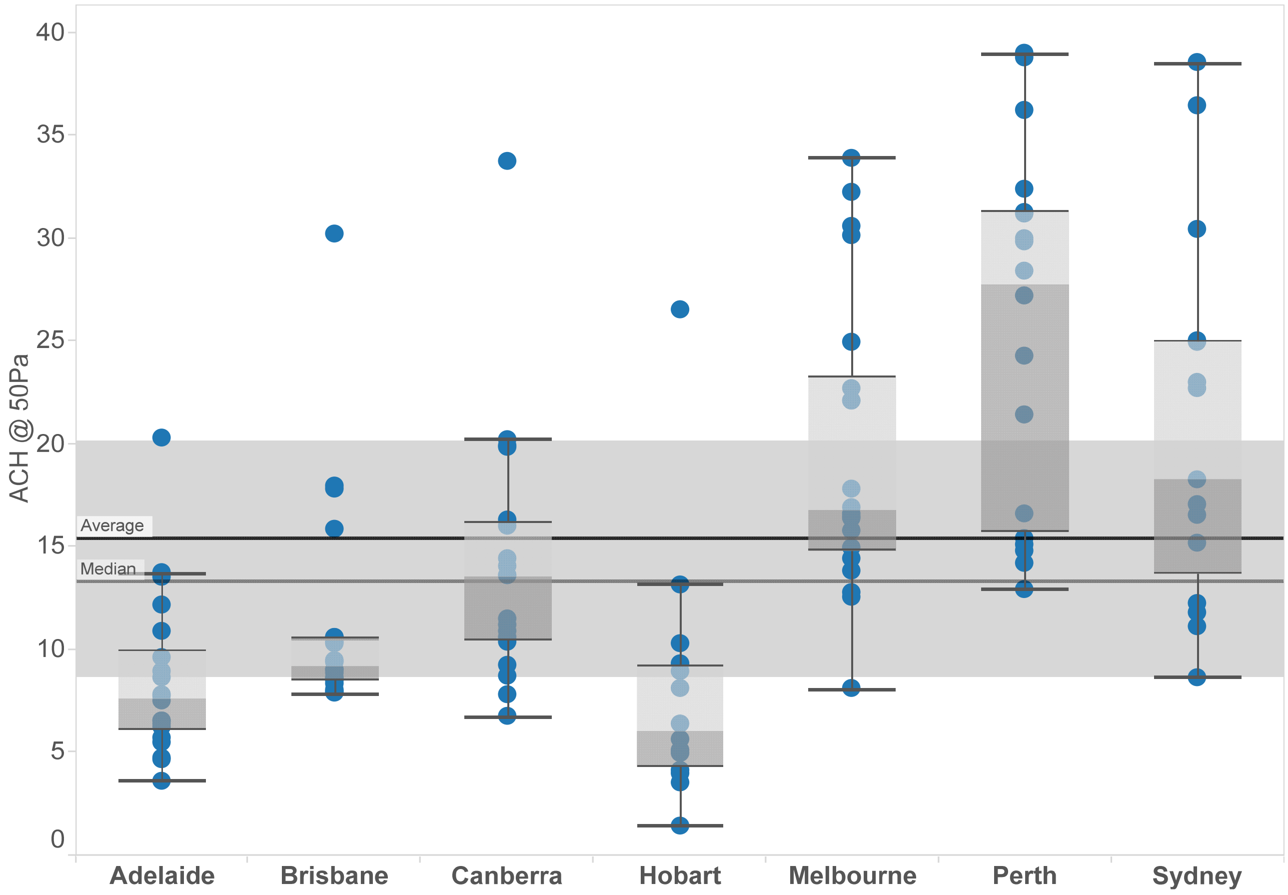


Figure 9 Air changes per hour at pressure by city

Overall, the average air change rate was 15.4 ACH@50Pa which is only slightly higher than the upper range assumed in the NatHERS software.

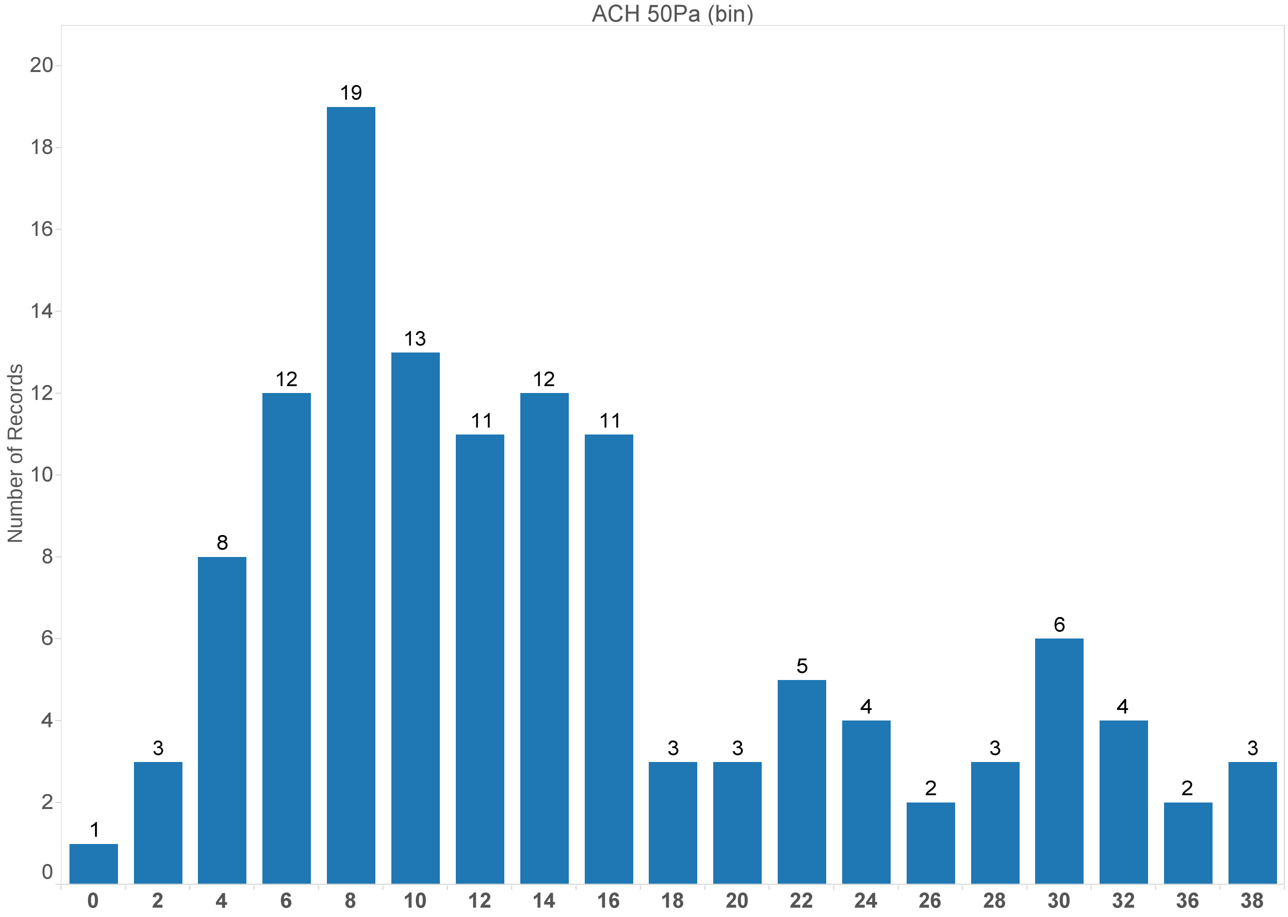


Figure 10 shows the binned distribution of results in increments of 2 ACH@50Pa with each bin being the lower mark. So for example, houses that achieved 15 ACH@50Pa would be counted in the 14 ACH@50Pa bin as it is equal to a greater than 14, but less than 16 ACH@50Pa. The figure shows that a third of 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 is considered 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 the home owner 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.

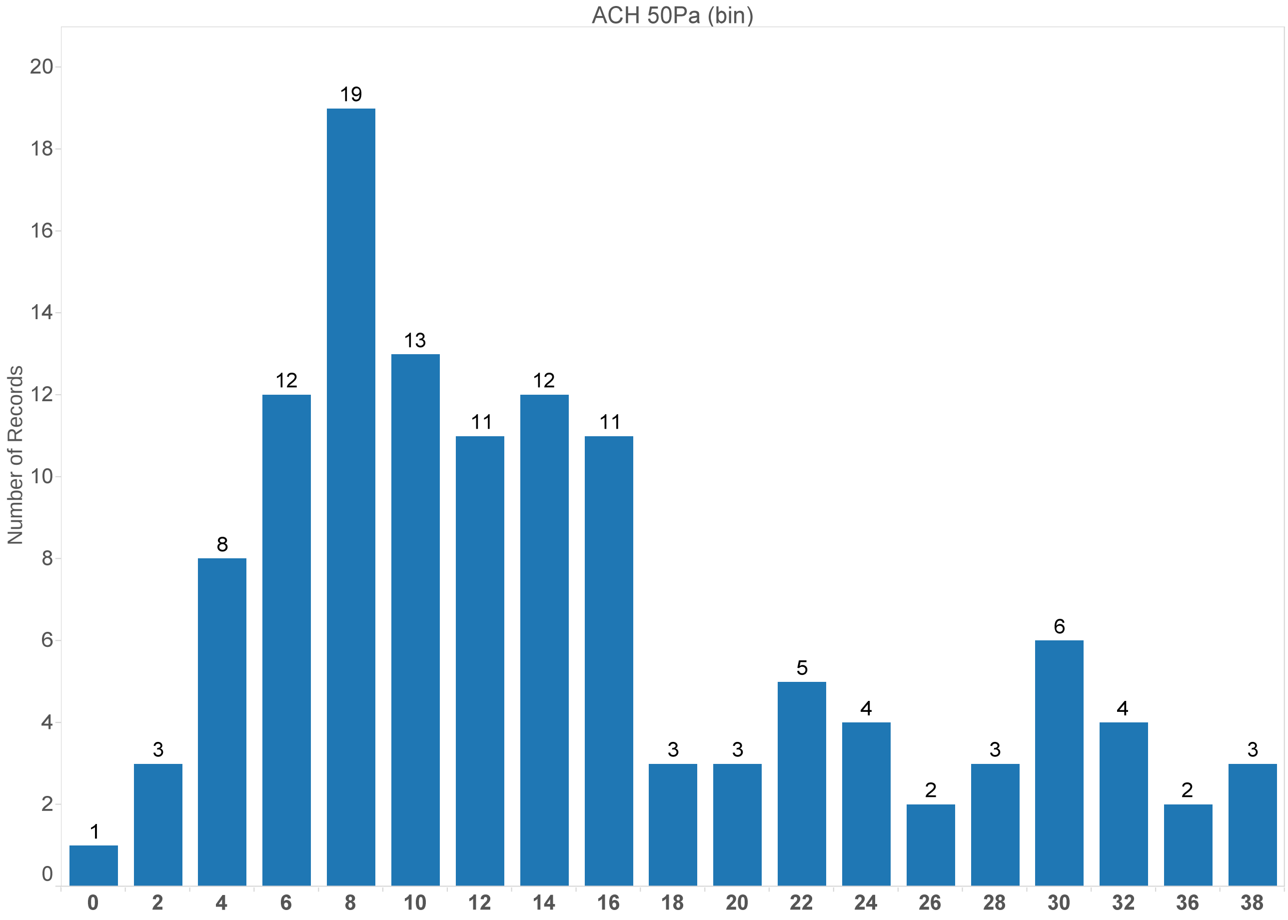


Figure 10 Distribution of air change results

Table 6 lists typical air infiltration rates from countries around the world. Some of these air change rates are minimum legislated requirements, while others are values obtained from research projects like this one and show “typical values”. Most of the countries that have required air infiltration rates set a value well below the rates we experience in Australia. Overseas standards regarding air-tightness are difficult to compare with the results from the current round of testing outlined in this report. There are a range of types of standards that vary from very strict requirements to rather loose requirements – often prescriptive/deemed-to-satisfy provisions that apply in most countries. The more strictly applied standards are necessary to meet the requirements of mainly voluntary schemes or national organisations such as PassivHaus or US Army Corp of Engineers. There are a range of less strict regulatory schemes that do not necessarily require systematic testing of all houses such as in France and the UK where it is common to test a small number of houses in a development to indicate that all houses in the development are likely to be performing adequately. In the US the International Energy Conservation Code (IECC) is adopted by some States, but not others.

In general, jurisdictions that have air-tightness testing as part of their regulation are in colder northern regions and the requirements may be quite tight. For example, in climate zones 6-8 (Montana, Minnesota and Alaska) they require 3 ACH@50Pa and at that level of airtightness, mechanical ventilation is required. In the UK normal practice for naturally ventilated dwellings is 7.7 ACH@50Pa – best practice for naturally ventilated dwellings is 5.5 ACH@50Pa. The general requirement in the UK is dwellings to have a permeability not greater than the equivalent of 10 ACH@50Pa (Air Tightness Testing and Measurement Association, 2010).

Table 6 Air infiltration requirements by country

Country	New Residential Building Requirements Equivalent Air Tightness @ 50Pa [1]	Average of Existing Stock [2]	Comment
Australia		26.3	Sample of 10 houses
		12.2	Sample of 12 houses
New Zealand		11	Sample of 10 houses
UK	10	13.9	
Finland	4.3		
Norway	4.3		
France	5.5		
Belgium	3.2		
Germany	3.2		Natural ventilation
	1.6		Mechanical ventilation
	0.6		PassivHaus standard
Netherlands	8	12	
Sweden	2.9	3.7	
Spain	31.6		Southerly, warmer areas
	17.1		Northerly, cooler areas
USA (Building Energy Codes, 2011)	5	4-8	Climate zones 1-2
	3		Climate zones 3-8
Canada	3-5	4.4	Depending on climate zone

[1] (European Commission, 2013) [2] (Biggs, Bennie, & Michell, 1987)

It is clear that the average air-tightness of houses in all capital cities around Australia except Adelaide and Hobart is considerably higher than the maximum requirement in the UK. In terms of energy efficiency, air-tightness is more important in colder regions because heating is applied to maintain occupant comfort for longer periods during the year than in warmer regions, where natural ventilation can more regularly provide comfortable internal conditions throughout the year.

3.2 Insulation, weather sealing and ductwork inspection results

Visual and thermal inspection of ceiling insulation and heating/cooling ductwork, and visual inspection of weather sealing around windows and external doors 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). One Brisbane based house was found to have no ceiling insulation installed (Figure 11). This is concerning, but it is not known whether this is a breach of the NCC without knowing the building standard that applied to the house at time of build and the compliance path chosen.

16% of ceiling spaces were not accessible, so no visual inspection could be made.

Assessment criteria for quality of installation of insulation

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. Potentially, ceiling insulation that was rated as poor could breach the NCC as it would not be providing the stated R-Value of the insulation material. For example, if a ceiling has R4.2 batts installed but has around 2% of the area uninsulated then the overall effective R-Value of the ceiling is R3.0, a reduction of around 30%. If the area uninsulated increases to 3%, than the effective R-Value is reduced by 40% (Insulation Council of Australia and New Zealand, 2010). If houses have been assessed with a certain assumed R-Value in the ceiling and gaps exist and no corrections have been made to the effective R-Value, then the NatHERS modelling will overestimate the star rating of the house.

Assessment results

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.

Figure 12 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. The centre image has batts still in their packaging and not installed, while the right hand image shows gaps at the end of a batt that have not been filled. Figure 13 shows examples of ceiling insulation rated as average. The image on the left shows larger than required gaps around downlights, the centre image shows damage to the sarking and the image on the right shows inconsistent thickness of the insulation. Finally, Figure 14 shows examples of ceiling insulation as good with both images showing consistent, even and adequate thickness of coverage.

Figure 11 Brisbane house with no ceiling insulation installed

Figure 15 shows the ceiling insulation installation quality for each city and shows that Hobart has the highest percentage of houses with ceiling insulation installation quality rated as good (75%), while Canberra has the lowest (10%).

Figure 12 Examples of ceiling insulation rated as poor

Figure 13 Examples of ceiling insulation rated as average

Figure 14 Examples of ceiling insulation rated as good

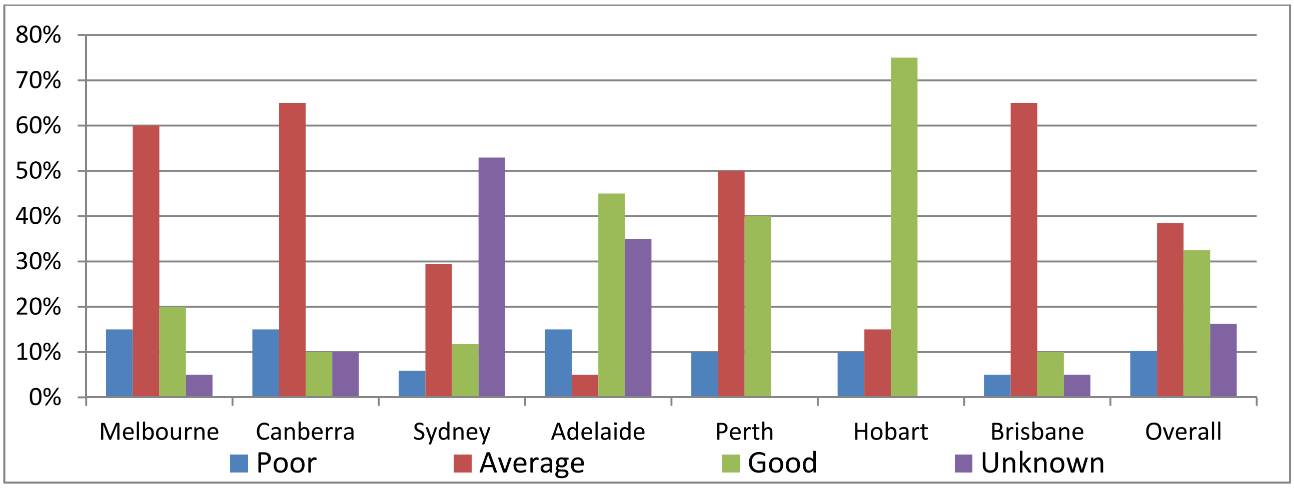


Figure 15 Ceiling insulation quality and condition by city, based on visual inspection

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 (CSIRO, 2001) and used to calculate the estimated R-Value of the insulation. Figure 16 shows the estimated R-Values 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.

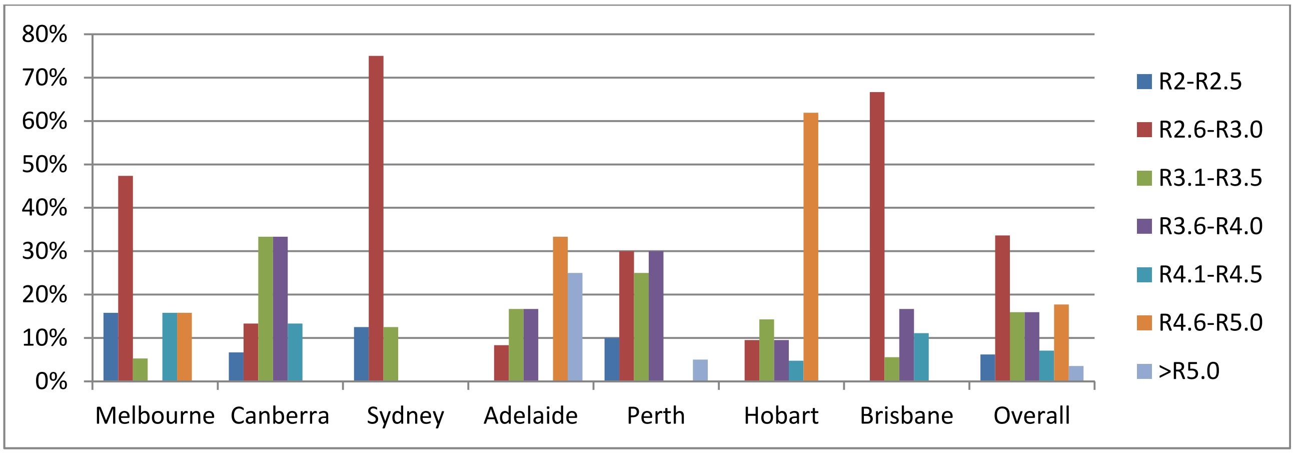


Figure 16 Estimated ceiling insulation R-Value by city

It was not possible to carry out visual inspection of wall insulation and in some cases ceiling insulation was also not accessible. Consequently, thermal imaging was used to try and determine the overall quality of the insulation installed in the houses. Thermal imaging does have limitations especially if climatic conditions inside and outside a house are similar, but nevertheless it does help identify the evenness of insulation coverage and can identify where gaps in the insulation coverage occur. Figure 17 shows the overall assessed quality of insulation in houses for each city based on the thermal imaging. The results are similar to those found for ceiling insulation, although it is interesting to note that in Sydney, no house was assessed as having poor insulation installation quality and in Melbourne and Hobart only one house in each city was rated as poor. The definition of good, average and poor condition is similar to that used for ceiling insulation, with good condition being consistent coverage in all areas, average being the majority of areas having consistent coverage and poor condition having inconsistent coverage with many gaps.

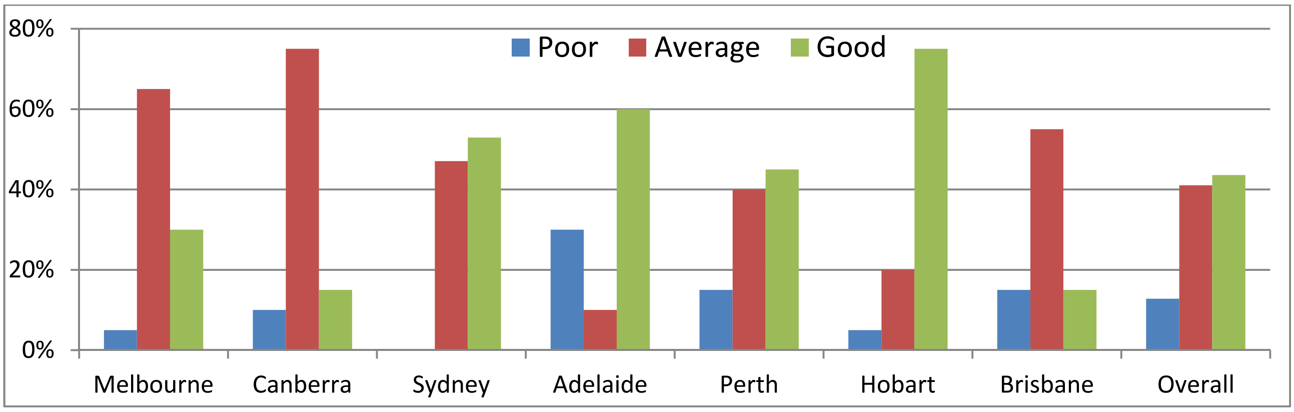


Figure 17 Overall house insulation quality by city based on thermal imaging

Visual inspection of weather sealing of windows and external doors was undertaken to determine the condition. Table 7 shows that 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 degrading 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.

Table 7 Weather stripping condition on windows by city

Condition	Melbourne	Canberra	Sydney	Adelaide	Perth	Hobart	Brisbane	Overall
Good	0.0%	100.0%	88.2%	100.0%	100.0%	90.0%	70.0%	91.5%
Average	85.0%	0.0%	11.8%	0.0%	0.0%	0.0%	10.0%	3.4%
Poor	10.0%	0.0%	0.0%	0.0%	0.0%	5.0%	5.0%	1.7%
No weather stripping	5.0%	0.0%	0.0%	0.0%	0.0%	5.0%	15.0%	3.4%

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. Figure 18 shows that 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.

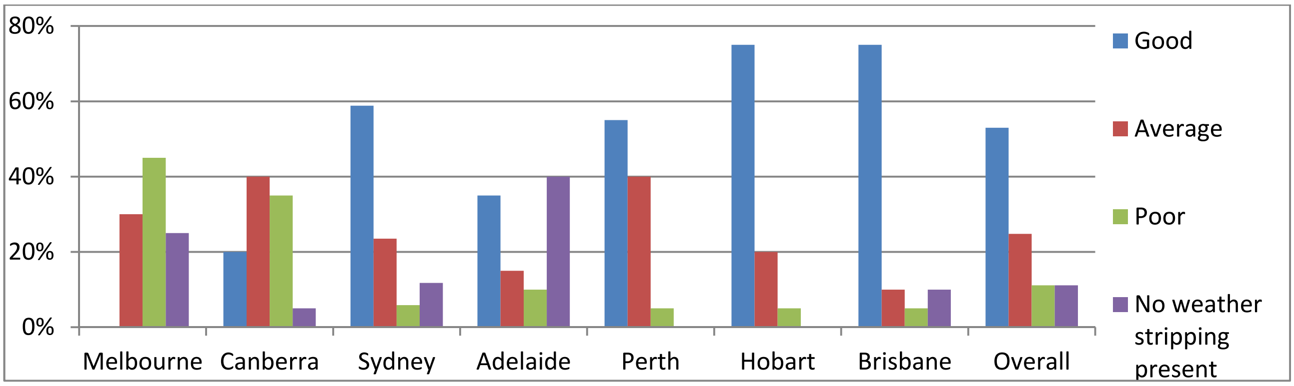


Figure 18 External door weather stripping condition by city

Inspection of heating and cooling ductwork was more problematic than inspection of the ceiling insulation and weather sealing. Generally, the insulation level around the ductwork was unable to be determined unless it was physically printed on the ductwork itself. Thickness of ductwork insulation was also impossible to determine as this would have required dismantling of the ductwork. Visual inspection of ductwork was possible although limited to what could be viewed through the access hatch into the ceiling space. The Melbourne based houses did not have their ductwork inspected as these houses were inspected as part of the RBEES and ductwork was out of scope for that project.

Thermal imaging of ductwork was undertaken and this was effective in determining gaps in the insulation cover and also demonstrated significant heat loss around duct junctions which often had little if any insulation coverage. Figure 19 shows examples of the thermal imaging of duct junctions and reveals that these points are often areas of significant heat loss.

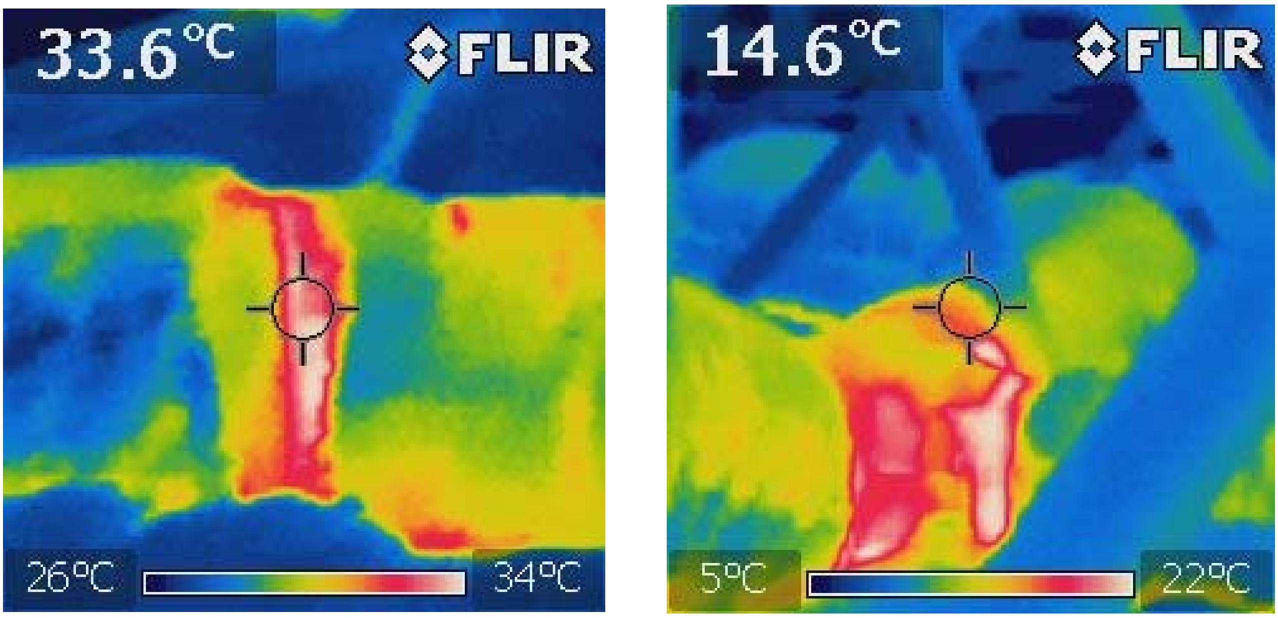


Figure 19 Thermal images showing heat loss around duct junctions

Ducted heating and/or cooling systems are common in many houses but their popularity does vary from city to city. Table 3 lists the number of ducted systems in each of the cities. It can be seen that in Canberra nearly all the houses in the study had ducted systems, while in Sydney and Perth around half the houses had ducted systems. In Adelaide and Hobart very few houses had ducted systems. Many of the ducted systems are reverse cycle heat pumps and are used for both heating and cooling, while some houses have separate ducted systems for cooling (mainly evaporative cooling).

Table 8 and Table 9 show the estimated R-Value for insulation around heating and cooling ductwork respectively. Where the cooling system is the same as the heating system, then ductwork insulation is recorded against the heating system only. It can be seen that trying to determine the insulation level was difficult and in most cases the R-Value could not be determined. However, it is important to note that with heating ductwork all ductwork was found to have insulation present, while only one house in Canberra was found to have no insulation around its cooling ductwork. This means ductwork where R-Value could be identified did comply with the requirements listed in Table 4.

Table 8 Estimated R-Value for heating ductwork

Insulation Level	Canberra	Sydney	Adelaide	Perth	Hobart	Brisbane
R0.5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R1.0	0.0%	0.0%	0.0%	11.1%	0.0%	7.1%
R1.5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
R2.0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Unconfirmed	100.0%	100.0%	100.0%	88.9%	100.0%	92.9%
No insulation	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 9 Estimated R-Value for cooling ductwork (where different to heating ductwork)

Insulation Level	Canberra	Sydney	Adelaide	Perth	Hobart	Brisbane
R0.5	16.7%	-	0.0%	0.0%	-	0.0%
R1.0	0.0%	-	0.0%	0.0%	-	0.0%
R1.5	0.0%	-	0.0%	0.0%	-	0.0%
R2.0	0.0%	-	0.0%	0.0%	-	0.0%
Unconfirmed	66.7%	-	100.0%	100.0%	-	100.0%
No insulation	16.7%	-	0.0%	0.0%	-	0.0%

The presence of insulation around fittings such as junctions and connectors on ductwork was determined through visual inspection. Table 10 shows the results of the inspections and reveals mixed results. Insulation around fittings was found in all Adelaide houses and the majority of Canberra houses, but houses in Hobart and Sydney had low levels of insulated fittings. Potentially, this means ductwork with uninsulated fittings do not comply with the requirements listed in Table 4.

Table 10 Ductwork fittings insulated by city

Duct fittings insulated	Canberra	Sydney	Adelaide	Perth	Hobart	Brisbane
Heating Yes	73.3%	22.2%	100.0%	33.3%	0.0%	50.0%
Heating No	26.7%	77.8%	0.0%	66.7%	100.0%	50.0%
Cooling Yes	83.3%	-	100.0%	0.0%	-	16.7%
Cooling No	16.7%	-	0.0%	100.0%	-	83.3%

The final part of the ductwork inspection involved identifying any other defects. Table 11 and Table 12 list the findings for the heating and cooling ductwork respectively. Overall both heating and cooling ductwork was found to be in good condition with no obvious defects, although a third of ductwork in Sydney was found to have some defects, while two thirds of the cooling ductwork in Canberra had certain defects noted. Other defects included insulation that was compromised at joints or had missing insulation around fittings and in one house conditioned air could be felt escaping from the ductwork, although the exact location could not be identified.

Table 11 Heating ductwork defects by city

Heating ductwork defects	Canberra	Sydney	Adelaide	Perth	Hobart	Brisbane
None - All in good condition	73.3%	66.7%	100.0%	88.9%	100.0%	25.0%
Poor connection sealing	6.7%	0.0%	0.0%	0.0%	0.0%	15.0%
Punctures and tears	0.0%	0.0%	0.0%	0.0%	0.0%	5.0%
Crushed	0.0%	0.0%	0.0%	0.0%	0.0%	5.0%
Stretched	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Excess length of ductwork used	0.0%	0.0%	0.0%	0.0%	0.0%	5.0%
Other defect	20.0%	33.3%	0.0%	11.1%	0.0%	15.0%

Table 12 Cooling ductwork defects by city

Cooling ductwork defects	Canberra	Sydney	Adelaide	Perth	Hobart	Brisbane
None - All in good condition	33.3%	-	100.0%	100.0%	-	50.0%
Poor connection sealing	16.7%	-	0.0%	0.0%	-	33.3%
Punctures and tears	0.0%	-	0.0%	0.0%	-	0.0%
Crushed	0.0%	-	0.0%	0.0%	-	0.0%
Stretched	0.0%	-	0.0%	0.0%	-	0.0%
Excess length of ductwork used	0.0%	-	0.0%	0.0%	-	0.0%
Other defect	50.0%	-	0.0%	0.0%	-	16.7%

3.3 Air changes compared to sealing

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 13 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 13 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.

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 and that those houses assessed to have an overall poor quality of insulation recorded a slightly lower average air change rate (13.7 ACH@50Pa) as those with good insulation (Figure 20).

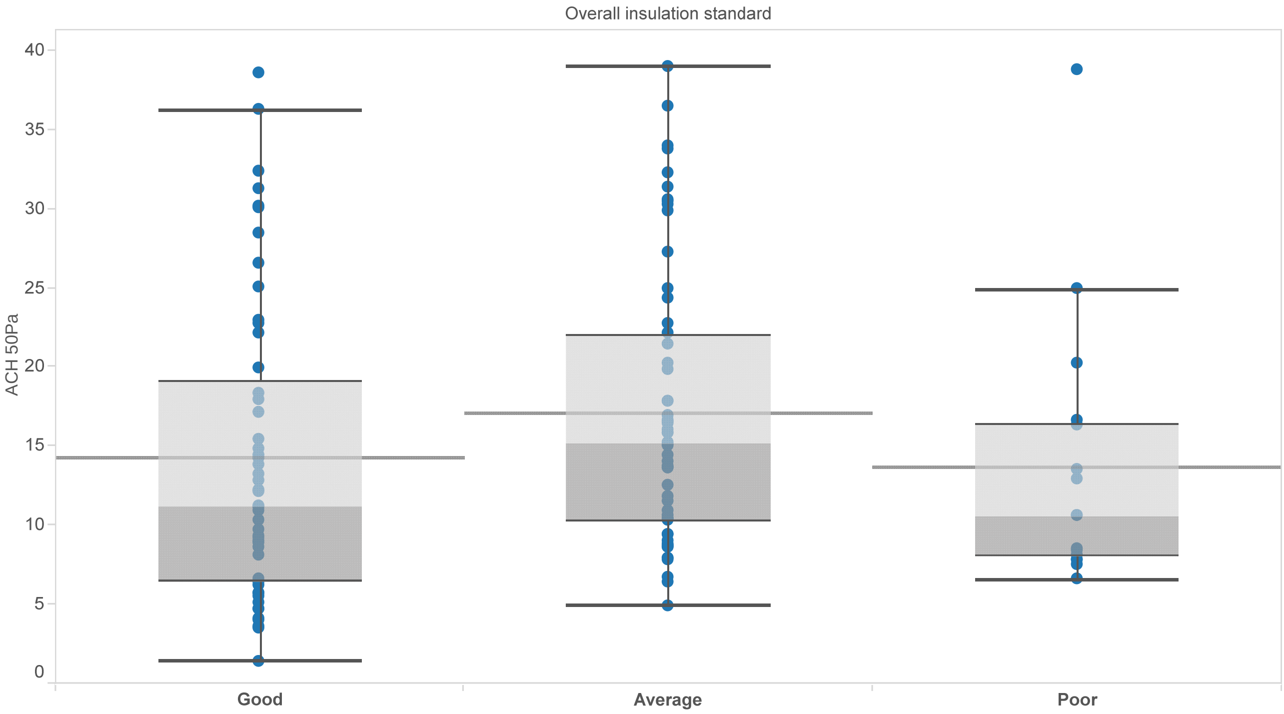


Figure 20 Air change rate by overall insulation standard

Ceiling insulation installation quality showed a slight correlation with air change rates, with houses with good ceiling insulation 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 standards (Figure 21).

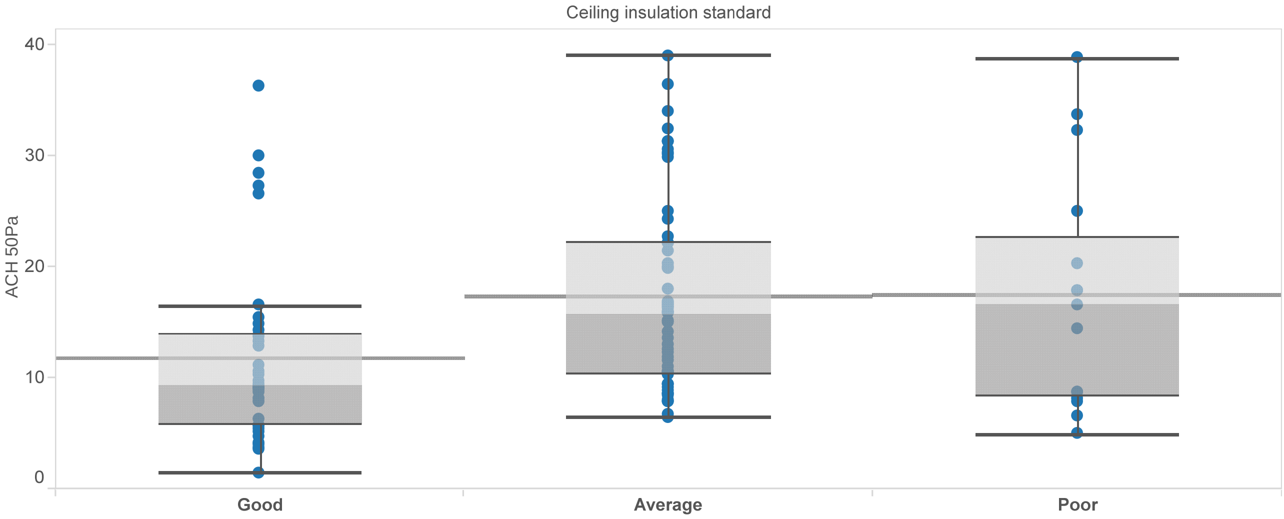


Figure 21 Air change rates by ceiling insulation standard

One interesting observation was that those houses with high estimated R-Values for the ceiling insulation tended to have low air change rates. Figure 22 shows the relationship between ceiling R-Value and the air change rate for each house in the study. A logarithmic trend line is attached with the model for the trend line outlined below. 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 infiltration rates.

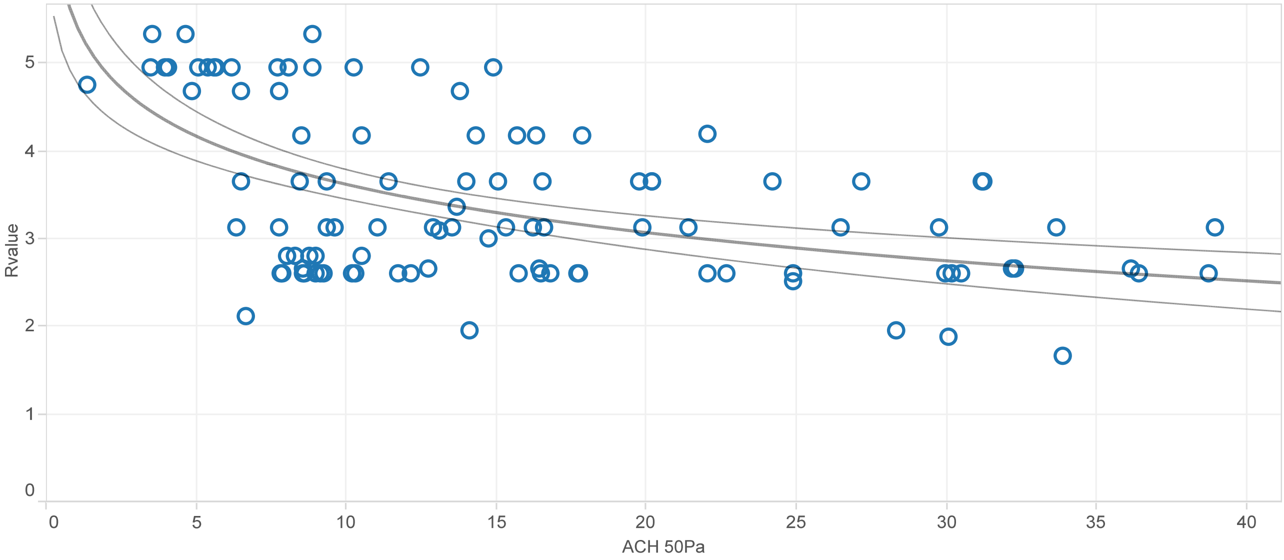


Figure 22 Air change rates by estimated ceiling insulation R-Value

Trend Lines Model

A logarithmic trend model is computed for R-value given ACH 50Pa. The model may be significant at p <= 0.05.

Model formula:	(log(ACH 50Pa) + intercept)
Number of modelled observations:	103
Number of filtered observations:	28
Model degrees of freedom:	2
Residual degrees of freedom (DF):	101
SSE (sum squared error):	65.4595
MSE (mean squared error):	0.648114
R-Squared:	0.286248
Standard error:	0.805055
p-value (significance):	< 0.0001

Individual trend lines:

Panes		**Line**		**Coefficients**				
Row	**Column**	**p-value**	**DF**	**Term**	**Value**	**StdErr**	**t-value**	**p-value**
R-value	ACH 50Pa	< 0.0001	101	log(ACH 50Pa)	-0.794094	0.124771	-6.36441	< 0.0001
				intercept	5.44677	0.328103	16.6008	< 0.0001

Penetrations into the roof space by downlights and exhaust fans are also often considered a potential path for air leakage, but examination of the data found no relationship between number of unsealed downlights and air change rates, although for exhaust fans as the number of exhaust fans increased the air change rate initially tended to decrease (Figure 23), although the decrease in air change rate was only small. A few houses recorded high number of exhaust fans (more than five) and also higher air change rates, but the increased rate was not that much higher than the overall average.

Finally, gaps in subfloor systems is also a common pathway for air leakage. Although the majority of houses in this study were on concrete slabs, several houses had suspended floor systems with a variety of subfloor insulation being used. Figure 24 shows the air change rates for each house based on their subfloor system (including insulation method). The concrete slab on ground houses show a wide range of results, while the suspended floor houses actually have a closer grouping of results. The highest result for a suspended floor house was 30.1 ACH@50Pa. This house had no insulation being used under the floor. This result is high, but still lower than the highest overall result.

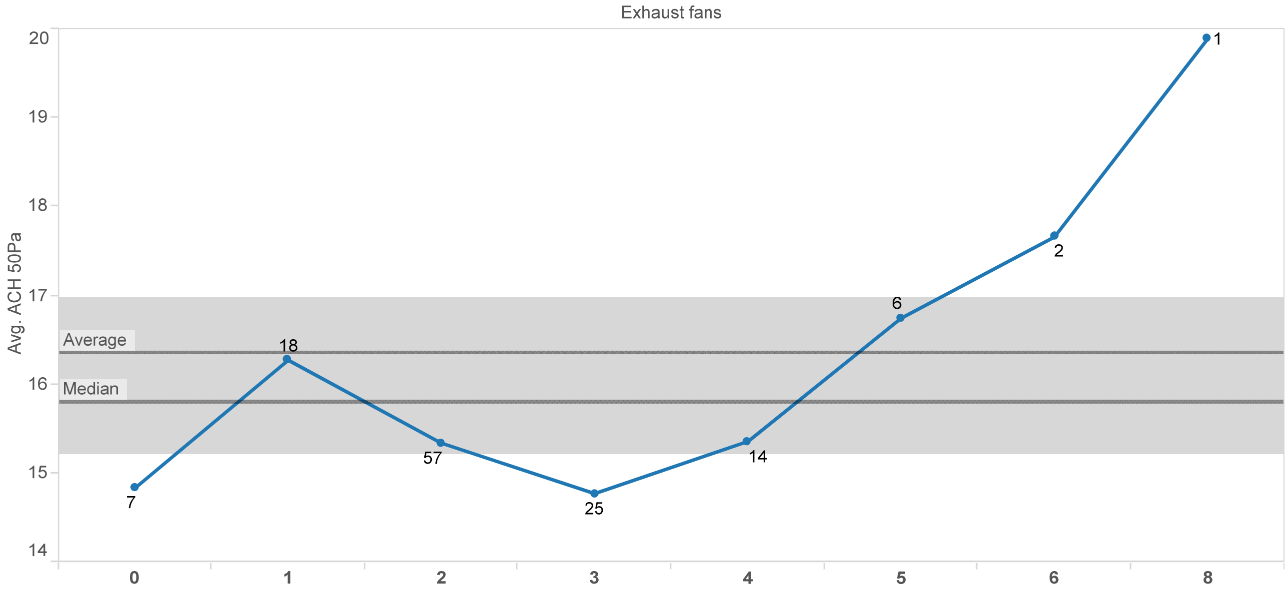


Figure 23 Average air change rate by number of exhaust fans

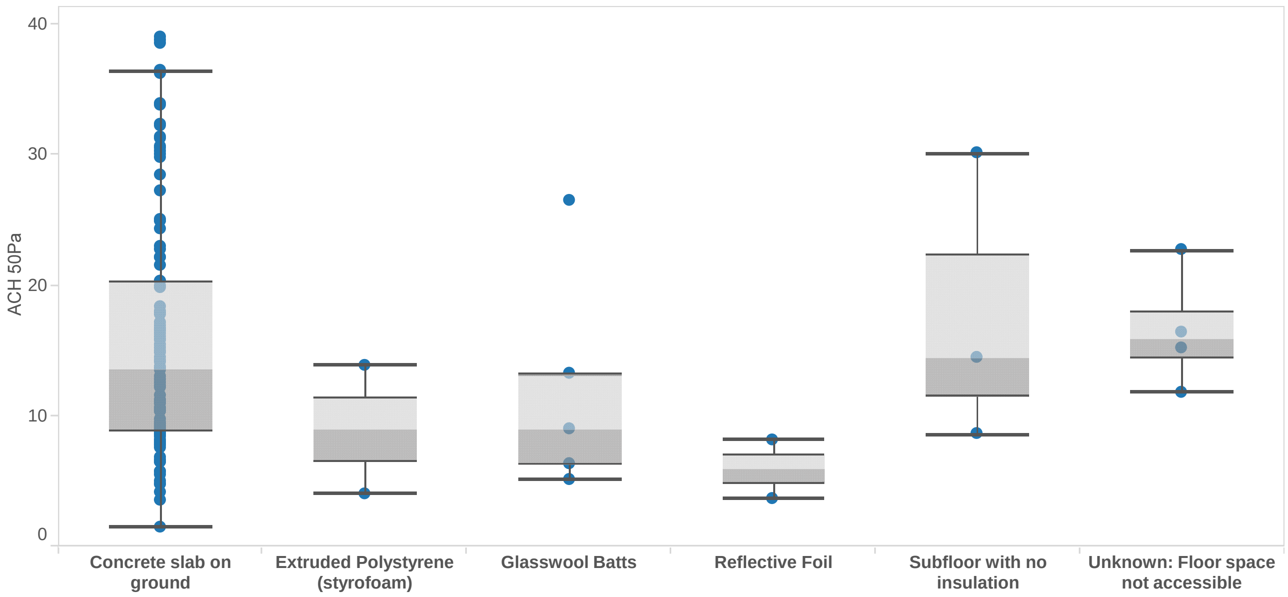


Figure 24 Air change rate by subfloor system and insulation type

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 (Figure 25), 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. Figure 26 shows the air change rates for each house by their window frame type. Houses with aluminium or timber frames have a broad range of results while houses with uPVC window frames recorded much lower air change rates than most other houses. Figure 27 shows examples from two houses of the sealing system that is typical on uPVC window and door frames.

Figure 25 Expanding foam sealant used to fill gap between window and house frame

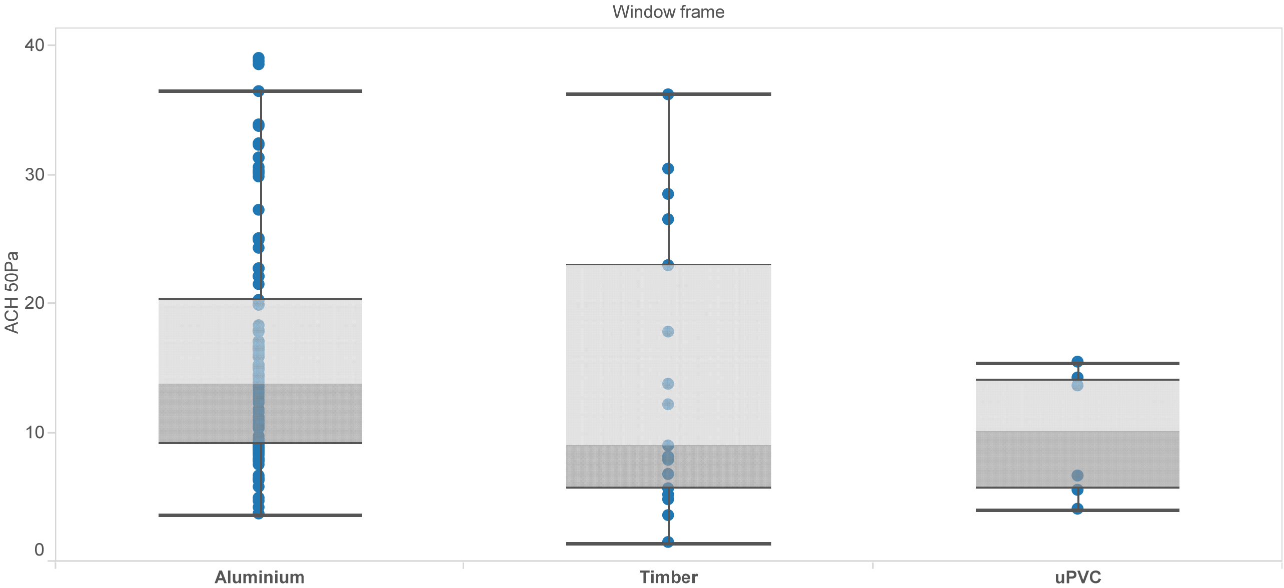


Figure 26 Air change rate by window frame type

Figure 27 Examples of seals on uPVC windows and door frames

3.4 Air changes compared to house volume

Infiltration testing is measured against the volume of the house and it was explored if the size of the house had any correlation with the air change rate. Figure 28 shows the relationship between air change rates and house volume. Overall, the majority of houses had a volume of between 370m^3 and 610m^3 with an average volume of 494m^3 and a median of 470m^3. It can be seen that no strong relationship could be seen between house volume and the air change rate recorded. However, it is interesting to note that the largest house (1249m^3) recorded a relatively low air change rate (6.5 ACH@50Pa), while the highest air change rates were recorded in houses with relatively small volumes.

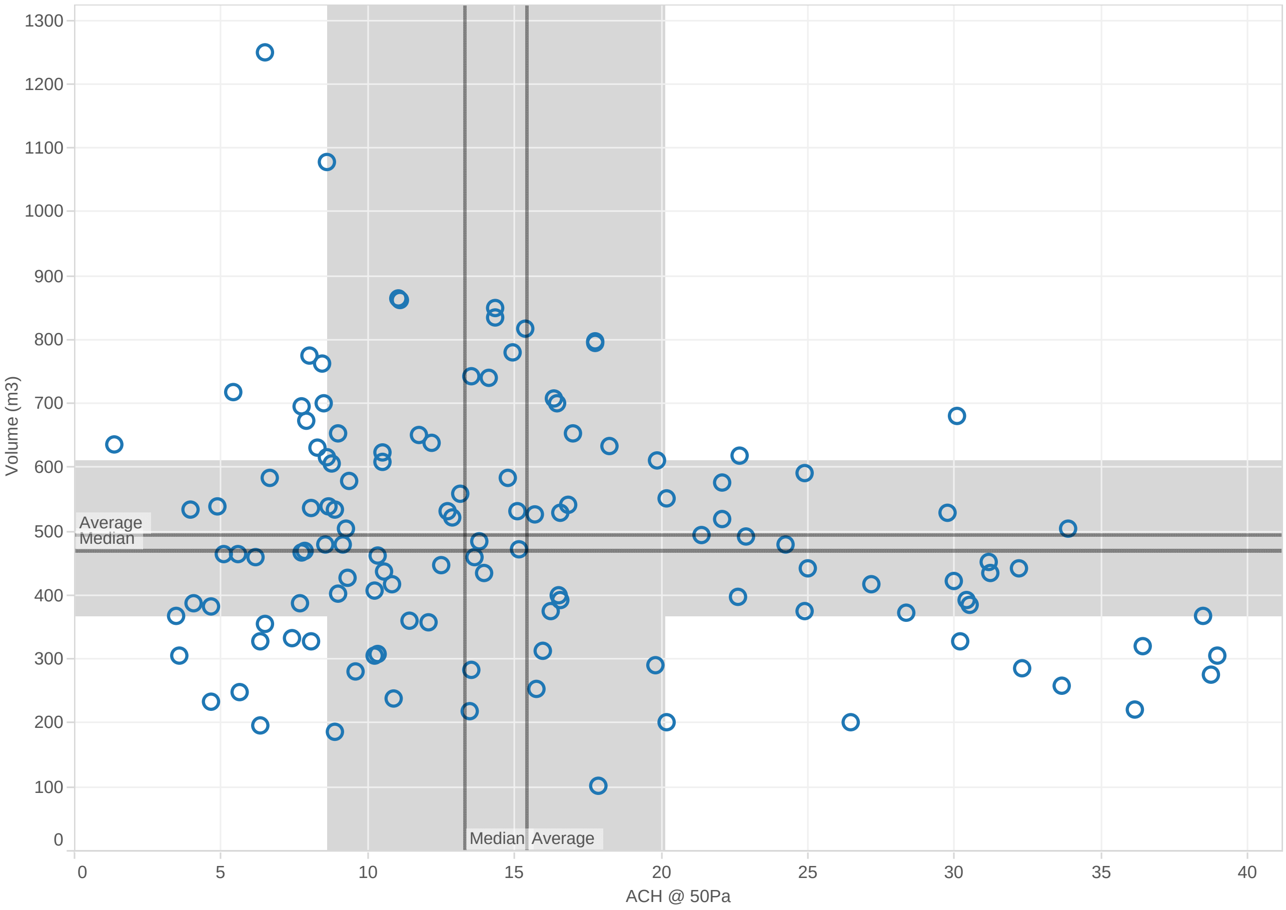


Figure 28 Air change rate by house volume

3.5 Air changes compared to heating system

Many of the houses tested had ducted heating systems, especially in Melbourne where 90% of houses had a ducted heating system. Initial thinking was that potential leaks in the ductwork or poorly operating dampers on heating units could increase air leakage from these houses. However, analysis of the data showed no strong correlation between the heating system type and the air change rate. Figure 29 shows the air change rate by the heating system type. Houses with ducted systems did show a large range of results, but houses with wall mounted systems (which were predominantly reverse cycle units) also showed a large range of results. Overall, houses with ducted heating systems had an average air change rate around the average for all houses, while houses with no heating system or portable heating units actually recorded the highest average air change rate. Many houses with ducted systems recorded air change rates below 10ACH@50Pa, demonstrating that houses with ducted systems could still achieve low air change rates.

Some additional testing of houses with ducted systems was undertaken to determine how great an influence these systems have on the overall air tightness of houses. Four houses in Sydney were retested to determine air change rates with the ductwork included in the test and then isolated from the test. The first test left registers and vents open, which was the methodology used on all houses tested with ducted systems. The second test isolated the ductwork from the air pressure tests by sealing all registers, vents and the air return vent with contact film and rerunning the test. Table 14 lists the results and shows that improvements in air change rates were observed in all four houses tested. Overall, around an 8% improvement was noted when the registers and vents were sealed and isolated from the test. These results suggest that although ducted systems may contribute to increased air change rates, the overall impact is relatively small and cannot be attributed as the primary reason why some houses recorded very high air change rates.

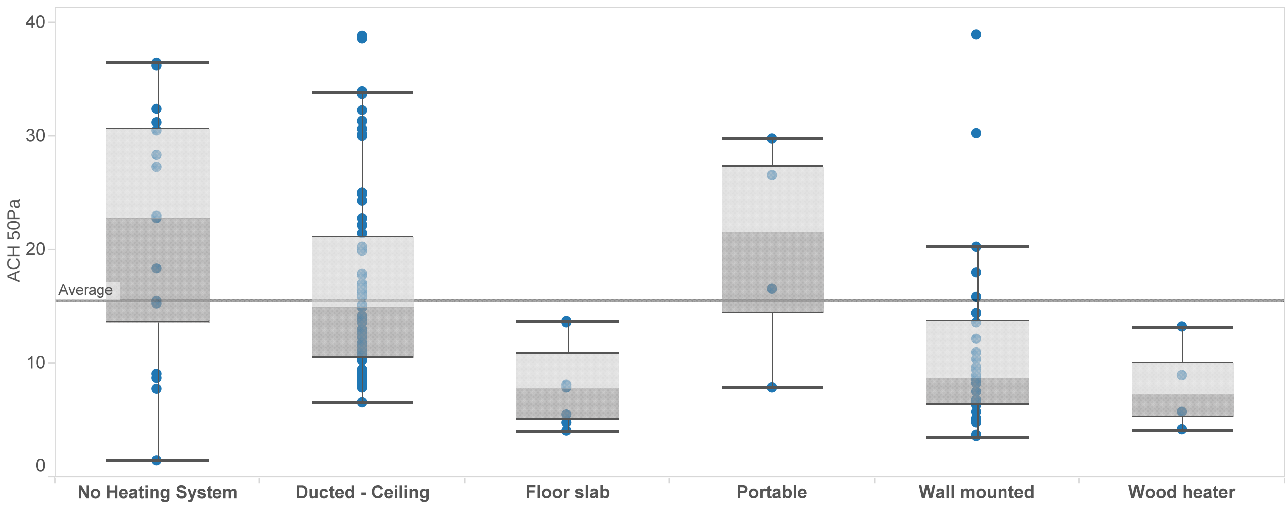


Figure 29 Air change rate by heating system type

Table 14 Changes in air change rates through heating duct isolation

House No.	Pressurisation ACH@50Pa		Difference
	Ductwork included	Ductwork isolated	
1	18.4	18.1	2%
2	17.7	15.2	14%
3	12.0	11.3	6%
4*	14.8	13.0	12%
		Average	8%

*Potentially wind effected results

4 Adelaide and Hobart results

As mentioned earlier, the infiltration results obtained from the Adelaide and Hobart based volunteers was significantly lower than the other cities tested. On average, Adelaide and Hobart houses had an ACH@50Pa of 8.5 and 7.9 respectively, whereas the next closest average was for Canberra at 14.1 ACH@50Pa (see Table 5). The reason for this significant difference was not clear and additional investigation and data analysis was undertaken of the Adelaide houses as a case study to try and determine a factor or factors that may be responsible. It should be noted that the Hobart houses needed retesting due to a fault in the equipment that was identified post testing. This delayed the Hobart results and when received they were lower than the Adelaide results. However, the decision had already been made to further explore the Adelaide house results. Ideally, the Hobart houses should also have been further investigated, although as has been mentioned in the report, a significant proportion of the Hobart houses were architect designed with the specific intent of being tightly sealed, including the overall top performing house, which recorded a result of 1.4 ACH@50Pa and had the specific objective of aiming for the PassivHaus standard of 0.6 ACH@50Pa. Limited discussion of the Hobart houses is included here with some additional analysis, but the full analysis is restricted to the Adelaide houses.

Initial focus looked at the construction materials utilised in the Adelaide houses. Plans for as many of the Adelaide houses as possible were collected and the main wall and floor materials identified. It was found that a significant proportion of the Adelaide houses used autoclaved aerated concrete panels (ACC panels) for the exterior walls (35%), while the cohort also contained two houses with reverse brick veneer wall and another used straw bales. These external wall systems are different to systems used in the other capitals and are also different from the main external wall systems that are used in Adelaide, which based on the RBEES and discussion with local builders, is dominated by brick veneer like most new houses on the eastern side of Australia.

Discussions with some of the builders of the houses tested suggested that because many of the houses included in the Adelaide cohort were more specialist houses greater care and attention was paid to the build quality of the houses. However, despite the different wall systems being utilised, no particular bias was found between the various systems. Figure 30 shows the pressure results for the various wall systems and it can be seen that houses with brick veneer walls generally performed better than those using alternative systems.

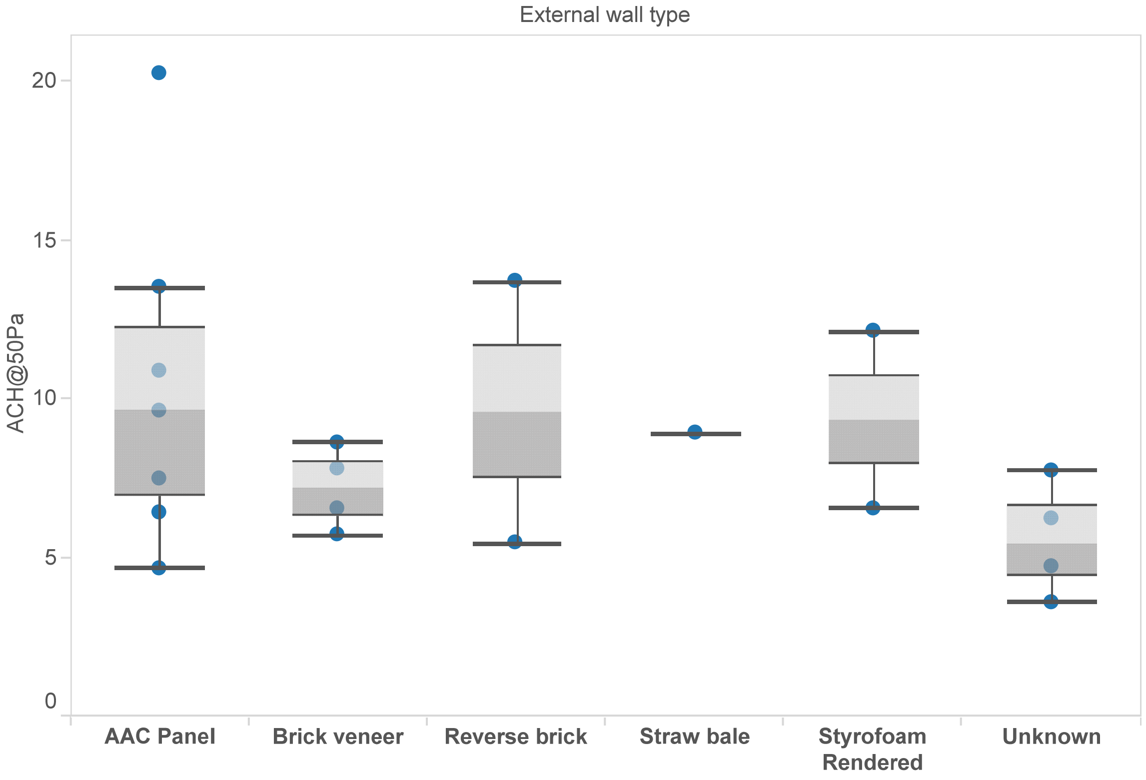


Figure 30 Adelaide houses air change rate by external wall type

The floor systems used were also investigated and although the majority of houses tested were concrete slab on ground, it is interesting to note that two houses were on stumps and that these two houses actually had very good pressure results at around 5 ACH@50Pa (Figure 31). This result seems counterintuitive, but the houses used concrete panel floor systems which provide excellent sealing conditions.

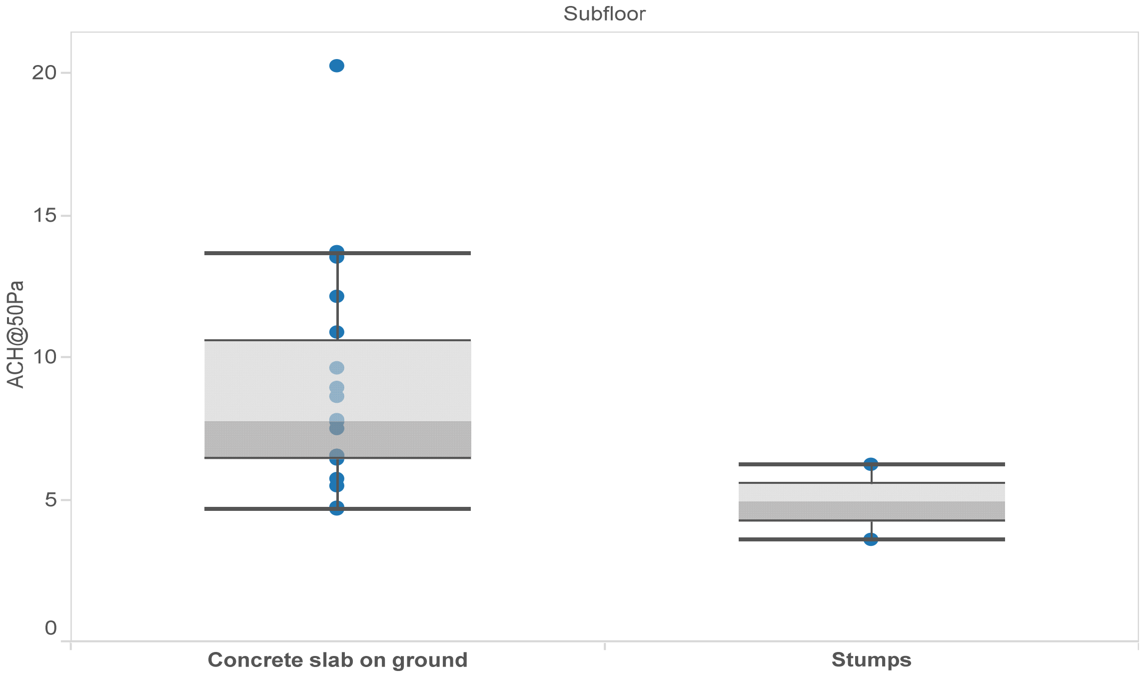


Figure 31 Adelaide houses air change rate by floor system

Discussions with builders and architects indicated that Adelaide construction techniques are similar to those practised in the eastern states of Australia. Indeed, there were suggestions that Adelaide practices may be worse than other parts of Australia. Wrapping building frames with sisulation foil was uncommon in Adelaide and it was mentioned that some window suppliers believe Adelaide builders often don't seal the windows correctly. Inspection of window frame sealing on some of the buildings visited indicated that sealing was not done between the window frame and house fame (Figure 32) and instead the architrave is relied on to provide a barrier to the cavity. This is fairly common practice around Australia.

Figure 32 No sealing between window frame and house frame

As was mentioned earlier, houses using uPVC window frames were noted as having lower air change rates. Two of the architects interviewed in Adelaide also mentioned that many uPVC window systems have a built-in sealing system that provides for a tight seal between the window frame and house frame. Two of the houses in Adelaide and one in Hobart utilised uPVC window frames and all recorded low air change rates (5.4, 6.5 and 4.0 ACH@50Pa). Figure 33 compares the air change results by window frame type for the Adelaide and Hobart houses and the uPVC window houses perform well compared to the other frame types. It is also worth noting that the Hobart houses saw a very high use of double glazing. Overall, 95% of Hobart houses used double glazing which is significantly higher than any other city. Interestingly, Adelaide had the next highest usage at 40%. The high use of double glazing in Hobart is to be expected given the climate and the high number of custom/architect designed houses that were in the Hobart cohort. To achieve the 6 star NatHERS rating in Hobart many houses would need to utilise double glazing.

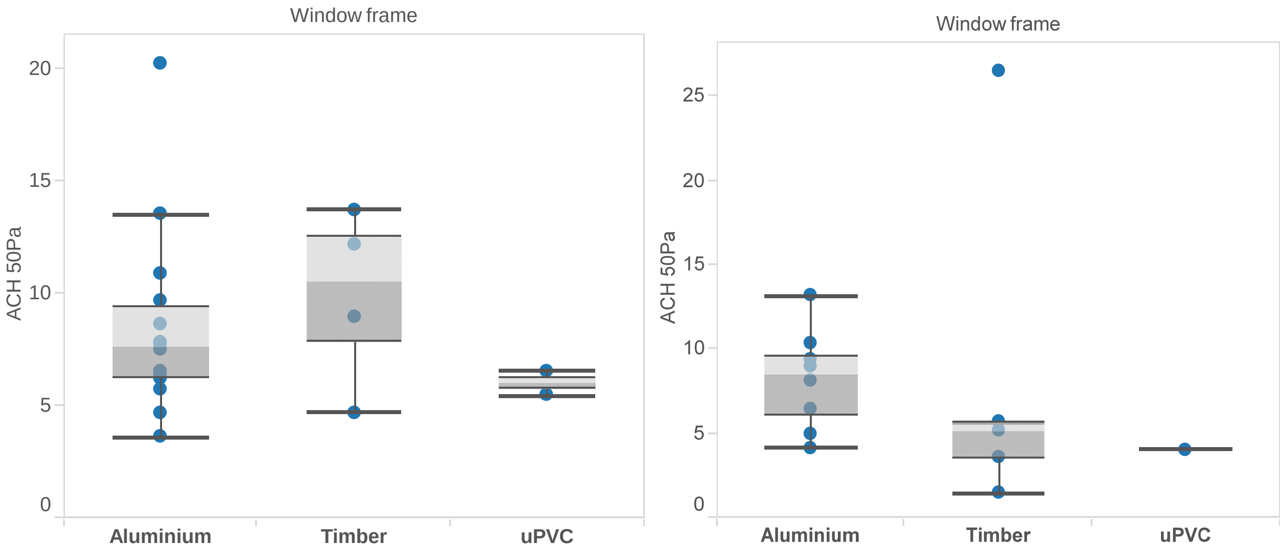


Figure 33 Adelaide (left) and Hobart (right) houses air change rate by window frame

Figure 34 shows the sealing around one of the Adelaide houses that used uPVC window frames. In addition to the window frame's in-built sealing, additional sealing has been used in the form of expanding foam.

Figure 34 Example of good sealing of window frame to house frame

Good sealing around doors also appeared to be a factor in helping houses achieve a good air change rate. Figure 35 shows the Adelaide house results of air change rates by the quality and condition of door seals and shows that houses with good seals performed significantly better than houses with average or poor levels of sealing. Figure 36 shows the Hobart house results and also shows that houses with door seals in better condition did generally perform better.

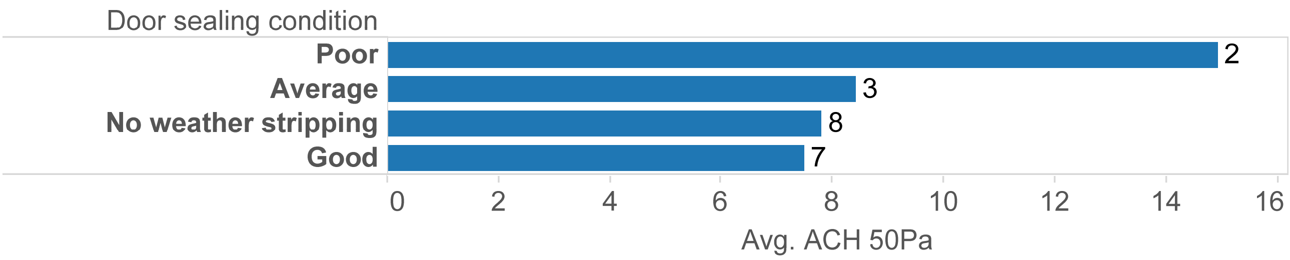


Figure 35 Adelaide houses air change rate by door sealing

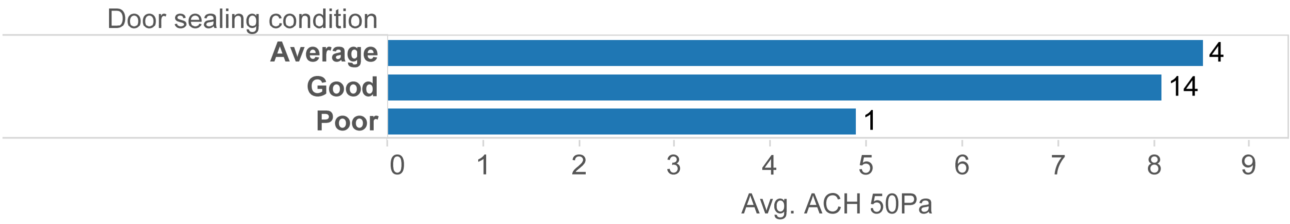


Figure 36 Hobart houses air change rate by door sealing

It is interesting to note that one of the architects interviewed commented that one of their houses tested has French double doors that open to the outside and that providing a good seal to this style of doors is very difficult. Bi-fold doors (Figure 37) were also noted as being very difficult to properly seal between each door and that over time the seals that are provided in the gaps degrade and become ineffectual. Bi-fold doors have become increasingly popular in many new home designs and are often marketed as a luxury feature.

Figure 37 Examples of typical bi-fold doors showing the gaps between each door

5 Conclusion

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 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 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 build techniques.

The overall average air change rate was 15.4 ACH@50Pa. This is very close to upper bound of the assumed air change rate that is used in the NatHERS methodology. This would suggest that the assumed 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 would 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.

5.1 Project issues

Although the project overall achieved its aims, several challenges were encountered that are worth mentioning for any possible future studies in this area. Recruitment of households is always a challenging part of studies of this nature. Trying to minimise bias and have a representative sample of houses can be difficult. Originally, the plan was to include houses in all capital cities, including Darwin. However, the recruitment of Darwin houses proved very difficult and despite several different approaches (including advertisements in local papers and letterbox drops), not enough volunteer households could be recruited to justify the costs involved in testing in this remote city.

The energy assessment inspection was generally carried out before the blower door test was undertaken. The wide range of air infiltration results that was obtained raised the obvious question of why. Had the energy assessment inspection been done after the blower door results for a particular house were known, then potentially there would have been an opportunity to investigate the reasons why a particular blower door result was achieved. Of course, this would still be speculation, but nevertheless potential reasons may have been identified. Another option would be to also have the blower door technician undertake tracer tests with smoke pencils (at additional cost).

The blower door contractors used a hybrid test approach that involved recording specific values at specified pressure levels and only determining the actual infiltration rate post visit back in their office. This was done to allow a greater number of tests to be undertaken in a given time frame, but unfortunately meant that spurious results were not discovered until well after the visit. The initial Hobart house results revealed an obvious error in the test and subsequent investigation found that there was a fault in the equipment used that had not been identified. This resulted in all Hobart houses having to be retested. It is suggested for future studies that greater time could be allowed to determine a result in the field so that any suspicious results can be determined quickly and retesting done again without the need for a follow up visit.

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Appendix A Additional tables

Table 15 Is the house zonable?

	Melbourne	Canberra	Sydney	Adelaide	Perth	Hobart	Brisbane	Overall
Yes	60.0%	70.0%	64.7%	40.0%	40.0%	70.0%	15.0%	51.1%
No	40.0%	30.0%	35.3%	60.0%	60.0%	30.0%	85.0%	48.9%

Note: A zonable house is able to have areas closed off to avoid conditioning spaces not in use through using doors and isolating staircases

Table 16 What is the brand of the main heating system?

	Melbourne	Canberra	Sydney	Adelaide	Perth	Hobart	Brisbane	Overall
ActronAir	0.0%	10.0%	29.4%	5.0%	5.0%	0.0%	5.0%	7.3%
Archer	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Bonaire	10.0%	5.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.2%
Braemar	30.0%	15.0%	0.0%	0.0%	0.0%	0.0%	0.0%	6.6%
Brivis	25.0%	10.0%	0.0%	0.0%	0.0%	0.0%	0.0%	5.1%
Cannon	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Daikin	0.0%	15.0%	5.9%	0.0%	25.0%	30.0%	50.0%	18.2%
Everdure	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Fujitsu	0.0%	0.0%	5.9%	20.0%	5.0%	5.0%	20.0%	8.0%
Hitachi	0.0%	5.0%	0.0%	0.0%	5.0%	0.0%	0.0%	1.5%
Kelvinator	0.0%	0.0%	0.0%	0.0%	5.0%	0.0%	0.0%	0.7%
Lennox	5.0%	5.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.5%
LG	5.0%	5.0%	5.9%	0.0%	0.0%	0.0%	0.0%	2.2%
Mitsubishi	0.0%	0.0%	5.9%	25.0%	0.0%	15.0%	5.0%	7.3%
Paloma	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Panasonic	0.0%	5.0%	0.0%	10.0%	0.0%	0.0%	10.0%	3.6%
Regency	0.0%	5.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.7%
Rinnai	0.0%	0.0%	0.0%	0.0%	10.0%	0.0%	0.0%	1.5%
Samsung	0.0%	5.0%	0.0%	5.0%	0.0%	0.0%	0.0%	1.5%
Vulcan	10.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.5%
Other	15.0%	15.0%	0.0%	25.0%	10.0%	45.0%	5.0%	16.8%

Table 17 Heating system characteristics

	Melbourne	Canberra	Sydney	Adelaide	Perth	Hobart	Brisbane	Overall
Ducted - Ceiling	90.0%	80.0%	52.9%	10.0%	45.0%	0.0%	70.0%	49.6%
Ducted - Subfloor	0.0%	0.0%	0.0%	0.0%	0.0%	5.0%	0.0%	0.7%
Floor slab	0.0%	5.0%	0.0%	15.0%	0.0%	5.0%	0.0%	3.6%
Portable	0.0%	0.0%	0.0%	0.0%	10.0%	10.0%	5.0%	3.6%
Wall mounted	5.0%	10.0%	0.0%	60.0%	10.0%	50.0%	20.0%	22.6%
Hydronic	5.0%	5.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.5%

Table 18 Is the heating system zonable?

	Melbourne	Canberra	Sydney	Adelaide	Perth	Hobart	Brisbane	Overall
Yes	45.0%	45.0%	52.9%	30.0%	40.0%	10.0%	45.0%	38.0%
No	55.0%	50.0%	0.0%	0.0%	5.0%	0.0%	45.0%	22.6%
Not Applicable	0.0%	5.0%	47.1%	65.0%	55.0%	90.0%	5.0%	38.0%

Note: A zonable heating system is one that allows certain areas of a house to be heated or not. For example, upstairs or downstairs or both.

Table 19 Number of heater outlets/registers

	Canberra	Sydney	Adelaide	Perth	Hobart	Brisbane	Overall
0	5.0%	5.9%	0.0%	10.0%	0.0%	0.0%	3.4%
1	5.0%	0.0%	50.0%	0.0%	70.0%	10.0%	23.1%
2 to 5	5.0%	0.0%	20.0%	5.0%	10.0%	0.0%	6.8%
6 to 10	40.0%	29.4%	0.0%	25.0%	5.0%	70.0%	28.2%
11 to 15	25.0%	17.6%	0.0%	10.0%	0.0%	0.0%	8.5%
16 to 20	5.0%	0.0%	0.0%	0.0%	5.0%	0.0%	1.7%
Not Applicable	15.0%	47.1%	30.0%	50.0%	10.0%	20.0%	28.2%

Note: Melbourne data not available

Table 20 Does household use zoning when cooling

	Melbourne	Canberra	Sydney	Adelaide	Perth	Hobart	Brisbane	Overall
Yes	25.0%	5.0%	0.0%	5.0%	0.0%	0.0%	0.0%	5.1%
Sometimes	5.0%	5.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.4%
No	10.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.5%
No Answer	60.0%	90.0%	100.0%	95.0%	100.0%	100.0%	100.0%	92.0%

Table 21 Dominant glazing type

	Melbourne	Canberra	Sydney	Adelaide	Perth	Hobart	Brisbane	Overall
Single glazing	80.0%	65.0%	76.5%	60.0%	75.0%	5.0%	100.0%	65.7%
Double glazing	20.0%	35.0%	23.5%	40.0%	25.0%	95.0%	0.0%	34.3%

Table 22 Dominant window frame

	Melbourne	Canberra	Sydney	Adelaide	Perth	Hobart	Brisbane	Overall
Aluminium	95.0%	85.0%	82.3%	70.0%	75.0%	60.0%	95.0%	80.3%
Timber	5.0%	10.0%	11.8%	20.0%	15.0%	35.0%	5.0%	14.6%
uPVC	0.0%	5.0%	5.9%	10.0%	10.0%	5.0%	0.0%	5.1%

Table 23 Dominant window furnishings

	Melbourne	Canberra	Sydney	Adelaide	Perth	Hobart	Brisbane	Overall
open weave curtains	10.0%	0.0%	17.6%	5.0%	0.0%	5.0%	15.0%	5.8%
close weave curtains	20.0%	10.0%	5.9%	0.0%	5.0%	0.0%	30.0%	7.3%
heavy drapes only	15.0%	30.0%	5.9%	10.0%	5.0%	5.0%	0.0%	8.0%
curtains and pelmets	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
heavy drapes and pelmets	15.0%	0.0%	0.0%	10.0%	20.0%	0.0%	0.0%	4.4%
holland blinds	30.0%	35.0%	35.3%	45.0%	30.0%	55.0%	15.0%	30.7%
venetian blinds	5.0%	20.0%	5.9%	5.0%	35.0%	5.0%	30.0%	14.6%
none	5.0%	5.0%	29.4%	25.0%	5.0%	30.0%	10.0%	14.6%

Table 24 Window Standard AS2047 label visible

	Melbourne	Canberra	Sydney	Adelaide	Perth	Hobart	Brisbane	Overall
Yes	35.0%	60.0%	5.9%	60.0%	30.0%	50.0%	45.0%	41.6%
No	65.0%	40.0%	94.1%	40.0%	70.0%	50.0%	55.0%	58.4%

Table 25 Window Energy Rating (WERs) label visible

	Melbourne	Canberra	Sydney	Adelaide	Perth	Hobart	Brisbane	Overall
Yes	10.0%	30.0%	0.0%	35.0%	10.0%	40.0%	30.0%	22.6%
No	20.0%	70.0%	100.0%	65.0%	90.0%	60.0%	70.0%	67.2%
Unknown	70.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	10.2%

Table 26 Number of unsealed downlights with access to roof space

	Canberra	Sydney	Adelaide	Perth	Hobart	Brisbane	Overall
0	70.0%	41.2%	55.0%	40.0%	55.0%	25.0%	47.9%
1 to 10	5.0%	17.6%	10.0%	25.0%	20.0%	25.0%	17.1%
11 to 30	15.0%	23.5%	25.0%	35.0%	25.0%	25.0%	24.8%
31 to 50	5.0%	5.9%	10.0%	0.0%	0.0%	15.0%	6.0%
51 to 70	5.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.9%
>70	0.0%	11.8%	0.0%	0.0%	0.0%	10.0%	3.4%

Note: Melbourne data not available

Table 27 Dominant lighting type

	Melbourne	Canberra	Sydney	Adelaide	Perth	Hobart	Brisbane	Overall
Halogen	20.0%	25.0%	17.6%	20.0%	35.0%	5.0%	5.0%	18.2%
CFL	0.0%	0.0%	0.0%	10.0%	5.0%	0.0%	55.0%	10.2%
LED	0.0%	5.0%	41.2%	15.0%	20.0%	40.0%	15.0%	19.0%
Unknown	80.0%	70.0%	41.2%	55.0%	40.0%	55.0%	25.0%	52.6%

Table 28 Number of exhaust fans with access to roof space

	Melbourne	Canberra	Sydney	Adelaide	Perth	Hobart	Brisbane	Overall
0	0.0%	0.0%	0.0%	0.0%	5.0%	20.0%	15.0%	5.8%
1	0.0%	5.0%	5.9%	35.0%	15.0%	10.0%	25.0%	13.9%
2	50.0%	30.0%	52.9%	40.0%	30.0%	60.0%	50.0%	44.5%
3	30.0%	50.0%	11.8%	15.0%	15.0%	0.0%	10.0%	19.0%
4	10.0%	5.0%	17.6%	10.0%	20.0%	10.0%	0.0%	10.2%
5 or more	10.0%	10.0%	11.8%	0.0%	15.0%	0.0%	0.0%	6.6%

Table 29 Ceiling and roof insulation type

	Melbourne	Canberra	Sydney	Adelaide	Perth	Hobart	Brisbane	Overall
Glasswool Batts	55.0%	85.0%	35.3%	50.0%	80.0%	80.0%	70.0%	65.7%
Rockwool Batts	5.0%	5.0%	0.0%	20.0%	0.0%	5.0%	20.0%	8.0%
Rockwool Loose-fill	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Polyester Batts	15.0%	0.0%	11.8%	0.0%	10.0%	5.0%	0.0%	5.8%
Wool Batts	0.0%	0.0%	0.0%	0.0%	0.0%	5.0%	0.0%	0.7%
Wool Loose-fill	10.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.5%
Cellulose Fibre Loose-fill	10.0%	0.0%	0.0%	0.0%	5.0%	5.0%	0.0%	2.9%

	Melbourne	Canberra	Sydney	Adelaide	Perth	Hobart	Brisbane	Overall
Extruded Polystyrene (styrofoam)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Expanded Polystyrene (EPS)	0.0%	0.0%	0.0%	0.0%	5.0%	0.0%	0.0%	0.7%
Anticon Blanket	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	5.0%	0.7%
Reflective Foil	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
No ceiling insulation	0.0%	5.0%	0.0%	0.0%	0.0%	0.0%	5.0%	1.5%
Unknown: Ceiling space not accessible	5.0%	5.0%	52.9%	30.0%	0.0%	0.0%	0.0%	12.4%

Table 30 Ceiling insulation thickness

	Melbourne	Canberra	Sydney	Adelaide	Perth	Hobart	Brisbane	Overall
< 50mm	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
50-69mm	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
70-89mm	10.0%	5.0%	0.0%	0.0%	10.0%	0.0%	0.0%	3.6%
90-109mm	35.0%	10.0%	35.3%	5.0%	15.0%	5.0%	60.0%	23.4%
110-129mm	20.0%	25.0%	11.8%	10.0%	40.0%	10.0%	5.0%	17.5%
130-149mm	0.0%	25.0%	0.0%	10.0%	30.0%	15.0%	15.0%	13.9%
150-169mm	10.0%	10.0%	0.0%	0.0%	0.0%	0.0%	10.0%	4.4%
170-189mm	5.0%	0.0%	0.0%	10.0%	0.0%	5.0%	0.0%	2.9%
>190mm	15.0%	0.0%	0.0%	35.0%	5.0%	65.0%	0.0%	17.5%
Unknown	5.0%	25.0%	52.9%	30.0%	0.0%	0.0%	10.0%	16.8%

Table 31 Subfloor insulation type

	Melbourne	Canberra	Sydney	Adelaide	Perth	Hobart	Brisbane	Overall
Concrete slab on ground	85.0%	95.0%	82.4%	90.0%	100.0%	50.0%	95.0%	85.4%
Subfloor with no insulation	5.0%	5.0%	0.0%	0.0%	0.0%	5.0%	5.0%	2.9%
Unknown: Floor space not accessible	5.0%	0.0%	17.6%	0.0%	0.0%	0.0%	0.0%	2.9%
Glasswool Batts	0.0%	0.0%	0.0%	5.0%	0.0%	25.0%	0.0%	4.4%
Rockwool Batts	0.0%	0.0%	0.0%	0.0%	0.0%	5.0%	0.0%	0.7%
Polyester Batts	0.0%	0.0%	0.0%	0.0%	0.0%	5.0%	0.0%	0.7%
Wool Batts	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Extruded Polystyrene	5.0%	0.0%	0.0%	0.0%	0.0%	5.0%	0.0%	1.5%

	Melbourne	Canberra	Sydney	Adelaide	Perth	Hobart	Brisbane	Overall
(styrofoam)								
Expanded Polystyrene (EPS)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Reflective Foil	0.0%	0.0%	0.0%	5.0%	0.0%	5.0%	0.0%	1.5%

Table 32 Subfloor insulation thickness

	Melbourne	Canberra	Sydney	Adelaide	Perth	Hobart	Brisbane	Overall
< 50mm	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
50-69mm	5.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.7%
70-89mm	0.0%	0.0%	0.0%	0.0%	0.0%	5.0%	0.0%	0.7%
90-109mm	0.0%	0.0%	0.0%	0.0%	0.0%	5.0%	0.0%	0.7%
110-129mm	0.0%	0.0%	0.0%	0.0%	0.0%	5.0%	0.0%	0.7%
130-149mm	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
150-169mm	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
170-189mm	0.0%	0.0%	0.0%	0.0%	0.0%	5.0%	0.0%	0.7%
>190mm	0.0%	0.0%	0.0%	5.0%	0.0%	0.0%	0.0%	0.7%
Not applicable	95.0%	100.0%	100.0%	95.0%	100.0%	80.0%	100.0%	95.6%

Table 33 Subfloor insulation condition

	Melbourne	Canberra	Sydney	Adelaide	Perth	Hobart	Brisbane	Overall
Poor	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Average	0.0%	0.0%	0.0%	0.0%	0.0%	5.0%	0.0%	0.7%
Good	5.0%	0.0%	0.0%	5.0%	0.0%	15.0%	0.0%	3.6%
Not applicable	95.0%	100.0%	100.0%	95.0%	100.0%	80.0%	100.0%	95.7%

Appendix B House data summary

House ID (1)	Build Year	Floor Type	Heating		Cooling		Window		Weather Sealing Condition		Un-sealed down-lights	Ex-haust fans	Ceiling Insulation			Overall insul. Standard (2)	Blower Door Results		
			System	Type	System	Type	Frame	Glazing	Window	Door			Type	Standard	Est. R value		ACH 50Pa	Volume (m^3)	Envelope Area (m^2)
ACT01	2011	CS	RC	Duct	Same		Al	SG	Good	Average	0	3	GWB	Average	3.6	Average	14.01	433	494
ACT02	2013	CS	EL	Duct	Same		Al	SG	Good	Good	0	8	GWB	Average	3.1	Good	19.88	611	680
ACT03	2011	CS	Gas	Duct	None		Al	SG	Good	Average	0	2	GWB	Average	3.1	Poor	16.27	375	332
ACT04	2011	CS	Gas	Duct	Fans		Al	DG	Good	Good	0	3	GWB	Good	2.6	Good	9.18	478	542
ACT05	2011	CS	RC	Duct	Same		Al	SG	Good	Poor	0	1	GWB	Average	3.6	Average	Not tested		
ACT06	2012	CS	RC	Duct	Same		Al	DG	Good	Average	13	3	UK	NA	NC	Good	11.14	860	936
ACT07	2011	RNI	Gas	Wall	Evap	Duct	Al	SG	Good	Poor	69	4	GWB	Poor	4.2	Average	14.37	834	910
ACT08	2011	CS	RC	Duct	Same		Al	SG	Good	Poor	25	3	GWB	Average	NC	Average	10.87	415	477
ACT09	2012	CS	RC	Duct	Same		Al	DG	Good	Average	0	2	UK	NA		Average	13.58	282	340
ACT10	2011	CS	Gas	Duct	RC	Wall	Al	SG	Good	Poor	0	2	GWB	Poor	3.1	Average	33.70	258	315
ACT11	2012	CS	RC	Duct	Same		Al	SG	Good	Average	34	2	GWB	Average	NC	Average	10.34	461	524
ACT12	2013	CS	RC	Duct	RC	Duct	Al	SG	Good	Average	0	3	GWB	Average	4.2	Poor	10.57	436	498
ACT13	2013	CS	EL	Wall	Fans		Tmb	DG	Good	Good	0	3	RWB	Average	2.1	Average	6.70	583	651
ACT14	2012	CS	Gas	Duct	RC	Duct	Al	DG	Good	Average	0	6	GWB	Average	3.6	Average	20.20	549	615
ACT15	2013	CS	RC	Duct	Same		Al	SG	Good	None	0	2	GWB	Poor	2.6	Average	8.66	538	604
ACT16	2013	CS	RC	Duct	Same		Al	SG	Good	Poor	0	2	GWB	Average	3.6	Average	11.46	358	418
ACT17	2013	CS	EL	Slab	RC	Duct	uPVC	DG	Good	Poor	0	3	GWB	Average	3.1	Average	13.54	742	815
ACT18	2011	CS	Gas	Duct	RC	Duct	Al	SG	Good	Poor	29	3	GWB	Average	NC	Average	15.99	311	369
ACT19	2011	CS	Gas	Duct	Evap	Duct	Al	SG	Good	Average	10	3	GWB	Average	3.6	Average	19.81	290	348
ACT20	2011	CS	EL	Slab	Fans		Tmb	DG	Good	Good	0	3	GWB	Good	3.1	Average	7.78	466	529
NSW02	2014	CS	RC	Duct	Same		Al	SG	Good	Good	8	2	UK	NA	NC	Good	38.51	367	404
NSW04	2012	RUK	None		None		Al	SG	Good	Good	36	2	UK	NA	NC	Good	22.65	397	255
NSW05	2014	CS	None		None		Al	SG	Good	Average	0	2	GWB	Average	2.6	Average	36.43	318	397
NSW06	2013	CS	RC	Duct	Same		Al	SG	Average	None	15	4	GWB	Average	2.6	Average	16.52	399	367
NSW07	2011	CS	None		None		uPVC	SG	Average	Average	0	2	PB	Good	2.2	Average	Excluded from analysis		
NSW08	2014	CS	None		Fans		Tmb	DG	Good	Good	7	2	UK	NA	NC	Good	22.93	490	440
NSW09	2014	CS	None		Fans		Al	DG	Good	Good	10	2	UK	NA	NC	Good	Excluded from analysis		
NSW10	2011	CS	None		None		Tmb	SG	Good	Poor	0	1	UK	NA	NC	Average	30.44	390	440
NSW11	2014	RUK	None		Fans		Al	SG	Good	Average	0	2	UK	NA	NC	Average	15.18	471	426

NSW12	2012	CS	RC	Duct	Same		Al	SG	Good	Good	0	4	GWB	Average	2.6	Good	12.20	637	449
NSW13	2012	CS	RC	Duct	Same		Al	DG	Good	Good	0	5	GWB	Good	3.1	Good	11.09	863	440
NSW14	2013	RUK	RC	Duct	Same		Al	SG	Good	Average	0	2	GWB	Average	2.6	Average	11.75	650	451
NSW15	2013	CS	RC	Duct	Same		Al	DG	Good	Good	129	4	PB	Poor	2.6	Average	8.61	1077	1168
NSW16	2012	CS	None		Fans		Al	SG	Good	Good	14	5	UK	NA	NC	Good	18.25	632	425
NSW18	2012	CS	RC	Duct	Same		Al	SG	Good	Good	85	3	UK	NA	NC	Good	17.04	652	525
NSW20	2014	CS	RC	Duct	Same		Al	SG	Good	Good	20	2	UK	NA	NC	Good	25.02	440	402
NSW21	2013	CS	RC	Duct	Same		Al	SG	Good	None	20	3	GWB	Average	2.6	Average	24.94	374	450
Qld01	2012	RNI	RC	Wall	Same		Al	SG	Good	Good	25	3	GWB	Average	4.2	Good	8.54	700	553
Qld02	2013	CS	RC	Duct	Same		Al	SG	Good	None	8	2	AB	Good	NC	Average	10.53	61	569
Qld03	2014	CS	None		None		Al	SG	Average	Good	13	2	RWB	Good	2.8	Average	9.01	400	481
Qld04	2012	CS	RC	Duct	Same		Al	SG	Good	Good	40	0	RWB	Average	2.8	Average	8.82	605	661
Qld05	2012	CS	RC	Duct	Same		Al	SG	Good	Good	37	2	GWB	Average	2.6	Good	9.02	652	526
Qld06	2012	CS	RC	Duct	Same		Al	SG	None	Good	85	1	GWB	Average	2.6	Average	7.91	671	567
Qld07	2013	CS	RC	Duct	Same		Al	SG	Good	Good	0	0	GWB	Average	3.6	Average	Not tested		
Qld08	2013	CS	RC	Duct	Same		Al	SG	Good	Good	0	0	GWB	Average	3.6	Average	9.41	578	649
Qld09	2013	CS	RC	Duct	Same		Al	SG	Good	Good	47	3	RWB	Average	2.8	Poor	8.32	630	685
Qld11	2013	CS	RC	Duct	Same		Al	SG	None	Good	90	1	RWB	Average	2.8	Poor	10.55	623	547
Qld12	2014	CS	RC	Wall	Same		Al	SG	Good	Good	0	1	GWB	Average	4.2	Good	17.90	100	158
Qld13	2014	CS	RC	Wall	Same		Al	SG	Good	Good	0	1	GWB	Average	2.6	Average	30.20	327	386
Qld14	2014	CS	RC	Duct	Same		Al	SG	Good	Average	18	2	GWB	Average	3.1	Average	9.36	426	483
Qld15	2013	CS	RC	Wall	Same		Al	SG	Good	Good	4	2	GWB	Average	2.6	Average	15.80	253	335
Qld17	2014	CS	RC	Duct	Same		Al	SG	Good	Good	0	2	GWB	Average	3.6	Poor	8.47	761	819
Qld18	2014	CS	RC	Duct	Same		Al	SG	Average	Good	11	1	GWB	Average	2.6	Average	10.35	308	398
Qld19	2013	CS	RC	Duct	Same		Al	SG	Poor	Poor	10	2	None	NA	NA	Poor	8.62	616	525
Qld20	2013	CS	EL	Port	Fans		Al	SG	Good	Average	3	2	GWB	Average	2.6	Average	7.85	469	474
Qld21	2012	CS	RC	Duct	Same		Al	SG	Good	Good	3	2	GWB	Average	2.6	Average	10.23	406	371
Qld22	2014	CS	RC	Duct	Same		Tmb	SG	None	None	24	2	GWB	Poor	2.6	Average	17.75	796	651
SA01	2012	CS	RC	Wall	Same		Al	SG	Good	Poor	1	1	GWB	Good	3.1	Good	9.62	280	365
SA02	2013	CS	RC	Wall	Same		Al	SG	Good	None	0	1	UK	NA	NC	Good	6.37	195	236
SA03	2012	CS	RC	Wall	Same		Al	SG	Good	Poor	14	1	GWB	Poor	3.6	Poor	20.23	199	261
SA04	2012	CS	RC	Wall	Same		Al	SG	Good	None	26	1	UK	NA	NC	Good	10.89	237	273
SA05	2011	CS	RC	Wall	Same		Al	SG	Good	None	39	2	UK	NA	NC	Poor	7.45	333	437
SA06	2011	CS	RC	Wall	Same		Al	SG	Good	None	12	1	UK	NA	NC	Poor	13.49	216	238
SA07	2012	CS	RC	Wall	Same		Al	DG	Good	None	0	1	GWB	Good	4.9	Good	5.68	248	345
SA08	2014	CS	RC	Wall	Same		uPVC	DG	Good	Good	0	2	GWB	NA	3.6	Good	6.52	353	374
SA10	2013	CS	RC	Duct	Same		Al	DG	Good	Average	38	4	GWB	Average	4.7	Poor	7.78	694	571
SA11	2014	RRF	RC	Wall	Same		Al	SG	Good	Good	0	2	RWB	Good	5.3	Good	3.59	305	363
SA12	2013	CS	None		None		Al	SG	Good	None	0	3	GWB	Poor	4.9	Poor	7.72	385	432
SA13	2013	CS	EL	Slab	Same		Tmb	DG	Good	Good	0	2	RWB	Good	5.3	Good	4.67	380	326

SA14	2011	CS	RC	Duct	Same		Al	SG	Good	Good	16	4	GWB	Poor	4.7	Poor	6.53	1249	862
SA15	2011	CS	RC	Slab	Evap	Duct	Tmb	DG	Good	Good	27	3	RWB	Good	3.4	Average	13.69	458	451
SA16	2013	CS	Wood	Wood	Fans		Tmb	SG	Good	Average	0	2	RWB	Good	5.3	Good	8.91	534	412
SA18	2013	CS	EL	Slab	Same		uPVC	DG	Good	Good	0	3	GWB	Good	4.9	Good	5.43	717	684
SA19	2011	RB	RC	Wall	Same		Al	DG	Good	None	0	2	GWB	Good	4.9	Good	6.21	457	463
SA20	2013	CS	None		None		Al	SG	Good	Average	0	2	GWB	Good	2.6	Average	8.60	477	518
SA21	2013	CS	RC	Wall	Same		Al	SG	Good	None	2	1	UK	NA	NC	Good	4.66	232	257
SA22	2013	CS	RC	Wall	Same		Tmb	DG	Good	Good	0	2	UK	NA	NC	Good	12.11	357	389
Tas01	2012	CS	EL	Wall	None		Al	DG	Good	Average	0	2	GWB	Good	4.9	Good	10.26	305	297
Tas02	2013	CS	RC	Wall	Same		Al	DG	Good	Poor	14	2	GWB	Poor	4.7	Average	4.89	539	499
Tas03	2011	RB	RC	Wall	Same		Al	SG	Good	Good	5	2	GWB	Average	4.9	Average	Not tested		
Tas04	2013	REP	EL	Slab	None		uPVC	DG	Good	Good	7	2	GWB	Good	4.9	Good	3.98	534	710
Tas05	2011	RB	EL	Port	None		Tmb	DG	Poor	Good	0	0	GWB	Good	3.1	Good	26.49	200	255
Tas06	2014	CS	Wood	Wood	None		Tmb	DG	Good	Good	0	2	GWB	Good	4.9	Good	5.62	464	514
Tas07	2013	CS	EL	Wall	Fans		Tmb	DG	Good	Good	0	4	GWB	Good	4.9	Good	3.49	368	437
Tas08	2013	CS	Other		None		Tmb	DG	Good	Good	0	0	CF	Good	4.8	Good	1.40	634	670
Tas09	2011	RRF	RC	Wall	Same		Al	DG	Good	Good	13	4	GWB	Poor	4.9	Poor	8.11	326	311
Tas10	2013	CS	RC	Wall	Same		Al	DG	Good	Average	17	2	GWB	Average	3.1	Average	6.38	327	417
Tas11	2012	RB	Wood	Wood	Fans		Al	DG	Good	Good	0	2	WB	Good	3.1	Good	13.15	558	800
Tas12	2011	RB	RC	Duct	Same		Al	DG	Good	Average	6	2	GWB	Good	4.9	Good	Not tested		
Tas13	2012	CS	RC	Port	None		Tmb	DG	Good	Good	23	0	PB	Good	4.2	Good	Not tested		
Tas14	2013	CS	RC	Wall	Same		Al	DG	None	Good	6	2	GWB	Average	4.9	Average	Not tested		
Tas15	2013	CS	RC	Wall	Same		Al	DG	Good	Good	0	2	GWB	Good	2.6	Good	9.30	503	624
Tas17	2011	CS	Wood	Wood	None		Al	DG	Good	Good	0	0	GWB	Good	4.9	Good	4.07	387	423
Tas18	2011	RNI	Wood	Wood	Fans		Tmb	DG	Good	Good	11	1	RWB	Good	3.9	Good	Not tested		
Tas20	2012	RB	RC	Wall	Same		Al	DG	Good	Average	0	1	GWB	Good	4.9	Good	8.90	186	239
Tas21	2012	RB	None		None		Al	DG	Good	Good	0	2	GWB	Good	3.6	Good	Not tested		
Tas22	2012	RB	RC	Wall	Same		Tmb	DG	Good	Good	0	2	GWB	Good	4.9	Good	5.10	463	507
Vic01	2009	CS	RC	Duct	RC	Duct	Al	SG	Average	Average	This data was not collected in the previous RBEE study	3	GWB	Average	3.1	Average	16.60	390	This data was not collected in the previous RBEE study
Vic02	2004	REP	Gas	Duct	RC	Duct	Al	SG	Average	Average		2	GWB	Good	4.7	Good	13.81	482	
Vic03	2002	CS	Gas	Duct	Evap	Duct	Al	SG	Poor	None		2	PB	Good	2.6	Average	16.46	698	
Vic04	2009	CS	Gas	Hydronic	None		Tmb	DG	Average	Poor		2	RWB	Good	2.8	Good	8.07	536	
Vic05	2003	CS	Gas	Duct	Evap	Duct	Al	SG	None	Poor		3	GWB	Average	4.9	Average	14.95	778	
Vic06	2006	CS	Gas	Duct	None		Al	DG	Average	Average		3	GWB	Average	4.2	Average	15.74	526	
Vic07	2008	CS	Gas	Duct	Evap	Duct	Al	SG	Average	Average		2	GWB	Average	2.6	Average	16.86	540	
Vic08	2010	CS	Gas	Duct	Evap	Duct	Al	SG	Average	None		2	GWB	Poor	2.6	Average	17.78	793	
Vic09	2010	CS	Gas	Duct	RC	Duct	Al	DG	Average	Average		5	WLF	Good	2.6	Good	12.76	530	
Vic10	2009	RUK	Gas	Duct	Evap	Duct	Al	SG	Average	Poor		5	GWB	Average	4.2	Average	16.36	707	
Vic11	2004	CS	Gas	Duct	Evap	Duct	Al	SG	Average	None		3	GWB	Average	2.6	Average	22.70	617	
Vic12	2004	CS	Gas	Duct	RC	Wall	Al	DG	Average	Poor		3	GWB	Average	4.9	Average	12.51	446	

Vic13	2007	CS	Gas	Duct	Evap	Duct	Al	SG	Average	Poor	🟥	2	GWB	Average	2.6	Average	22.09	518	🟥
Vic14	2005	CS	Gas	Duct	Evap	Duct	Al	SG	Average	Average		2	CF	Poor	2.5	Poor	24.90	590	
Vic15	1999	RNI	Gas	Duct	Evap	Duct	Al	SG	Average	None		3	CF	Average	1.9	Good	30.11	679	
Vic16	2003	CS	Gas	Duct	Evap	Duct	Al	SG	Average	Poor		2	PB	Average	4.2	Good	22.08	574	
Vic17	2002	CS	RC	Wall	Same		Al	SG	Average	Poor		4	UK	NA	NC	Good	14.36	847	
Vic18	2001	CS	Gas	Duct	Evap	Duct	Al	SG	Average	Poor		2	WLF	Average	1.7	Average	33.88	503	
Vic19	2004	CS	Gas	Duct	Evap	Duct	Al	SG	Poor	None		4	PB	Poor	2.6	Average	32.20	442	
Vic20	2003	CS	Gas	Duct	Evap	Duct	Al	SG	Average	Poor		2	GWB	Average	2.6	Average	30.54	383	
WA01	2011	CS	RC	Duct	Same		Al	SG	Good	Average	27	5	CF	Good	3.0	Good	14.78	582	432
WA02	2014	CS	RC	Duct	Same		Al	SG	Good	Good	10	2	GWB	Average	3.6	Average	24.25	478	559
WA04	2014	CS	RC	Duct	Same		Al	SG	Good	Average	0	3	GWB	Average	3.1	Average	21.42	494	485
WA05	2011	CS	None		None		Tmb	DG	Good	Good	0	2	EPS	Good	5.3	Good	Not tested		
WA06	2014	CS	None		Fans		Al	SG	Good	Good	16	5	GWB	Good	3.6	Average	27.18	417	494
WA07	2014	CS	RC	Duct	Same		Al	SG	Good	Good	0	4	GWB	Average	3.6	Average	31.27	434	514
WA08	2013	CS	None		Fans		Al	SG	Good	Average	7	2	GWB	Average	3.6	Good	31.19	452	510
WA09	2011	CS	RC	Wall	Same		Al	SG	Good	Average	1	1	GWB	Average	3.1	Average	38.96	304	385
WA10	2012	CS	None		Fans		Tmb	DG	Good	Good	0	2	GWB	Good	2.0	Good	28.36	372	413
WA11	2012	CS	None		Fans		Tmb	DG	Good	Good	0	1	PB	Good	2.6	Good	36.19	221	437
WA12	2013	CS	RC	Duct	Same		Al	SG	Good	Average	0	4	GWB	Good	2.6	Good	29.98	420	383
WA13	2011	CS	RC	Duct	Same		Al	SG	Good	Poor	19	6	GWB	Average	3.6	Average	15.10	531	380
WA14	2011	CS	None		Fans		uPVC	DG	Good	Good	0	2	GWB	Good	3.1	Good	15.38	816	733
WA16	2012	CS	Gas	Port	Evap	Duct	Al	SG	Good	Good	18	3	GWB	Average	3.1	Average	29.78	528	625
WA17	2011	CS	RC	Wall	Same		Al	SG	Good	Good	6	3	GWB	Average	2.6	Average	Excluded from analysis		
WA18	2011	CS	RC	Duct	Same		Al	SG	Good	Average	20	4	GWB	Average	3.1	Poor	12.92	520	541
WA19	2012	CS	RC	Duct	Same		Al	SG	Good	Average	1	0	GWB	Poor	2.6	Poor	38.77	276	250
WA20	2012	CS	RC	Duct	Same		uPVC	DG	Good	Good	25	1	GWB	Good	2.0	Good	14.15	738	871
WA21	2011	CS	None		None		Al	SG	Good	Average	27	2	PB	Average	2.6	Good	32.33	284	281
WA22	2011	CS	Gas	Port	Evap	Duct	Al	SG	Good	Good	0	4	GWB	Poor	3.6	Poor	16.56	527	603

Table Key:

Floor Type		**Heating and Cooling**	
CS	Concrete Slab	RC	Reverse Cycle
RNI	Raised - No Insulation	EL	Electric (Other than RC)
RUK	Raised - Unknown Insulation	Duct	Ducted system
RRF	Raised - Reflective Foil	Slab	In slab system
RB	Raised - Batt Insulation	Wall	Wall mounted
		Port	Portable system
Ceiling Insulation		Same	Cooling system same as heating system
GWB	Glasswool Batts	Evap	Evaporative cooling
RWB	Rockwool Batts	Fans	Ceiling fans
PB	Polyester Batts		
WB	Wool Batts	**Windows**	
AB	Anticon Blanket	Al	Aluminium Framed
CF	Cellulose Fibre Loose Fill	Tmb	Timber Framed
WLF	Wool Loose Fill	SG	Single Glazed
EPS	Expanded Polystyrene	DG	Double Glazed
UK	Unknown – Ceiling not accessible		
NA	Not Applicable		
NC	Not Calculable		

Notes:

(1) There are some gaps in the numbering of houses as some of the recruited houses were excluded before inspections commenced

(2) Assessment of overall insulation standard is based on thermal imaging of walls and ceilings to identify evenness of coverage and extent of gaps

Appendix C House inspection survey questions

Question ID	Question	Answer	Figures and Tables relating to question
1	Enter home details		
	House ID Number		Procedural question
2	Does the house meet the CSIRO age criteria (<4 years old)?	Yes No	Procedural question
3	This house does not meet the CSIRO age criteria, therefore DO NOT PROCEED with this assessment. Please confirm that you wish to CANCEL this household's participation in this project based on this condition:	CANCEL household's participation	Procedural question
4	Turn ON the main heating or cooling system to allow for contrast in thermal images.	Complete NOT complete	Procedural question
5	Is the house zonable?	Yes No	Table 15
6	What is the main type of heating system used in the house?	Reverse cycle Gas Electric (Other than RC) Wood Other No Heating System	Figure 2
7	What is the brand of the main heating system?	ActronAir Archer Bonaire Braemar Brivis Cannon Daikin Everdure Fujitsu Hitachi Kelvinator	Table 16

		Lennox LG Mitsubishi Paloma Panasonic Regency Rinnai Samsung Vulcan Other- pls specify	
8	Heating System Details		
	Brand		
	Model Number		
	Manufacture Year		
	Star Rating		
	Input Power usage (quantity only)		
	Output Power (quantity only)		
	Number of registers		Table 19
9	Which of the following characteristics apply to the main heating system	Ducted - Ceiling Ducted - Subfloor Floor slab Portable Wall mounted Hydronic	Table 3 Table 17
10	Is the heating system zonable?	Yes No Not Applicable	Table 18
11	Take a photo of the heating system and name plate (TWO photos)		Procedural question
12	What is the main type of cooling system used in the house?	Reverse cycle Evaporative Ceiling fans Same device as heating system No Cooling System	Figure 3
13	What is the brand of the cooling system?	ActronAir Archer	

		Bonaire Braemar Breezeair Brivis Cannon Coolair Daikin Everdure Fujitsu Hitachi Kelvinator Lennox LG Mitsubishi Panasonic Samsung Other - pls specify	
14	Which of the following characteristics apply to the main cooling system	Ducted - Ceiling Ducted - Subfloor Wall mounted Portable	Table 3
15	Cooling System Details		
	Brand		
	Model Number		
	Manufacture Year		
	Star Rating		
	Input Power usage (quantity only)		
	Output Power (quantity only)		
	Number of registers		
16	Is the cooling system zonable?	Yes No Not Applicable	
17	Does the householder use zoning (building or system) when cooling?	Yes Sometimes No	Table 20
18	Take a photo of the cooling system and name plate (TWO		Procedural question

	photos)		
19	Appliance Audit and House Background Information comments (record deviations from required task):		Procedural question
20	Take photos of typical window frames and weather stripping		Procedural question
21	Take a photo of the same window and frames with the thermography camera	Complete NOT Complete	Procedural question
22	Completed Thermography scan and image collection of the rest of the house. Photos should be representative of overall insulation coverage of house. From inside of house, take up to 10 photos of poorly insulated (cold/hot spots) and well insulated sections of external walls, ceilings and floors (if relevant).	Complete NOT completed	Procedural question
23	Qualify the overall standard of insulation within the house from the thermography photos:	Poor insulation: Inconsistent insulation coverage – lots of gaps or large gaps Average insulation: Typical outcome, majority of coverage consistent – expect gaps/cold spots to ceiling perimeter, around down lights, under heater platforms & tight corners Good insulation: Majority of coverage consistent – only minimal gaps/cold spots	Figure 17
24	Download thermography (.BMT or .JPG) files to netbook and renamed as "House ID_RoomDescript_SURFACE TYPE" (eg. ACT01_Bedmain_WALL.jpg):	Complete NOT completed	Procedural question
25	Upload Thermography (.BMT or JPG) files (collated in zip file) to DropBox online site:	Complete NOT completed	Procedural question
26	Thermography comments (record deviations from required task):		Procedural question
27	Dominant glazing type:	Single glazing Double glazing	Table 21

28	Dominant window frame:	Aluminium Timber uPVC	Table 22
29	Dominant window furnishings:	open weave curtains close weave curtains heavy drapes only curtains and pelmets heavy drapes and pelmets holland blinds venetian blinds none	Table 23
30	Is the window standards (AS2047) label visible?	Yes No	Table 24
31	Take a photo of the AS2047 label		Procedural question
32	Is the Window Energy Rating (WERs) label or window manufacturer information visible?	Yes No	Table 25
33	Take a photo of the WERs label or window manufacturer information		Procedural question
34	Windows comments (record deviation from required task):		Procedural question
35	Count the total number of unsealed downlights with access to roof space in the house?		Table 26
36	Most dominant type of downlight:	Halogen CFL LED	Table 27
37	Total number of exhaust fans in the house (excluding rangehood) with access to roof space in the house?		Table 28
38	What is the condition of the weather stripping on the windows?	Good Average Poor No weather stripping present	Table 7
39	What is the condition of the weather stripping on the external doors?	Good Average Poor	Figure 18

		No weather stripping present	
40	Take a photo of the door weather stripping.		Procedural question
41	What is the ceiling and roof insulation type?	Glasswool Batts Rockwool Batts Rockwool Loose-fill Polyester Batts Wool Batts Wool Loose-fill Cellulose Fibre Loose-fill Extruded Polystyrene (styrofoam) Expanded Polystyrene (EPS) Anticon Blanket Reflective Foil No ceiling insulation Unknown: Ceiling space not accessible	Table 29
42	What is the thickness of the ceiling insulation?	< 50mm 50-69mm 70-89mm 90-109mm 110-129mm 130-149mm 150-169mm 170-189mm >190mm	Table 30
43	What condition is the ceiling insulation in from visual inspection?	Poor insulation: Inconsistent insulation coverage – lots of gaps or large gaps, thin degraded or ripped Average: Typical outcome, majority of coverage consistent – expect gaps to ceiling perimeter, around down lights, under heater platforms & tight corners Good: Majority of coverage consistent – only minimal	Figure 15

		gaps	
44	Take a photo of the ceiling insulation		Procedural question
45	Ceiling insulation comments (record deviation from required task):		Procedural question
46	Heating Duct Details (if visible)		
	Brand		
	R-Value		
	Other information		
47	Estimated R-Value of heating ductwork	R0.5 R1.0 R1.5 R2.0 Unconfirmed No insulation	Table 8
48	Are fittings (e.g. connectors and junctions) insulated?	Yes No	Table 10
49	What defects are present in the ductwork?	None - All in good condition Poor connection sealing Punctures and tears Crushed Stretched Excess length of ductwork used Other - please specify	Table 11
50	Take a photo of the heating ductwork		Procedural question
51	Cooling Duct Details (if visible)		
	Brand		
	R-Value		
	Other information		
52	Estimated R-Value of cooling ductwork	R0.5 R1.0 R1.5 R2.0 Unconfirmed No insulation	Table 9

53	Are fittings (e.g. connectors and junctions) insulated?	Yes No	Table 10
54	What defects are present in the ductwork?	None - All in good condition Poor connection sealing Punctures and tears Crushed Stretched Excess length of ductwork used Other	Table 12
55	Take a photo of the cooling ductwork		Procedural question
56	What is the subfloor insulation type?	Concrete slab on ground Subfloor with no insulation Unknown: Floor space not accessible Glasswool Batts Rockwool Batts Polyester Batts Wool Batts Extruded Polystyrene (styrofoam) Expanded Polystyrene (EPS) Reflective Foil	Table 31
57	What is the thickness of the subfloor insulation?	< 50mm 50-69mm 70-89mm 90-109mm 110-129mm 130-149mm 150-169mm 170-189mm >190mm	Table 32
58	What condition is the subfloor insulation in?	Poor: Inconsistent insulation coverage – lots of gaps or large gaps &/or thin or degraded Average: Typical outcome, majority of coverage consistent – expect gaps to	Table 33

		subfloor perimeter & tight corners Good: Majority of coverage consistent – only minimal gaps	
59	Take a photo of the subfloor insulation		Procedural question
60	Subfloor insulation comments (record deviation from required task):		Procedural question
61	Pack up equipment and check that its all present:	Netbook, charger & mouse Android Phone & charger Optus Modem & charger Thermography Camera & charger	Procedural question

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