October 2016

Improving Australian Housing Envelope Integrity

A Net Benefit Case for Post Construction Fan Pressurisation Testing

Report prepared by:

The Australian Institute for Refrigeration Air Conditioning and Heating (AIRAH)

Building Physics Special Technical Group

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Improving Australian Housing Envelope Integrity

A Net Benefit Case for Post Construction Fan Pressurisation Testing

"A large fraction of a modern, well-insulated building's space conditioning energy load is due to uncontrolled air leakage. Wintertime condensation of water vapour in exfiltrating air (or summertime condensation of infiltrating air) within assemblies is one of the two major sources of moisture in the above-grade enclosure (driving rain being the other). Air flow through the enclosure can also carry; exhaust gases, odours, and sounds through enclosures as well as mould spores and off gassing generated within the enclosure. Uncontrolled air leakage through the enclosure is therefore often a major cause of performance (e.g. comfort, health, energy, durability, etc.) problems."

Building Science Digest 014
Air Flow Control in Buildings
October 2007, John Straube

"Productivity savings of up to $1.1 billion per annum may be achieved in part by increasing the uptake of Performance Solutions. This is because Performance Solutions can lead to more innovative and cost-effective construction practices."

Australian Building Codes Board
Australian Building Regulation Bulletin
April 2016

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GLOSSARY

Air barrier

A layer that greatly restricts the movement of air under the normal pressure differences found across building elements.

Air Changes

The number of times the air volume within a house is completely replaced with outside air in a one hour time period.

ABCB

The Australian Building Codes Board. A joint initiative of the Australian Government and state and territory governments, the ABCB regulates safety, health, and amenity and sustainability issues through the National Construction Code (NCC).

AccuRate

Is a CSIRO developed software tool. The software has been built on decades of scientific research and lessons from over a decade of the Nationwide House Energy Rating Scheme program.

AccuRate enables house designers to model a house to a fine level of detail, calculate temperatures, heating and cooling energy requirements on an hourly basis, and assess a house's energy efficiency in any one of 69 different climatic zones in Australia.

ACH^{-1}

Annual average air changes per hour under normal operating pressures.

ACH_{50}

Air changes per hour measured during a pressurisation test is reported at a nominal value of 50Pa and will generally be 20 times higher than the normal operating infiltration rate.

ASHRAE

American Society of Heating, Refrigerating and Air-Conditioning Engineers

BCA

The Building Code of Australia. Generally refers to Volume 1 and/or Volume 2 of the National Construction Code (NCC). Volume One contains the requirements for Class 2 to 9 (multi-residential, commercial, industrial and public) buildings and structures. Volume Two contains the requirements for Class 1 (residential) and Class 10 (non-habitable) buildings and structures.

BCR

Benefit to Cost Ratio

Chenath Engine

NatHERS Accredited Software tools are underpinned by CSIRO's Chenath Engine. The Chenath Engine is used by NatHERS software tools to perform the calculations and modelling supporting each home energy rating.

The Chenath Engine has been developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and is based on decades of scientific research on the way buildings operate in Australian conditions. It uses climate data and average user behaviour, among other factors, to predict annual totals of hourly heating and cooling energy requirements for residential dwellings.

Condensation

The process used to describe moisture formation on a surface as a result of moist air coming into contact with a surface which is at a lower temperature. As cool air is unable to retain the same amount of water vapour as warm air, excess moisture is released as condensation.

CSR House

Is a high performance energy efficient BCA Class 1 house built by CSR building products in 2012 for research and development of products and building systems.

Dew Point

The temperature at which the relative humidity of the air reaches 100%, at which time saturation occurs and water vapour contained in the air will begin to condense. The dew point temperature of the air depends upon the air temperature and the humidity of the air and can be determined using a psychrometric chart.

Energy Rating

A star value (from 0 to 10 stars) that is calculated based on the predicted annual Energy Load and the Star Band Criteria for each Climate Zone. The predicted annual Energy Load and the corresponding star rating band for the particular Climate Zone is the design's star rating for regulatory purposes.

Exfiltration

The leakage of room air out of a building, intentionally or not, is called exfiltration.

Heater, Flued

A dedicated exhaust pipe for combustion heating appliances that directs exhaust gases to the outside of a building.

Heater, Unflued (Flueless)

A combustion heating appliance that is not able to directly exhaust gases to the outside of a building.

Housing Research Facility (HRF)

CSR House is now used as a research facility for testing new innovations.

Infiltration

The unintentional or accidental introduction of outside air into a building, typically through cracks in the building envelope. Infiltration is sometimes called air leakage.

IPCC

Intergovernmental Panel on Climate Change

Kilowatt-hour, kWh

The kilowatt-hour (symbolized kWh) is a unit of energy equivalent to one kilowatt (1 kW) of power sustained for one hour. One watt is equal to 1 J/s. One kilowatt-hour is 3.6 megajoules, which is the amount of energy converted if work is done at an average rate of one thousand watts for one hour.

Megajoule, MJ

The joule, symbol J, is a derived unit of energy in the International System of Units. The megajoule (MJ) is equal to one million joules.

Moisture Content (Air)

Moisture content of air refers to the grams of water that is present in a cubic meter of air.

Moisture, External

The penetration of moisture into the building cavity through various sources such as rain, capillary action, leaks, solar driven moisture, air movement and vapour diffusion.

Moisture, Internal

Moisture generated by human activities inside a building, i.e. breathing, sweating, cooking, clothes drying or showering.

Energy Load (Thermal)

It is the predicted annual, energy requirements in conditioned zones arising from space conditioning to maintain thermal comfort within a dwelling reported in Megajoules per Meter Square per annum, $MJ/m^2.a$

NCC

The National Construction Code. It is an initiative of the Council of Australian Governments developed to incorporate all on-site building and plumbing requirements into a single code. The NCC sets the minimum requirements for the design, construction and performance of buildings throughout Australia.

Pliable building membrane (or underlay)

A pliable material, which may be installed to act as sarking, a thermal insulation or vapour control membrane, air barrier, ember barrier or any combination of these.

Relative Humidity (%RH)

The measure of the amount of water vapour in the air relative to the maximum amount of water that the air can hold at a given temperature.

Temperature, Dry bulb

A measure of the temperature of the air, excluding the influence of radiation and moisture. Together with wet bulb temperature, relative humidity and dew point at the ambient temperature can be determined.

Temperature, Wet bulb

Wet-bulb temperature reflects the physical properties of a system with a mixture of a gas and a vapour, usually air and water vapour. Wet bulb temperature is the lowest temperature that can be reached by the evaporation of water only. It is the temperature felt when the skin is wet and is exposed to moving air.

Vapour diffusion

Vapour diffusion occurs through air and/or porous building products when there is a vapour pressure difference between indoor and outdoor air conditions. The rate of diffusion depends upon the permeability of the linings and materials that make up the building fabric.

Ventilation

Ventilation is the removal of contaminated air and replacement with fresh outdoor air.

Ventilation, Extract

Extract ventilation is the removal of contaminated air by way of powered ventilators or fans that remove air from the building. Fresh outdoor air may enter into the building by leakage, purpose built openings or dedicated supply fans.

Ventilation, Mechanical

Mechanical ventilation is the removal of contaminated air and replacement with fresh outdoor air by utilising power ventilators, fans or the like.

Ventilation, Natural

Natural ventilation is the removal of contaminated air and replacement with fresh outdoor air by utilising operable windows, doors or purpose made openings.

Ventilation, Purge

Purge ventilation is the removal of large quantities of air and replacement with fresh outdoor air in a short period of time. This may be by mechanical or natural means.

Ventilation, Source Extract

Source extract ventilation is the removal of contaminated air at the source of contamination utilising power ventilators, fans or the like.

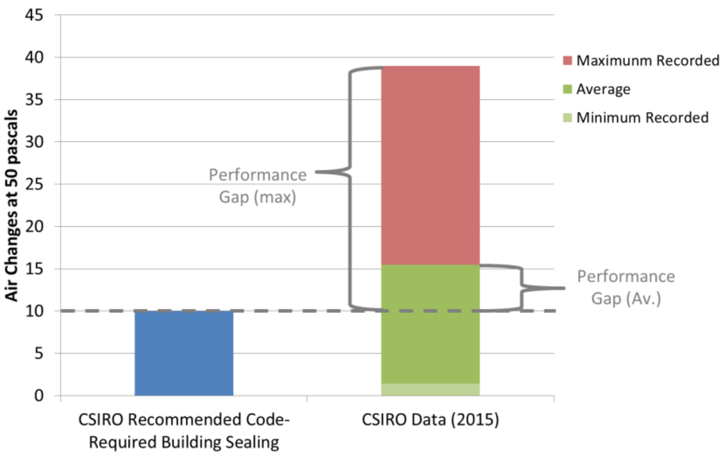
FOREWORD

The Problem

According to the Australian Government's YourHome guides, "Air leakage accounts for 15−25% of winter heat loss in buildings and can contribute to a significant loss of coolness in climates where air conditioners are used." Draughts are also one of the leading causes of discomfort in homes. The National Construction Code of Australia includes basic requirements for draught sealing residential homes, but the language is general and difficult to enforce. Ultimately, compliance with energy provisions of the code has been shown by the Federal Government's National Energy Efficient Building Project to be lacking.

Recent CSIRO data on Australian building air sealing highlights both problems and opportunities. The report mentions a recommended target for Australian building air sealing at 10 ACH_{50} deemed as "Fair" in the Australian Government's YourHome guide. While the average of fan pressurisation test results was 15.4 ACH_{50}, many homes were dramatically leakier, with a significant portion testing over 20 ACH_{50} deemed as "Poor" in the Australian Government's YourHome guide. These homes are at risk for major performance problems like the inability to keep the house comfortable during adverse weather conditions. This is often referred to as the "performance gap" which is the disparity between the planned outcomes and real outcomes. Furthermore energy calculations for code compliance may be based on assumed air infiltration rates less than or equal to 10 ACH_{50} but the building does not necessarily achieve this post construction.

Additionally houses are being built below 3 ACH_{50} which means that accumulation of internal moisture is a higher risk. If the extent of air sealing is validated mechanical ventilation can be suitably addressed within in the National Construction Code to alleviate this risk.



Difference between code-required building sealing and typical construction

The Opportunity

The current process of verifying that homes have been adequately sealed according to the requirements of the Australia's National Construction Code is visual and therefore subjective and unreliable. To overcome this limitation and enforce code and regulation requirements for draught-proofing of homes, European countries have for years required air leakage testing of homes for verification. Performance is measured by the fan pressurisation method, commonly called a blower door test. This method is quick and repeatable, and by comparison to visual methods of verification, it is quantifiable and therefore more reliable. This quantitative measure of air sealing allows for benchmarking and standardisation. Much of the argument for not adopting this in Australia to date is that our climate is mild and that the costs are not warranted. From a building physics perspective this is not the case in Australia and for every dollar spent will return $1.8 - $2.6 in economic benefit.

Fortunately, improving draught sealing of new homes is readily achievable by mainstream Australian construction. The CSIRO data shows that one third of the homes in the sample are already being built to meet the recommended target of 10 ACH_{50}.

Testing homes by fan pressurisation has been used for over 40 years to evaluate the air sealing adequacy of buildings internationally, and it is used by many countries as a performance based validation technique to ensure compliance with sealing requirements of building codes. This performance based measure allows a builder considerable flexibility in materials and methods used to meet requirements. In fact, basic levels of sealing may be achieved simply by following the acceptable construction practice in the National Construction Code. The difference is that a performance target can be prescribed and verified with a quantitative test.

EXECUTIVE SUMMARY

This report presents the case that performance based sealing and verification of as-constructed air leakage rates in new housing in accordance with AS/NZS ISO 9972 is greatly beneficial to Australia and is valid for inclusion in the 2019 Building Code.

The Need

Recent research by CSIRO has shown that the current prescriptive methods outlined in the BCA for sealing construction systems are not effectively achieving their purpose in 65% of cases and not fulfilling the NCC objectives to reduce carbon emissions. This also has potential sub-optimal outcomes for health, amenity and fire safety.

The case is presented for building integrity testing as a performance solution alternative to the acceptable construction practice for air sealing in BCA Volume 2 clause 3.12.3 for residential housing. The report concludes:

- Air sealing to a "Fair" level of 10 ACH_{50} is realistic and achievable with standard Australian construction practice.
- A building code target of value of 10 ACH_{50} would effectively bring 65% of new houses tested to a "Fair" level of performance.

Current Practice

Recommendations in this report are not advocating an increase in stringency of the current energy efficiency provisions in BCA Volume 2. It is advocating the use of a performance based method of verification to increase air sealing alignment with the current energy efficiency objectives, facilitating industry to develop performance based solutions for existing requirements and increase productivity within the Australian construction industry. This report makes the following recommendations:

- A performance target of 10 ACH_{50} is implemented as a performance based measure in parallel with acceptable construction practice in 2019 code revision.
- AS/NZS ISO 9972 is used as the standard test methodology to validate the performance.
- A performance based benchmark is in parallel with acceptable construction practice until 2022 building code update where performance verification becomes the only option.

Motive for This Report

To show that improved envelope integrity through draught sealing is possible and cost-effective in Australian construction. To establish evidence for a code based requirement for testing by fan pressurisation as a cost-effective way to improve compliance with National Construction Code requirements for building sealing.

Methodology

The analysis takes into account the many factors affecting the calculation of cost-effectiveness, including climate, housing construction activity by state, current building practice, state-specific construction methods, a variety of heating and cooling systems and their efficiencies, fuel prices, and the present value of future energy savings.

The Economic Benefit

The analysis within the report shows that the energy provisions can be greatly undermined by high air leakage rates through the building envelope. An achievable and realistic building code performance benchmark enabling post construction testing using AS/NS ISO 9972 will deliver an economic BCR of 1.7 @ 7% discount rate for 25 year projections. The BCR is calculated to be 2.1 @ 5% discount rate and as high as 2.5 @ 3.5% (IPCC) discount rate meaning that air sealing is valid for inclusion in the building code.

This measure would contribute towards the $1.1 billion per year productivity gain through the uptake of performance base solutions (ABCB, 2016). This report concludes:

- $255 - 371 million of economic benefit can be gained by $146.7 Million per year investment in air sealing technologies and practices.
- The cost of implementation of air control measures is estimated to be relatively minor ranging from $163-$1468 per house.

Other Benefits

Reduced air permeability is not only an energy, carbon emission and cost saving argument. Well established international building science research shows that improved air sealing will have the overall positive performance impact on buildings particularly in relation to the NCC objectives for health, amenity and fire safety.

The health and amenity benefits are difficult to quantify, however these benefits are described in this report which are additional to the direct economic savings. These include improved mechanical ventilation effectiveness, uniformity of thermal comfort, improved air quality, superior acoustics, better weather tightness and enhanced ability to manage moisture and mould risks resulting in overall healthier buildings.

The fire safety benefits may be enhanced by better auditing of construction work during the testing process in which air leaks undermine fire rated system performance. Diagnostic techniques to address air sealing for energy efficiency and fire compartmentalisation share the same fundamental scientific principles to achieve performance based code requirements.

This report concludes air sealing verification has potential to mitigate 33360 Tonnes of CO_2/year and will:

- Enhance overall innovation in manufacturing and construction sectors.
- Reduce the longer term relative risk of mortality and sickness
- Help safeguard occupants from illness or loss of amenity as a result of undue sound
- Enhance the ability to protect the building from damage caused by external humidity entering a building.
- Allow highly effective low cost balanced mechanical ventilation strategies to safeguard occupants from accumulation of internal moisture in a building.
- Improve the ability to prevent the penetration of water in walling systems
- Help to avoid the spread of fire
- Reduce peak load when a leaky home (35ACH_{50}) is sealed to a “fair” level (10 ACH_{50}) and operated with effective controlled natural ventilation strategies:
  - Peak heating load can be reduced by 21-32% in capital cities.
  - Peak sensible cooling load can be reduced by 7-22% in capital cities.
  - Peak latent cooling peak load can be reduced by 1-43% in capital cities.
  - Peak latent cooling load reduction due to air sealing is largely due to the prevention of infiltration of humid air, in warmer tropical climates this has the largest effect.

National Energy Efficiency Performance Target – BCA Climate Variations

The impact of the provisions varies across housing construction types and climate zones. Depending on the location, BCR ratios for houses using simulation compliance ranged from 0.4 to 4.9 (7% discount rate) on a climatic basis (excluding Northern Territory – BCA 1 & 3).

It should be noted that while the reference buildings used to create these estimates may be indicative of the economy as a whole, some caution should be used when interpreting results at a local level. There may be local influences which may affect the analysis. For instance, the BCR for BCA Zone 1 and 2 relate to achieving a 6 star energy rating. However, in climate zones

1 (Weipa, Wyndham) and 2 (Brisbane), where climates are conducive to outdoor living, there are optional credits in the BCA of up to 1 star for a covered outdoor living area that meets specific criteria. The star rating target with an outdoor living area is 5.5 stars when either complying roof insulation or at least one complying ceiling fan is installed. The target falls to 5 stars when both are installed.

In order to protect health and amenity in sealed buildings this report recommends:

- The 2019 building code incorporates requirements for the mechanical ventilation system configuration required to achieve air change effectiveness when performance based measurements below 7 ACH_{50} are achieved.
- Continuous outdoor air supply in BCA zone 1 (tropical climates) should be implemented with caution due to the high external humidity.
- The building code is updated to ensure all new buildings in Australia meet the intent of Energy Safe Victoria requirements as outlined in AS/NZS 5601.1.
- AS/NZS 5601.1 will need to be addressed in the Plumbing Code of Australia (Clause E1.2) in conjunction with AS/NZS ISO 9972 performance benchmarks incorporated into the BCA.

1 INTRODUCTION

The design detailing, construction techniques and workmanship are all essential in achieving adequate building envelope integrity which will deliver the objectives of the NCC. In 2015 ISO 9972:2006 was adopted as an Australian and New Zealand Standard. This standard outlines the principle methodology to undertake post construction verification of the thermal performance of buildings by determination of air permeability of the envelope using the fan pressurisation method. This provides a highly valuable performance based opportunity for the building code to quantify the air sealing requirements for energy efficiency, allowing this performance based solution to improve productivity. The Australian Building Codes Board is working to increase the ability of industry to develop performance based solutions which foster innovation and cost effective construction practices to realise a potential $1.1 billion per annum in productivity savings (ABCB, 2016). Some performance based requirements have already been introduced into the code but still excludes air sealing performance requirements.

> "Quantified Performance Requirements and Verification Methods have been progressively introduced into the NCC since NCC 2015. This is part of a long-term goal to increase the use of the performance-based opportunities of the code. In addition to quantifying the requirements of the NCC, the **ABCB is working to increase the awareness and ability of industry to develop Performance Solutions**."
>
> *"The Centre for International Economics has estimated that at this point in time the national code has improved the productivity of the Australian construction industry by $1.1 billion per annum. Of this, $780 million is attributed to the performance-based nature of the national code.* ***Further additional productivity savings of up to $1.1 billion per annum may be achieved in part by increasing the uptake of Performance Solutions. This is because Performance Solutions can lead to more innovative and cost-effective construction practices."***
>
> (ABCB, 2016)

A common misconception is that the only benefit to air sealing a building is to increase the energy efficiency of the building envelope. However, the benefits range from increased energy efficiency, improved fire performance, superior acoustics, better weather tightness and enhanced ability to manage moisture and mould risks in buildings. This has multiple benefits to society through reduction in energy costs, reduced stress in persistent cold and extreme hot weather for susceptible demographic groups, safer buildings, better quality of life and enhanced building longevity through controlling unintended moisture transfer and water damage.

The energy savings which could potentially be realised from widespread utilisation of air infiltration testing would have huge implications for economic savings for consumers. Amongst these benefits there are also the benefits of enhancing the correlation between building code design requirements for acoustics, fire, health and amenity objectives and as built outcomes.

Gaps in the envelope will carry, heat energy, acoustic energy, moisture laden air, hot gases and poisonous gases. Building sealing is essential to obtain performance outcomes for acoustic construction system, fire rating levels, effective mechanical ventilation, moisture management and energy performance.

Many issues arise from poor air sealing in buildings which generally fall into the categories as shown in Figure 1 (Berge, 2011). Enhancing air sealing can reduce moisture related issues, increase air quality, improve fire safety, improve acoustics and improve thermal comfort with associated energy and carbon emission savings. When aligned to the building code of Australia it is apparent that air leakage problems have adverse effects in delivering many of the performance requirements outlined within the National Construction Code potentially limiting the ability of the code to fulfil its objectives.

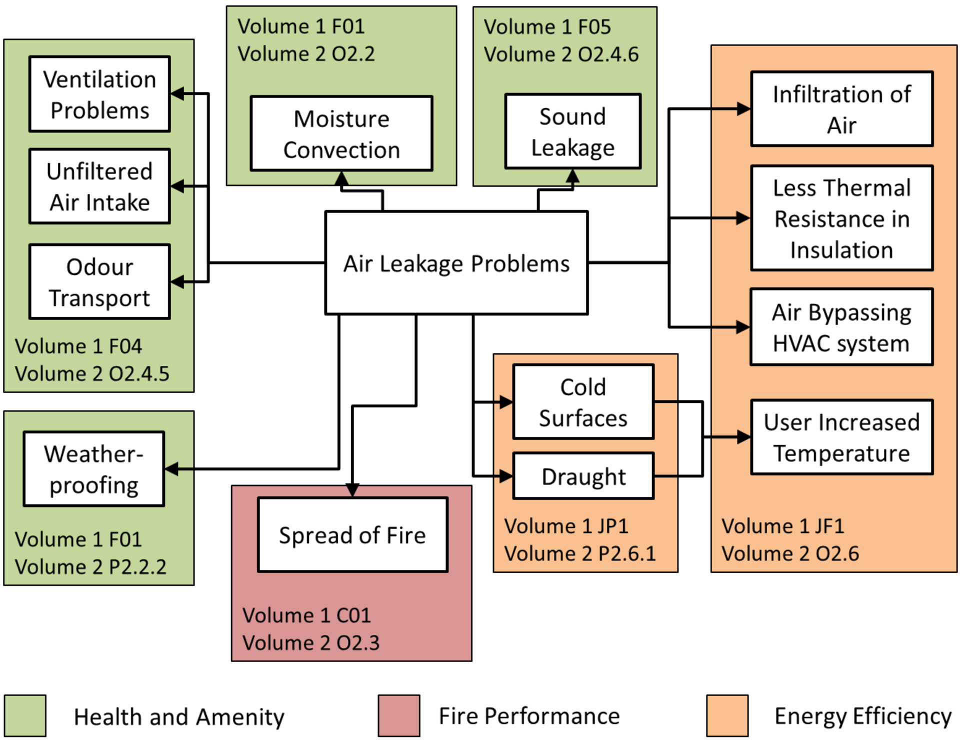


Figure 1 Problems related to poor air sealing in buildings, adapted from Berge 2011

The primary benefit of air sealing is gained through thermal comfort benefits and associated power bill reductions. From a safety aspect this includes reduced heat stress for the extremely young, the elderly and the frail in persistent cold and/or extreme hot conditions reducing morbidity and mortality rates in these extreme events as well as enhanced performance of passive fire protection.

For the purpose of this report the benefits primarily fall into two categories:

1) Quantitative benefits – Energy savings, financial savings and carbon savings
2) Qualitative benefits – Fire safety, acoustic performance, moisture management and mechanical ventilation effectiveness

The BCR calculated in this report accounts for the quantitative benefits and the qualitative benefits are an additional bonus.

2 THE NEED FOR IMPROVED HOUSING ENVELOPE INTEGRITY

The main need for a performance based measure within the building code is that the air control function of the building envelope plays a vital role in achieving energy efficient outcomes in all climates including cool climates, tropical climates and everything in between. Air control is also essential to the moisture balance of residential and commercial buildings particularly in tropical climates with high outdoor relative humidity or climates with very cool exterior conditions. International literature identifies adverse effects of condensation and mould when moisture laden air is not effectively controlled through the building envelope in cold and tropical climates. Effective performance based measures for quantifying the air leakage across the building envelope need to be made available to allow design professionals to carry out moisture balance calculations for optimising the heat, air and moisture relationships which occur in building envelopes, this can then be validated post construction to deliver the design intent and building code objectives.

The ability to reduce the amount of air that infiltrates into buildings can help mitigate peak load spikes on heating and air conditioning systems allowing them to maintain temperature control in cold snaps and heat waves. If adopted on a wide scale adequately sealed buildings can help to reduce the peak load of the energy grid in both winter and summer.

It is well documented worldwide that reducing the amount of infiltration air into building will reduce both the heating and cooling loads. In the current Australian Building Code for compliance with 3.12 energy provisions for residential buildings air infiltration is addressed as Acceptable Construction Practice with reference to specific air leakage paths through chimneys, flues, roof lights, windows, doors, exhaust fans, evaporative coolers, roof construction, wall construction and floor construction.

For all the leakage paths mentioned above the building code refers to each device or construction to have a "seal", be "sealed", have a "self-closing damper" or "constructed to minimise air leakage." The quality of the devices installed is not quantified or specified with a performance benchmark. Analysis outlined in the report identifies the difference between compliance calculations and the as-built air infiltration performance varies considerably due to specific design decisions, product selections and construction methods.

The infiltration rate according to the fan pressurisation technique (AS/NZS ISO 9972) is measured at an indoor to outdoor reference pressure difference of 50 Pascals. The number of times the total volume of air in the house is swapped per hour under pressure is measured and recorded. This is known as an air change rate and is normally notated at the test pressure as ACH_{50}.

For the purpose of energy calculations in this analysis a rule-of-thumb conversion of air changes @ 50Pa (ACH_{50}) to annual average air changes per hour (ACH^{-1}) was calculated using the approach attributed to Kronvall & Persily (Sherman M. , The Use of Blower Door Data, 1998). This identifies the air annual average infiltration (ACH^{-1}) to be equal to the ACH_{50} divided by 20. Further discussion of the applicability of this to Australian conditions is outlined in Appendix A.

2.1 Practical Implementation of air sealing

Figure 2 shows the measured range of air leakage rates and calculated energy performance (using chenath engine) versus air leakage for CSR Building Products Housing Research Facility in western Sydney. The house was specified to meet an 8 star NatHERS design benchmark indicated as "As Modelled" data point on the graph. Variations in the AccuRate air infiltration rate and associated energy implication was calculated by modifying inputs into AccuRate V2.0.2.13 Software. The annual average predicted air leakage rate in the compliance calculation was lower than a comparison with the air leakage rate measured post construction even though best attempts were made to eliminate air leakage paths during the design and construction. The design and construction paid particular attention to BCA 3.12.3.5 requirements for "sealing" including sealing around windows and architraves, and in addition eliminating the use of down lights to achieve an air change rate of 9.3 ACH_{50}. When the annual energy was calculated at an annual average 9.3ACH_{50} (0.465ACH) was compared to compliance calculations which assumed annual average of 4.36 ACH_{50} (0.218ACH) the compliance calculations estimated 25% less heating and 7% less cooling and The Housing Research Facility effectively achieved 0.6 stars less than the compliance calculation when adjusted for the measured air leakage.

In 2014 a study commissioned by the department of industry, "The NatHERS benchmark study" (Floyd, February 2014) resulted in modifications to the software to restrict user inputs for air leakage sites around windows to "medium gaps" for compliance calculations as is now incorporated into AccuRate V2.3.3.13. This effectively limits The Housing Research Facility model to an average annual air leakage rate equivalent to $7ACH_{50}$. Post construction improvements to The Housing Research Facility allowed a result of 6.5 ACH_{50} to be achieved aligning to NatHERS compliance calculation assumptions, BCA 3.12.3 and actual achieved performance.

Appendix B outlines the general air sealing requirements used in The Housing Research Facility to achieve below 10 ACH_{50} and would be typical of methods required for project homes to achieve this level of performance. This is one example that shows that air sealing to a "Fair" level of 10 ACH_{50} is easily achievable with standard Australian construction practice.

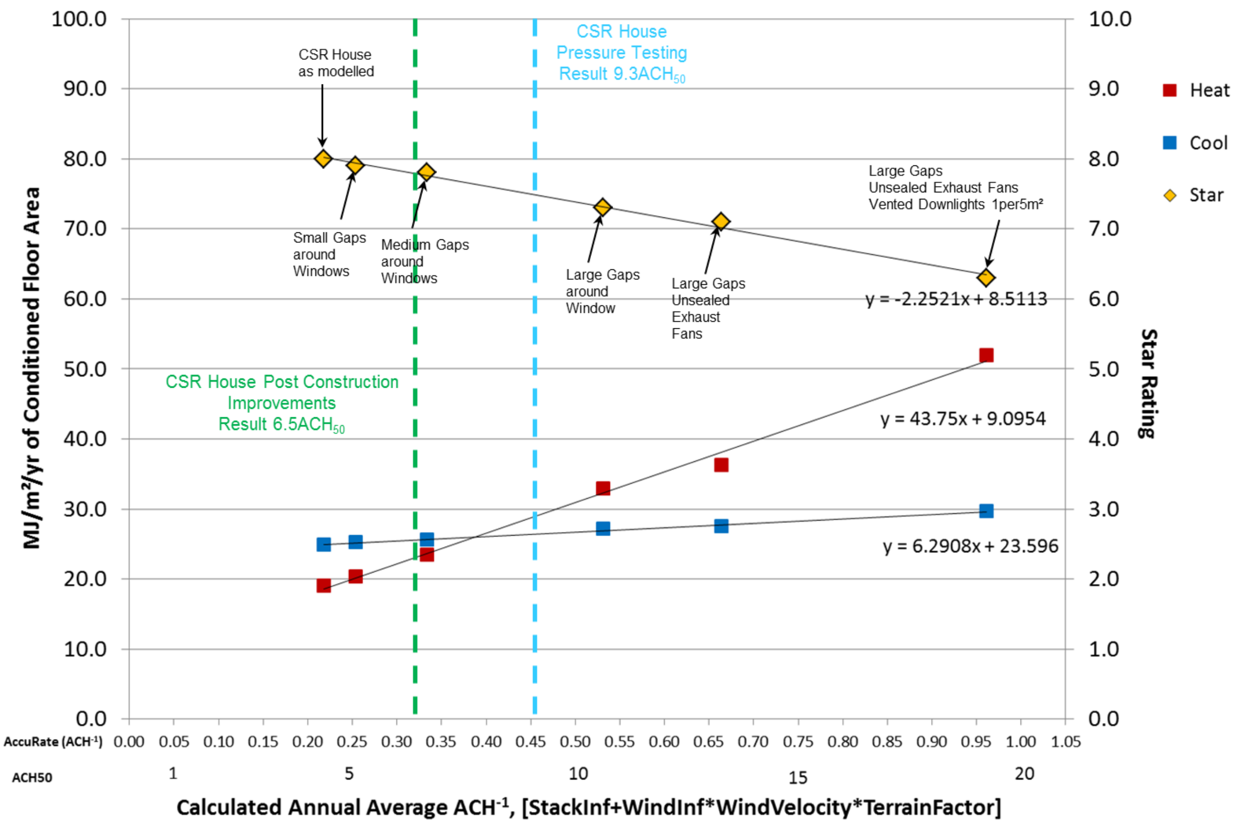


Figure 2 Effect of poor air sealing on heating and cooling loads (NatHERS 28)

2.2 Recent Research – A snapshot of Australia

A recent study into the air leakage rates of Australian houses (Ambrose & Syme, 2015) incorporated testing of 129 houses nationally with approximately 20 houses from each capital city. The houses in most cities were up to 3 years old and insulation and glazing assumed to be specified to a 6 star level under the Nationwide House Energy Rating Scheme (NatHERS). The Melbourne houses were an older data set up to 10 years old and of 4 and 5 star standard.

The overall national results (Figure 3) indicate that many Australian houses have far higher infiltration rates than would be reasonable expected by adopting BCA Volume 2 acceptable construction practice in section 3.12.3.

CSIRO recommended a building code target of value of 10 ACH_{50} (Ambrose & Syme, 2015) which would effectively bring 65% of houses tested to a “Fair” level of performance (Reardon, 2013). Figure 3 green bars indicate the 35% of tested houses which achieve a “Fair” level of performance. The research conducted at The Housing Research Facility also suggests this is a realistic and achievable target as shown in Figure 2 blue dotted line achieved (9.3ACH_{50}) with low cost implications to industry when practices such as those outlined in Appendix B are adopted.

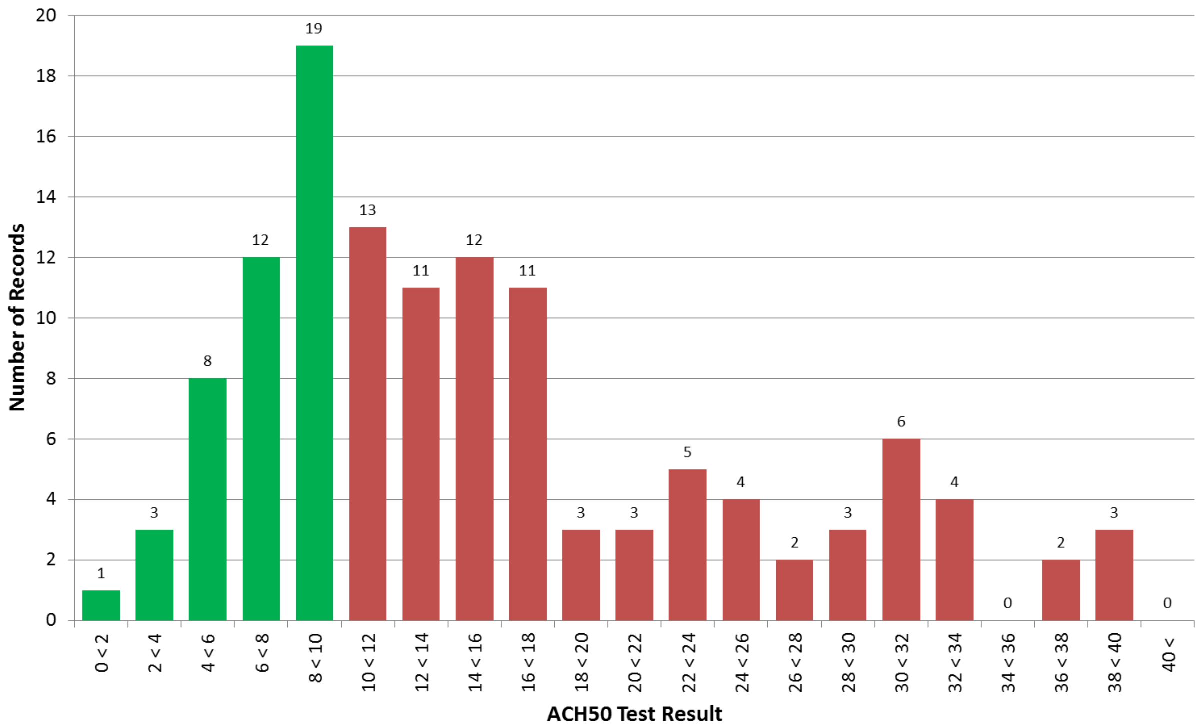


Figure 3 Distribution of pressure testing results, ACH_{50} (CSIRO 2015)

2.3 Options for addressing air leakage

To address excessive air leakage issues standardised test procedures would either need to be developed for all individual products that are identified as points of air leakage according to section J3 and 3.12.3 in the building code, or alternatively AS/NZS ISO 9972 provides a performance based test allowing any combination of product selection and build techniques to achieve a performance based envelope integrity after completion of the project. To test individual leakage points to drive better air sealing would require standards for air leakage rates of all individual building products and assemblies as identified in the BCA and outlined below:

1. chimney and flues products,
2. roof light products,
3. window and door products,
4. exhaust fan products,
5. evaporative coolers.

The process of individual product compliance becomes overly onerous for suppliers, very complex for compliance checks, costly, and difficult for building certifiers to check. In addition individual product compliance does not verify the workmanship in which was used to install these products and how well they are set into the structural components or linings.

The quality of the building envelope and its ability to control air transfer can only be effectively verified by post construction testing techniques. Specifically the items in section 3.12.3.5 for the construction quality of roofs, walls, floors can only effectively be addressed by post construction testing. AS/NZS ISO 9972 provides the ability for industry to verify the quality of air sealing techniques and allow industry learning to address the excessive air leakage issues undermining building performance and delivering the objectives of the building code.

Through public consultation process during the adoption of AS/NZS ISO 9972 industry agreed this standard test procedure will allow repeatable testing results and allow designers to specify testing for the validation of air infiltration performance of their buildings. This will allow buildings to realise the full potential of their designed energy efficiency measures and provide verification of system designs which can mitigate moisture related issues, such as mould, rot and mildew.

2.4 Industry Learning

As building energy efficiency regulations increase the diligence in construction method and design decisions surrounding the selection of sealing products will improve. Exhaust fans and roof lights which potentially transfer air across the building envelope as well as services which penetrate plasterboard linings and/or pliable building membranes at places such as around light fittings, wall sockets and plumbing will all contribute to increased air infiltration and exfiltration. Research suggests poor selection of these products leads to a disparity between the claimed performance and actual operational performance with poor long term financial outcomes for consumers. This is often referred to as the “performance gap” which is the disparity between the planned outcomes and real outcomes. The poor selection of air sealing products along with uncontrolled installation methods of these products can undermine the intended performance of insulation and windows in which the regulatory energy efficiency benchmarks are focussed. Validation through whole building testing of the infiltration performance can be used as a strong indicator of the collective effectiveness of all air control products, systems and construction methods in limiting wastage of conditioned air providing large financial benefits to consumers and a net positive impact for Australia.

3 QUANTIFYING THE BENEFIT – DEPENDENT VARIABLES

The foundation of building science principles; thermal performance, health and durability all rely on controlled airflow within the building envelope. Uncontrolled air flow through the building envelope results in unpredictable outcomes for energy performance as well as fire safety, acoustic and health and amenity.

The most easily quantifiable benefit of air sealing is the improvement to energy efficiency and the prevention of heated or cooled air escaping from the thermal envelope. For the purposes of this study the benefit and costs are limited to the energy savings and related cost saving to the consumer. The health and safety benefits will be additional to the cost savings and have been discussed in chapter 6, these benefits are difficult to quantify, however the benefit no matter how much will always be a positive improvement to building performance. In order to calculate the financial savings there are many parameters which will affect the collective national benefit of implementing performance based measures for air sealing. The parameters used in this study and the calculation process are outlined in Figure 4 and Figure 5 on the following pages.

Due to lack of data on current practice and air sealing performance in the Northern Territory no benefit could be calculated and is therefore excluded from the benefit calculations.

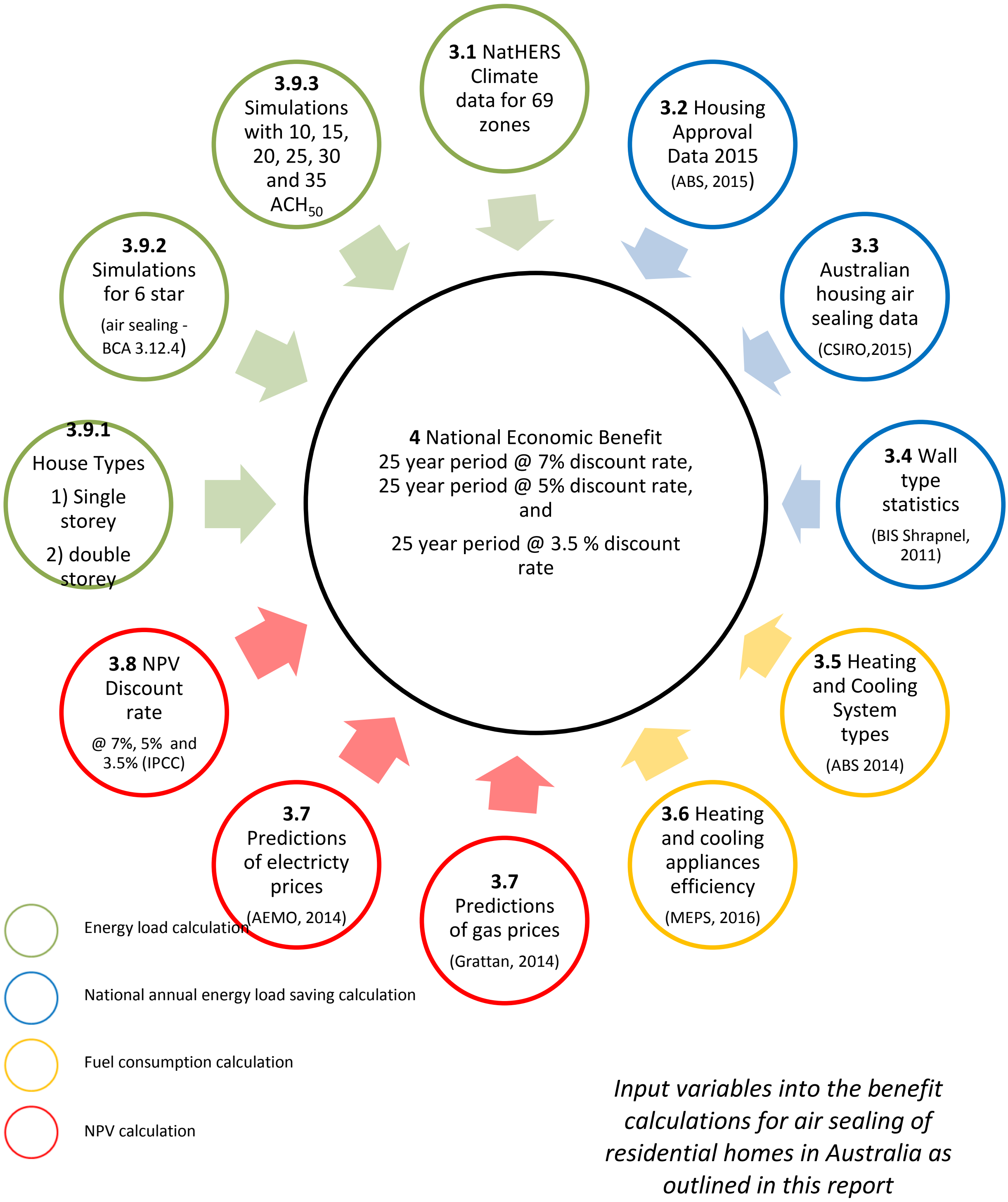


Figure 4 Input parameters for economic benefit calculation

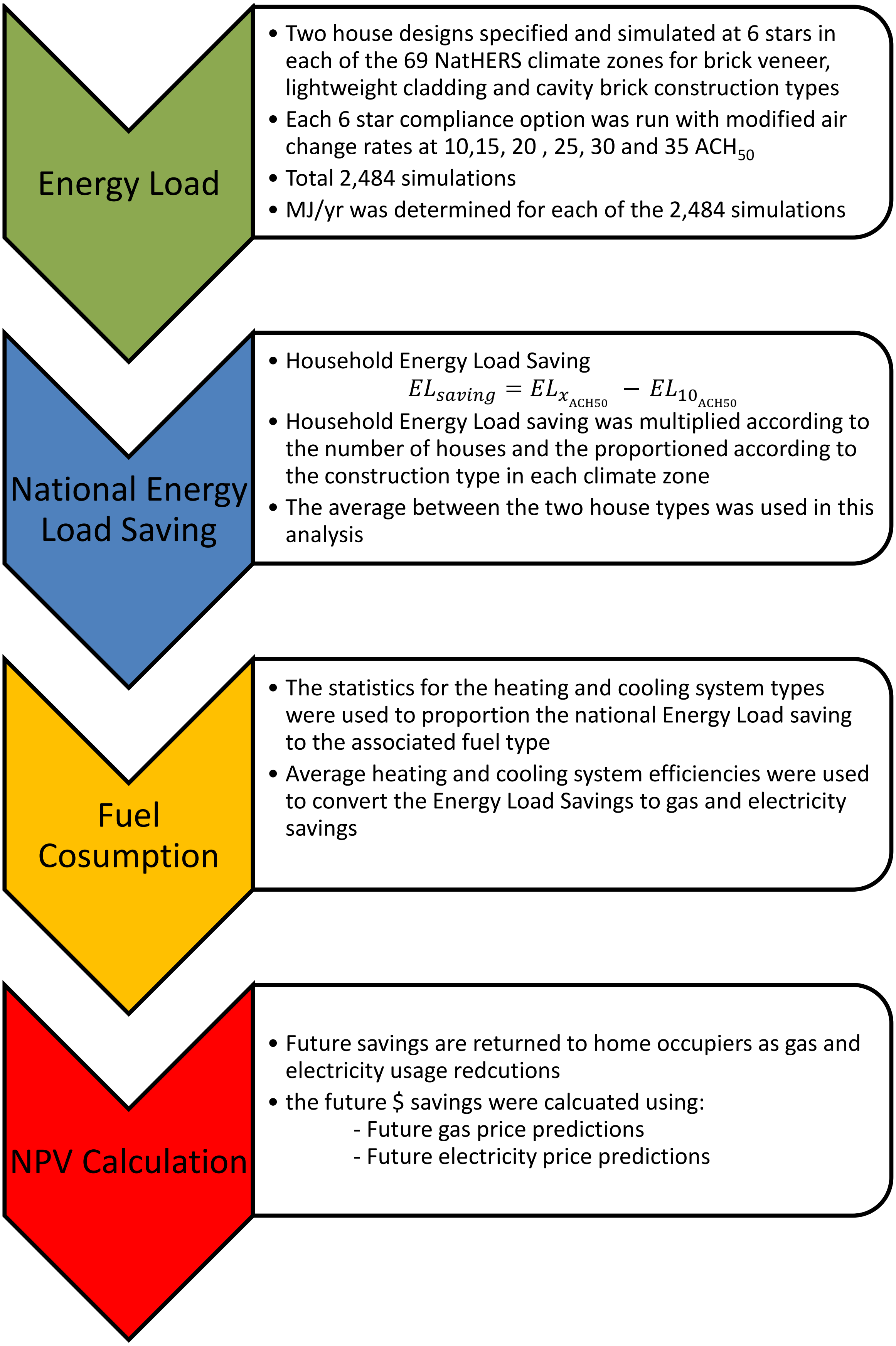


Figure 5 NPV calculation process

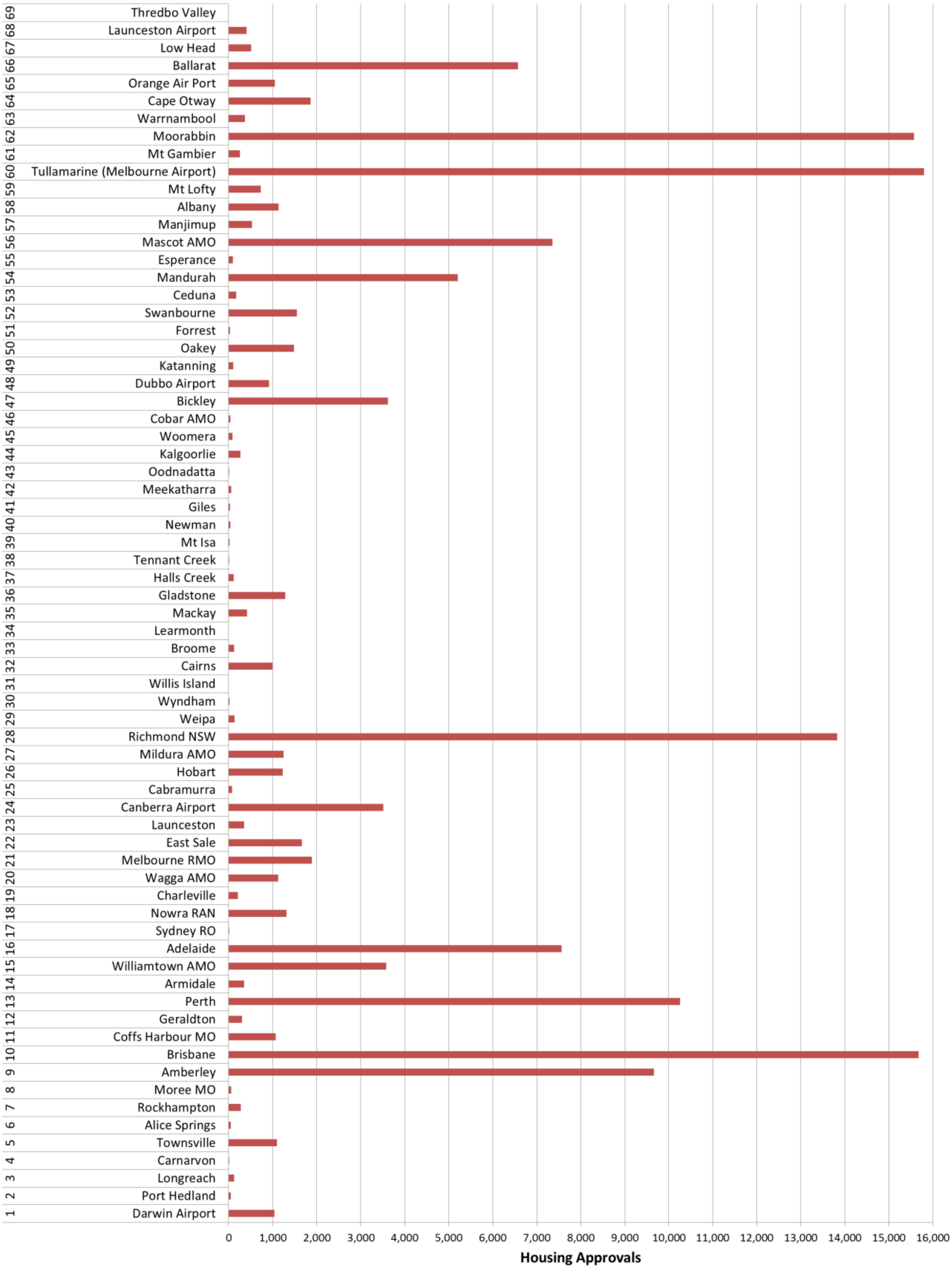


Figure 6 Housing Approvals by NatHERS Climate Zone, ABS 2015

3.1 Climate

Australia has one of the largest climate variations in the world ranging from tropical to alpine which will have vastly different benefits to mild climatic conditions in benign climates such as Brisbane. For the purpose of the benefit calculation the NatHERS climate data set for 69 zones across Australia has been utilised.

3.2 Housing Activity by Climate Region

Climate will determine the benefit to energy savings on an individual house scale. In order to quantify this on a national scale the number of houses built in each climate zone will have a large influence on the overall benefit achieved by a code based requirement.

The majority of houses are being built in and around the major centres of Sydney, Melbourne, Brisbane, Adelaide and Perth as shown in figure 6 (ABS Housing Approval Data, 2015).

3.3 Current Building Practice

Data recorded by CSIRO (Ambrose & Syme, 2015) indicates air infiltration rates which are indicative of new buildings in each state of Australia. For the purpose of this study the Ambrose and Syme data was grouped into 5 ACH_{50} bands to allow for relative energy benefit to be calculated. The data is shown in Figure 7 with the green columns indicating percentage of buildings which would already be compliant with the proposed benchmark of 10 ACH_{50}.

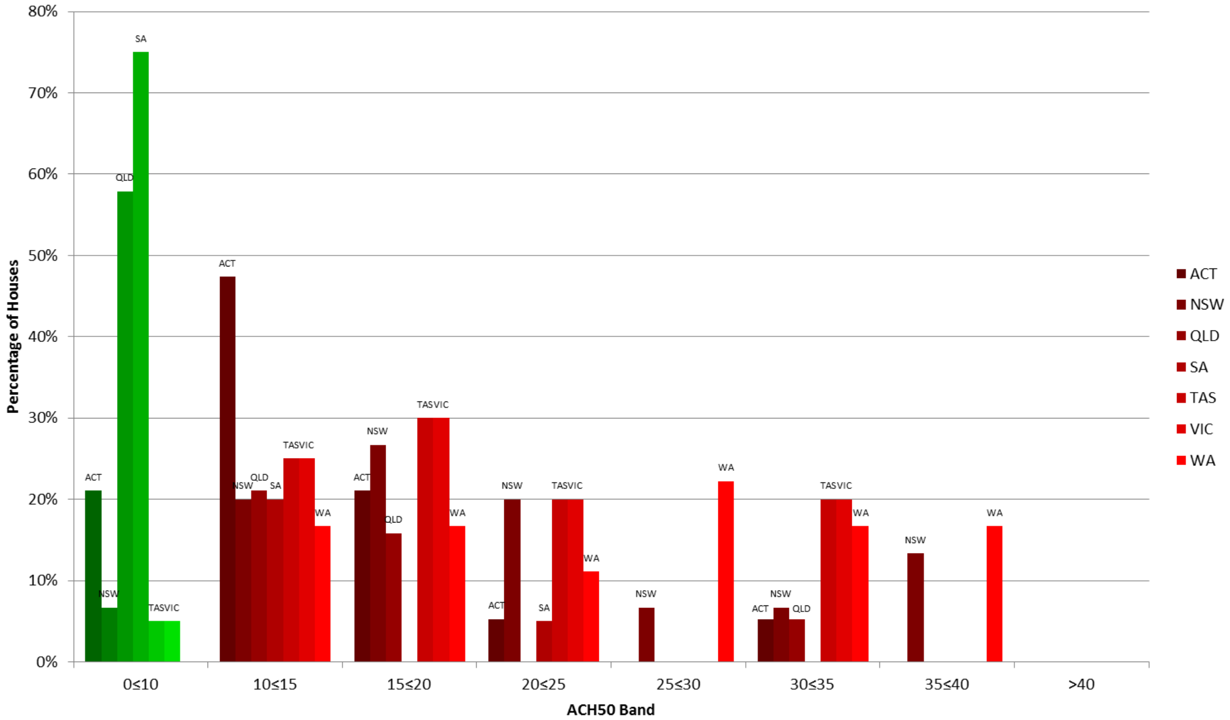


Figure 7 Air infiltration rates at 50Pa as measured by Ambrose and Syme (2015).

The data in Figure 7 shows that South Australia has 75% of houses below 10 ACH_{50} and Tasmania 79% below 10 ACH_{50}. Ambrose and Syme gave some explanation for this unusually good performance of buildings in both Hobart and Adelaide which was attributed to:

- 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.
- Adelaide cohort was more specialist houses and greater care and attention was paid to the build quality of the houses.

Since the release of the report in December 2015 further discussions with the author Michael Ambrose indicated that

> *"Hobart houses were middle to high spec architectural homes often with specific air tightness goals identified and many had high performance European style uPVC or timber windows incorporating effective gasket systems."* (Ambrose M. , 2016)

It is recommended that further investigations in to the infiltration rates in Tasmanian and South Australian Homes is further investigated to either validate or disprove the superior air infiltration performance of homes in these states as it may result in an actual benefit larger than calculated in this study.

The air infiltration rates used in the calculation of this benefit analysis utilises CSIRO data for all states (Excluding Northern Territory) as represented in Figure 7.

3.4 State Based Construction Methods

The ability of a house to remain comfortable with high or low infiltration rates can be greatly affected by the climate as well as the amount of thermal mass and energy stored within the envelope itself. For the purpose of this report; brick veneer, cavity brick and lightweight construction types were considered in the benefit calculation.

The regulatory software utilised in the Nationwide House Energy Rating Scheme (NatHERS) takes into account both the thermal conductance of building materials as well as the heat capacitance of materials used in buildings and their effect on the heating and cooling loads within a home. AccuRate Software was developed by CSIRO for the purpose of balancing these material attributes with floor plan layout and the designed form of a building.

In order to assess the effect of the construction type in relation to the air sealing of any given dwelling AccuRate Sustainability V2.3.3.13 was used to simulate different houses with three different wall construction types tuned to a benchmark level of 6 stars as per the National Construction Code.

The ratio of construction types in each state was considered in the calculations and the energy benefit under differing air infiltration levels weighted to the ratio of each construction type as per Figure 8 (BIS Shrapnel, 2011).

It should be noted that data for ACT and TAS was missing, therefore ACT was assumed to be the same construction as NSW, and TAS was determined from Housing Industry Association data (HIA, 2011).

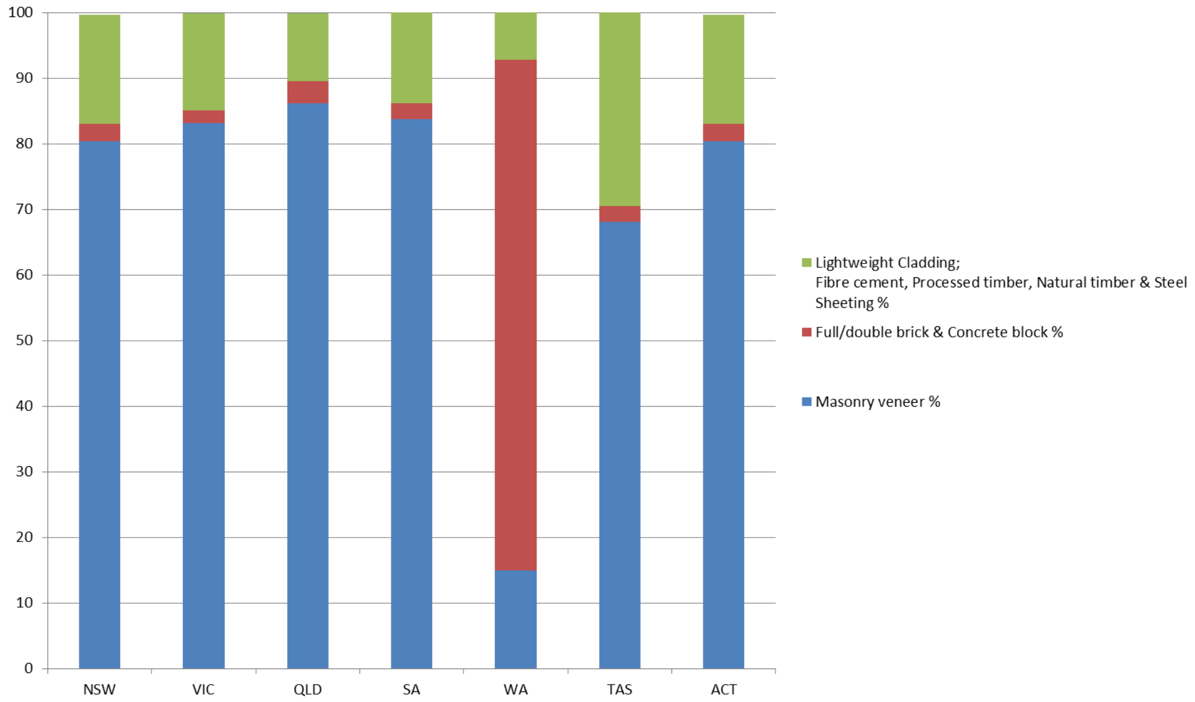


Figure 8 Cladding Types by State, BIS Shrapnel 2011

3.5 Heating and Cooling Systems

The type of heating and cooling systems used varies by state due to climatic extremes driving the ratio of heating to cooling, external humidity affecting the viability of evaporative cooling systems and fuel availability in each state.

The type of heating and cooling systems used in housing within each state was sourced from the Australian Bureau of Statistics (ABS, 2014) as represented in Figure 9 and 10. When no heating system was installed, for the purpose of this study it is assumed electric radiator or electric fan heaters are used to provide comfort as represented by the purple portion in Figure 9.

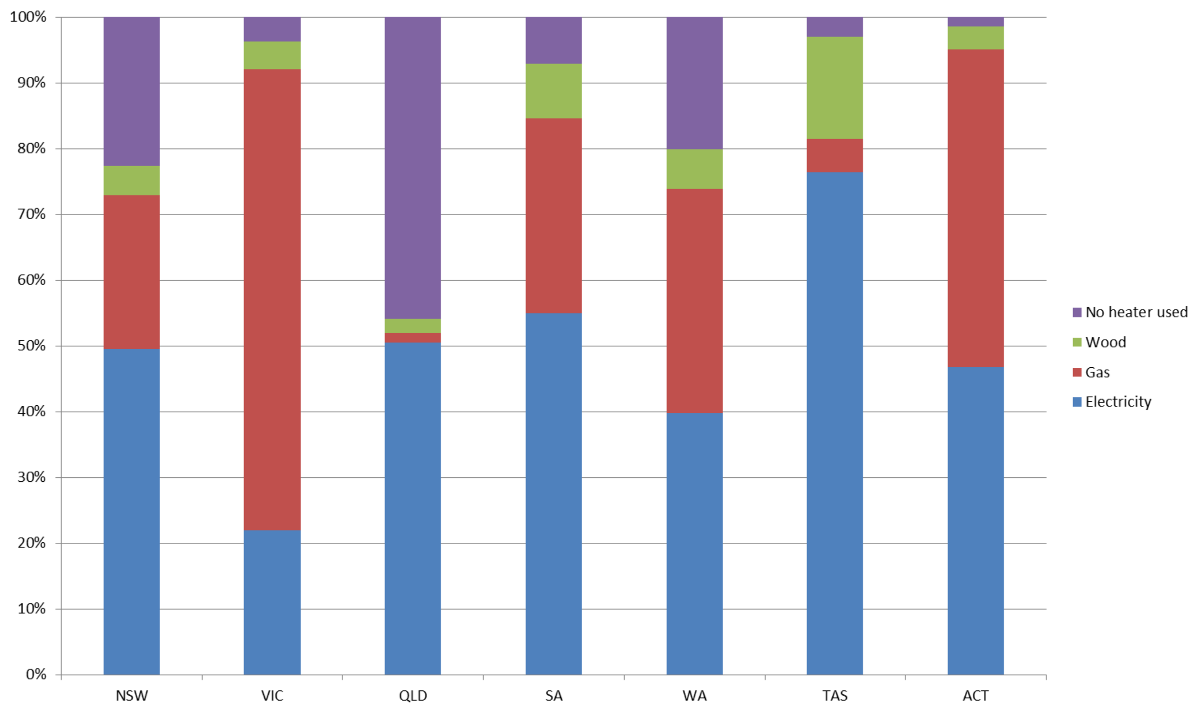


Figure 9 Type of heating system by household, ABS 2014

In Figure 10 there is a small portion of cooling systems which were identified as “other” in the ABS data. For this portion a conservative approach was taken and assumed that no cooling is present therefore no future benefit was attributed for cooling this portion in this study.

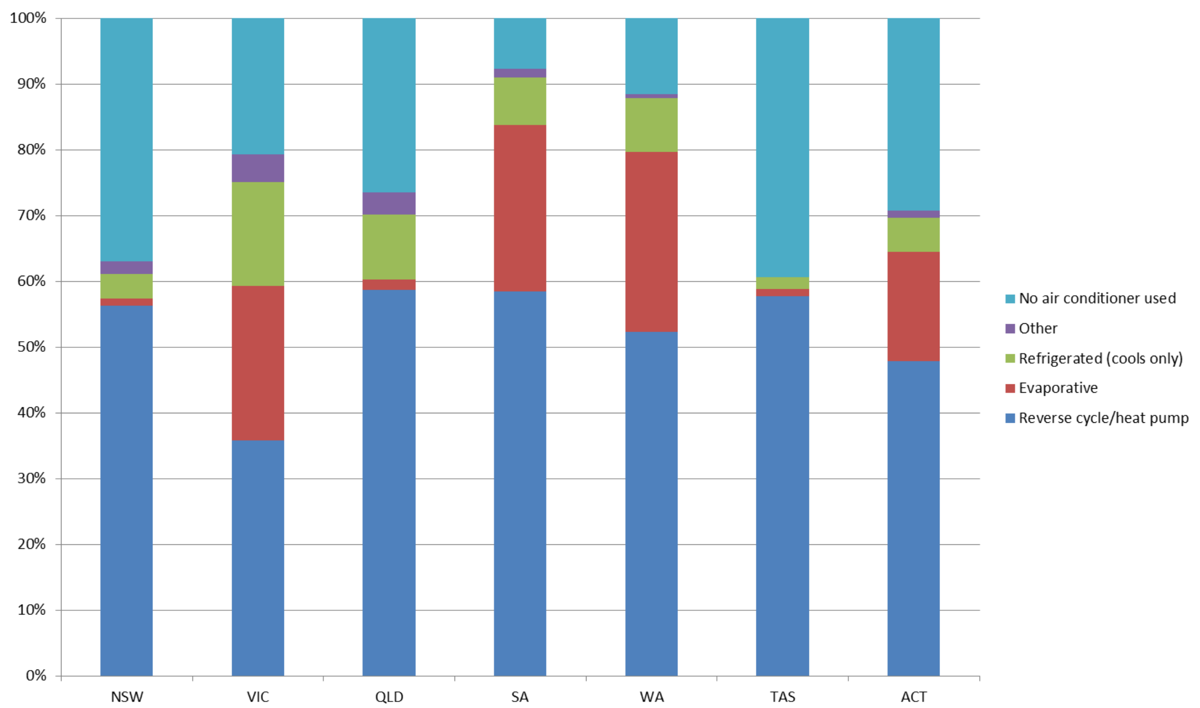


Figure 10 Type of cooling system by household, ABS 2014

3.6 Efficiency of Heating and Cooling Systems

The efficiency of residential heating and cooling systems varies depending on the type of system used and the size of the unit. Generally air conditioners and heat pumps using compression cycle to move heat from inside to outside or vice versa can deliver several times the heating or cooling energy compared to the electrical energy required to power the unit. This means that they have effective "efficiency" better than unity. In winter the amount of heating that can be delivered per unit of input electricity is known as the Co-Efficient of Performance (COP). In summer the amount of cooling that can be delivered per unit of input electricity is known as the Energy Efficiency Ratio (EER). The Mandatory Energy Performance Scheme (MEPS) standardises the measurement of COPs and EERs for all air conditioners sold in Australia. For the purpose of this study the average COP and EER for all Air Conditioners and Heat Pumps on the market ranging between 0-30kW capacities was used to determine the quantity of energy required to heat or cool under different construction and air leakage scenarios in each NatHERS climate zone.

Analysis of air conditioners rated under the Mandatory Energy Performance Scheme (Air Conditioner Database, 2015) found that the average COP of heat pumps was 3.65 and the average EER of air conditioners was 3.36 as per Figure 11.

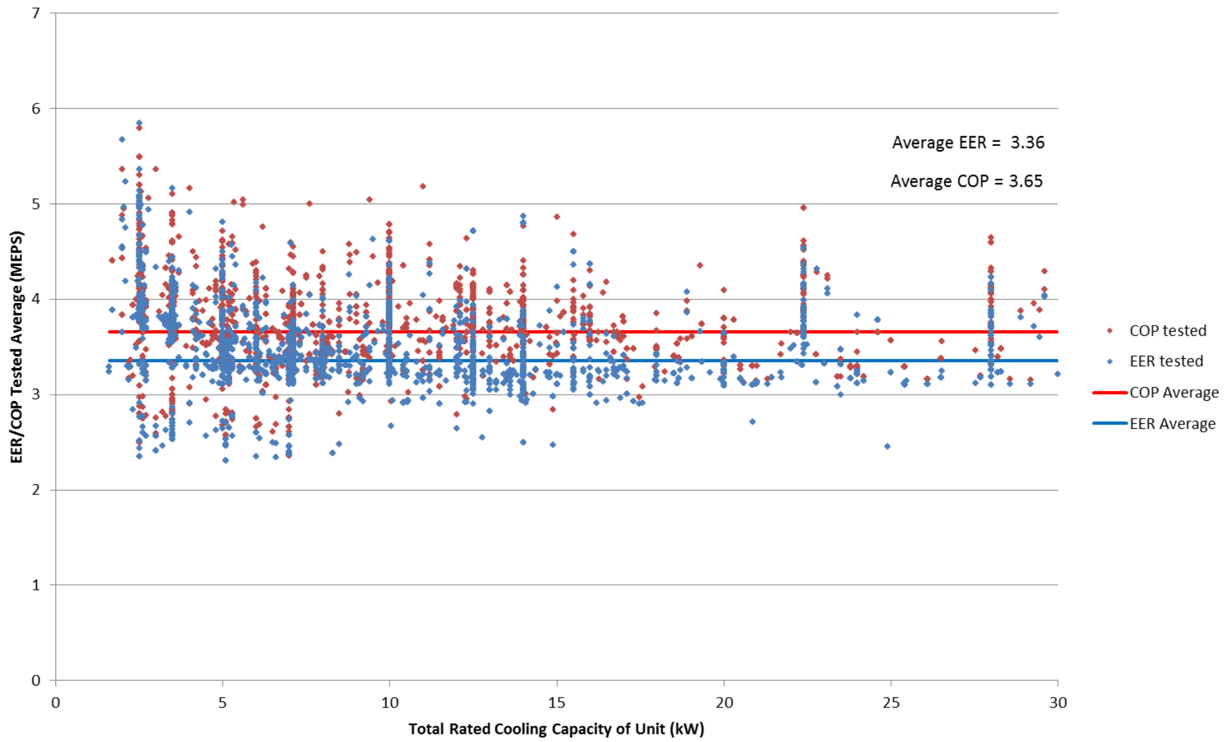


Figure 11 Average COP and EER of MEPS Air Conditioners (0 - 30kW)

Electrical heating element heaters, radiator heaters and fan heaters all supply one unit of heating for every unit of electricity input.

It has been assumed that only flued gas heating is utilised with an average efficiency of 76%, 3.5 Stars as defined by AS/NZS 5263.1.3 (Australian Standards, 2016) as shown in Figure 12.

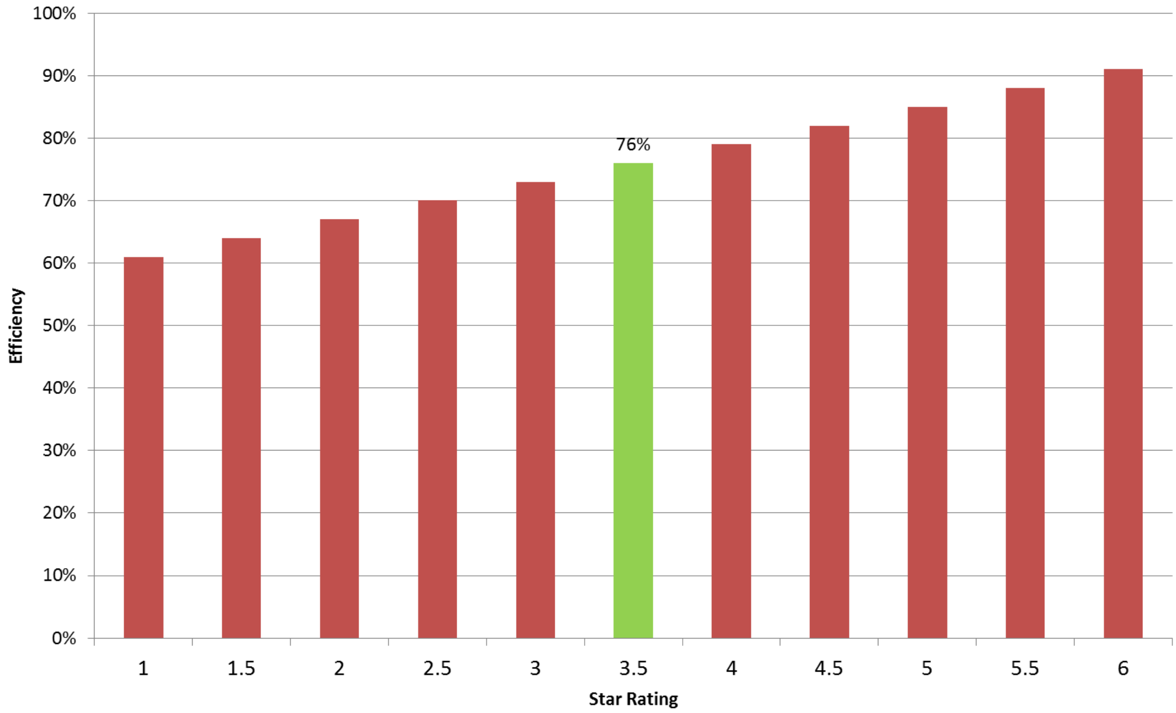


Figure 12 Thermal Efficiency of Gas Heating Systems, derived from AS/NZS 5263.1.3

For the purpose of this study to determine the primary energy demand from the simulated houses under different air leakage scenarios the heating system COPs in Figure 13 were used. It was assumed that a house with no heating system would utilise a small electric radiator or fan heater to maintain comfort. These will generally produce 1 kWh of heat for every kWh of electrical input.

Homes heated by wood make up a small portion of houses, however in Tasmania there is a notable portion around 15% (See Figure 9). It was assumed that wood heating utilises scrap wood or lumber likely from larger rural properties outside the main city centres and therefore a conservative approach was taken and a zero fuel cost applied to this heating method.

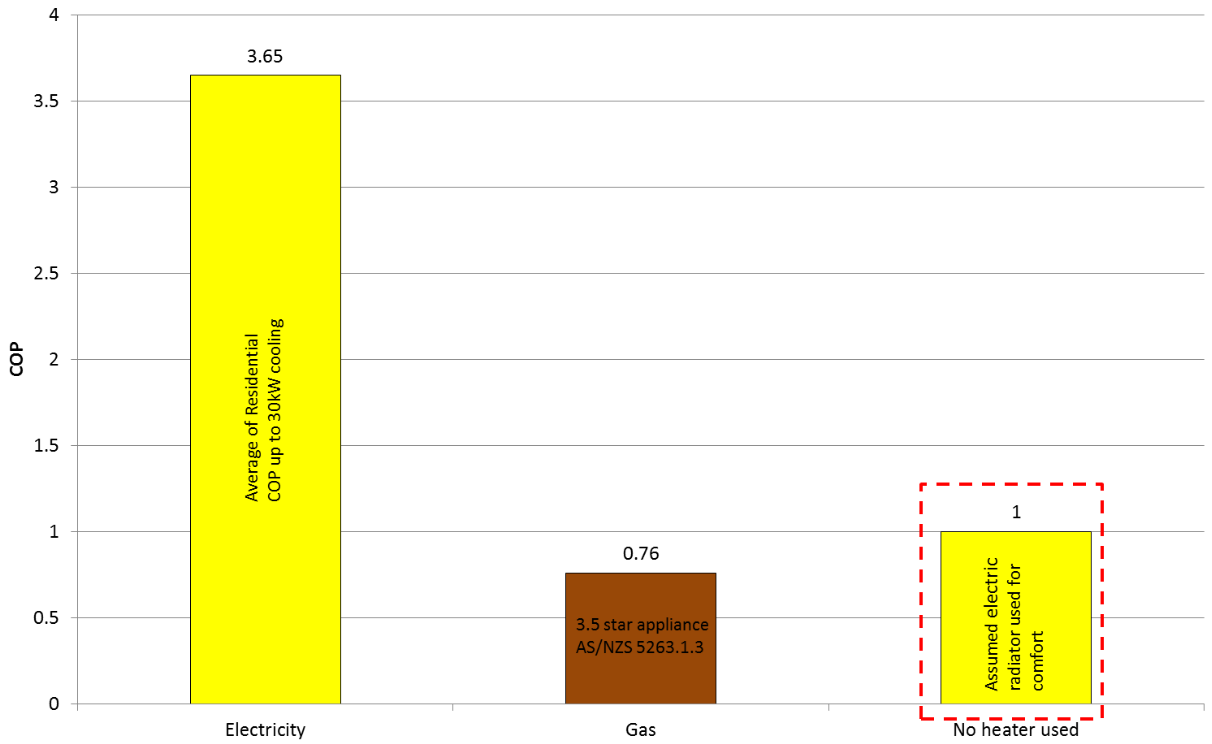


Figure 13 Co-Efficient of Performance (COP) of Heating Systems

In Australia cooling homes is generally achieved by use of compression cycle air conditioners. An EER of 3.36 for air conditioners was used in this study. This was based on the average performance of all reverse cycle and refrigeration only units (0-30kW) which make up the majority of residential cooling systems throughout Australia (See Figure 11).

According to 2014 ABS data in Figure 10, there is a significant portion of houses that utilise evaporative air conditioners in the hotter drier parts of Australia including South Australia, Western Australia, Victoria and Australian Capital Territory. The building code does not prescribe air sealing provisions to houses that utilise evaporative air conditioners as they can potentially add large amounts of moisture to the interior of the house which may result in adverse health outcomes for occupants in well-sealed homes. For the purposes of this study a conservative approach was taken and this portion of houses with evaporative air conditioners were excluded from the benefit calculations, assuming air sealing would not be carried out for this reason and therefore no benefit attributed.

3.7 Fuel Prices

For the purpose of this study future electricity prices were based on 25 year predictions published by the Australian Energy Market Operator (Frontier Economics, 2015). However, in this study predictions were not reported for Western Australia so the current WA electricity prices were based on 2014 residential price Trends (Australian Energy Market Comission, 2014) and a longer term annual price increase calculated to have the same long term linear trend as the eastern states published by AEMO. The assumed future price of electricity is shown in Figure 14.

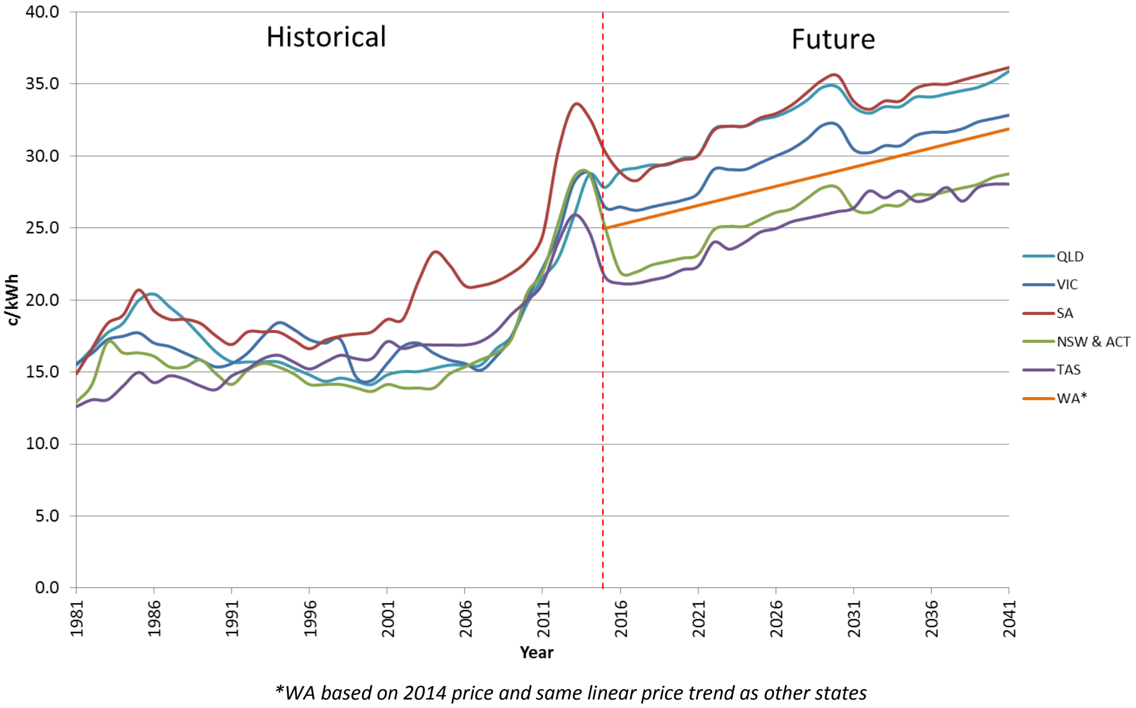


Figure 14 Electricity Price Predictions, AEMO 2015 (Including WA Estimation)

The current gas prices were taken from various sources based on retailer advertised state based consumer pricing. The gas price was based on forecasts (Wood, 2014) up to 2023 and increased at 2.5% CPI after 2023 up to 2041. The network and retail margin was calculated from current state prices and increased at 2.5% Consumer Price Index up to 2041. The state by state assumptions for the current total gas costs are as follows:

- QLD
    - Current consumer price based on first 8.2MJ/day (AGL (QLD), 2014)
    - Wholesale gas price increases based on 9 year predictions to 2023 (Wood, 2014)
    - Gas prices assumed to increase @ 2.5% CPI after 2023
    - Network Costs and Retail Margin assumed to increase @ 2.5% CPI
- NSW
    - Current consumer price based on first 20.712MJ/day (AGL (NSW), 2015)

- Wholesale gas price increases based on 9 year predictions to 2023 (Wood, 2014)
- Gas prices assumed to increase @ 2.5% CPI after 2023
- Network Costs and Retail Margin assumed to increase @ 2.5% CPI

- ACT
  - Current consumer price based on first 41MJ/day (ActewAGL, 2015)
  - Gas price increase assumed to be the same as Sydney predictions
  - Network Costs and Retail Margin assumed to increase @ 2.5% CPI
- VIC
  - Based on current price for first 27.4MJ/day (AGL (VIC), 2016)
  - Wholesale gas price increases based on 9 year predictions to 2023 (Wood, 2014)
  - Gas prices assumed to increase @ 2.5% CPI after 2023
  - Network Costs and Retail Margin assumed to increase @ 2.5% CPI
- SA
  - Current consumer price based on first 27.4725 MJ/day (AGL (SA), 2015)
  - Wholesale gas price increases based on 9 year predictions to 2023 (Wood, 2014)
  - Gas prices assumed to increase @ 2.5% CPI after 2023
  - Network Costs and Retail Margin assumed to increase @ 2.5% CPI
- TAS
  - Current consumer price based on current TAS Gas Pricing (Tas Gas, 2016)
  - Gas price increase assumed to be the same as Melbourne predictions
  - Network Costs and Retail Margin assumed to increase @ 2.5% CPI
- WA
  - Current consumer price based on WA department of finance cap July 2015 (Government of WA, Department of Finance, 2016)
  - Gas price increase based on average of east coast predictions
  - Network Costs and Retail Margin assumed to increase @ 2.5% CPI

Figure 15 shows the future projections of consumer gas prices which were used in this study assumed to fuel the portion of gas heating systems in each state as indicated in figure 9.

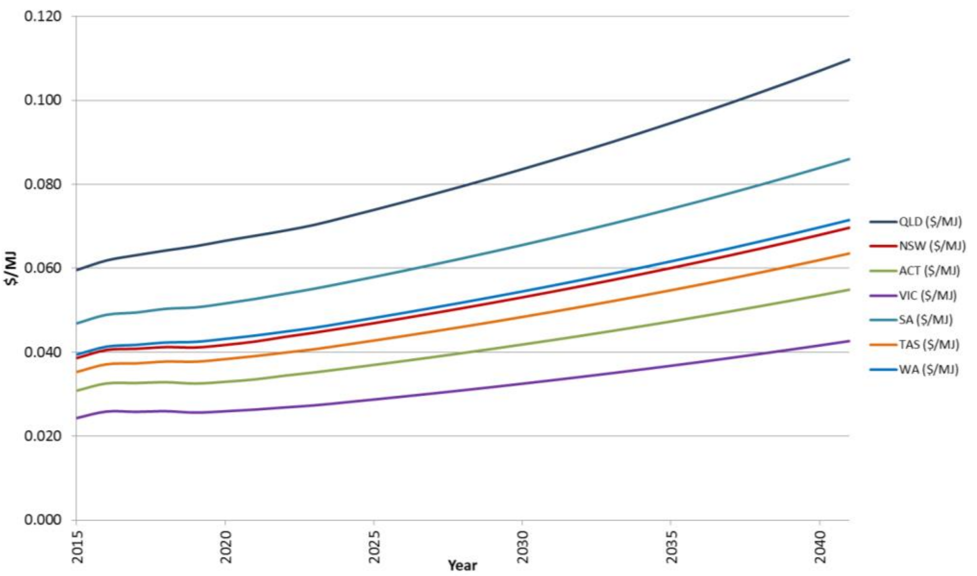


Figure 15 Calculated gas price projections

3.8 Present Value of Future Savings

The discount rate used in a Regulatory Impact Assessment (RIA) has a very significant impact on the value that is placed on benefits accumulated in the future over a long time, which is exactly the value that post construction air infiltration testing creates. The lower the discount rate used, the higher the value of future benefits.

For the purpose of this report a discount rate of 5% has been used, and also reports outcomes at 7% in line with the Office of Best Practice Regulation (OBPR, 2016). The IPCC (Intergovernmental Panel on Climate Change) recommendation on this point is the following:

> *"The recommendation here is to use a 3.5% rate for 1-30 years, a 3% rate for 31-75 years, a 2.5 rate for 76-125 years, a 2% rate for 125-200 years, 1.5 for 100-300 years, and 1% for longer periods"* (IPCC, 2007)

The analysis in this report is based on a 25 year future period aligning with the AEMO forecast period for electricity prices. A 5% discount rate has been applied and results are also reported with 7% and a 3.5% discount rate in line with IPCC recommendations for a 25 year period.

3.9 House Specifications

The current performance benchmark for residential housing in the National Construction Code is 6 Stars as calculated under the Nationwide House Energy Rating Scheme. This equates to a set amount of energy per square metre of floor area and the 6 star allowance varies for each climate zone in Australia.

The construction materials, insulation levels, window performance and shading to achieve 6 star will all vary on a climate zone basis. The actual energy predictions are also dependent on the house layout; house design, volume and thermal storage capacity of the materials used therefore two house designs with three primary construction types were assessed.

Common industry practice is to refer to a star rating as the performance metric therefore in this section performance is reported and discussed in "stars," the associated MJ/m²/yr savings which relate to the star ratings were used in the economic benefit calculations in section 5.

3.9.1 House Design

Air infiltration will have a major impact on both the heating and cooling requirements of a building. The actual volume of infiltration and exfiltration air is related to the total volume of the building. A high ACH_{50} value in a large dwelling means that the building is leaking an overall larger volume of air and the energy penalty will be higher as the cubic meters required to be reheated or cooled will be greater. For this reason two house designs were studied to indicate the energy loss due to elevated air change rates above a 10 ACH_{50} benchmark

The benchmark houses used for the analysis were a simple single storey 3 bedroom design (Table 1) and The Housing Research Facility floor plan (Table 2) in which specific details are outlined in Appendix D. Each of the two house designs were modelled in all 69 NatHERS climate zones for 3 construction types; brick veneer, cavity brick and lightweight construction.

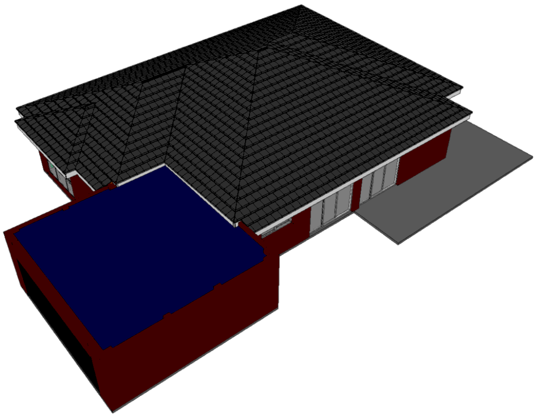
Single Storey 3 Bedroom House			
	Option 1	**Option 2**	**Option 3**
Ground Floor Construction	Slab on Ground	Slab on Ground	Slab on Ground
Ground Floor Walls Construction	Brick Veneer	Cavity Brick	Fibre Cement Cladding
Roof Construction	Tile	Tile	Tile
Conditioned Floor Area (CFA) (m^2)	140.8	140.8	140.8
Non-conditioned Floor Area (NCFA) (m^2)	41.8	41.8	41.8
Garage Floor Area (m^2)	37.9	37.9	37.9
Habitable Space (m^2)	144.7	144.7	144.7
Dwelling Habitable Volume (m^3)	434.8	434.8	434.8
Garage Floor Area (m^2)	37.9	37.9	37.9
Window Area (m^2)	34.9	34.9	34.9
Window to CFA ratio (%)	24.8%	24.8%	24.8%
Down lights	None / Sealed	None / Sealed	None / Sealed
Exhaust Fans (Bathrooms & Laundries)	Sealed (BCA 3.12.3.4)	Sealed (BCA 3.12.3.4)	Sealed (BCA 3.12.3.4)

Table 1 Single storey 3 bedroom house base construction scenarios

Double Storey 3 bedroom Housing Research Facility			
	Option 1	**Option 2**	**Option 3**
Ground Floor Construction	Slab on Ground	Slab on Ground	Slab on Ground
Ground Floor Walls Construction	Brick Veneer	Cavity Brick	Fibre Cement Cladding
Intermediate Floor Construction	Particle board on joists	Slab	Particle board on joists
Upper storey wall Construction	Fibre Cement Cladding	Fibre Cement Cladding	Fibre Cement Cladding
Roof Construction	Tile	Tile	Tile
Conditioned Floor Area (CFA) (m^2)	168.2	168.2	168.2
Non-conditioned Floor Area (NCFA) (m^2)	50.2	50.2	50.2
Garage Floor Area (m^2)	36	36	36
Habitable Space (m^2)	182.4	182.4	182.4
Dwelling Habitable Volume (m^3)	535.2	535.2	535.2
Window Area (m^2)	54.69	54.69	54.69
Window to CFA ratio (%)	32.5%	32.5%	32.5%
Down lights	None / Sealed	None / Sealed	None / Sealed
Exhaust Fans (Bathrooms & Laundries)	Sealed (BCA 3.12.3.4)	Sealed (BCA 3.12.3.4)	Sealed (BCA 3.12.3.4)

Table 2 Double storey 3 bedroom Housing Research Facility base construction scenarios

3.9.2 Building Envelope Specifications

The performance of the buildings was based on NatHERS compliant AccuRate simulations to meet a 6 star performance for all NatHERS climate regions in all states and territories. The 5 variables which were modified to improve heating and cooling energy requirements to the 6 star performance levels included:

1. Ceiling insulation levels,
2. Wall insulation Levels,
3. Roof insulation levels,
4. Window performance specification (U & SHGC),
5. Eave dimensions

All specifications for every simulated scenario are detailed in Appendix E.

The cost effectiveness of the material selections implemented to achieve 6 star NatHERS is not relevant in the case of this study. The objective was to define the resulting cooling energy and heating energy requirements at the 6 star performance level. A total of 414 combinations of house design and specifications were made to derive the house energy load (MJ/m²/yr) for both heating and cooling for each house type, with each of the 3 different construction types, with 6 star specifications in each climate region.

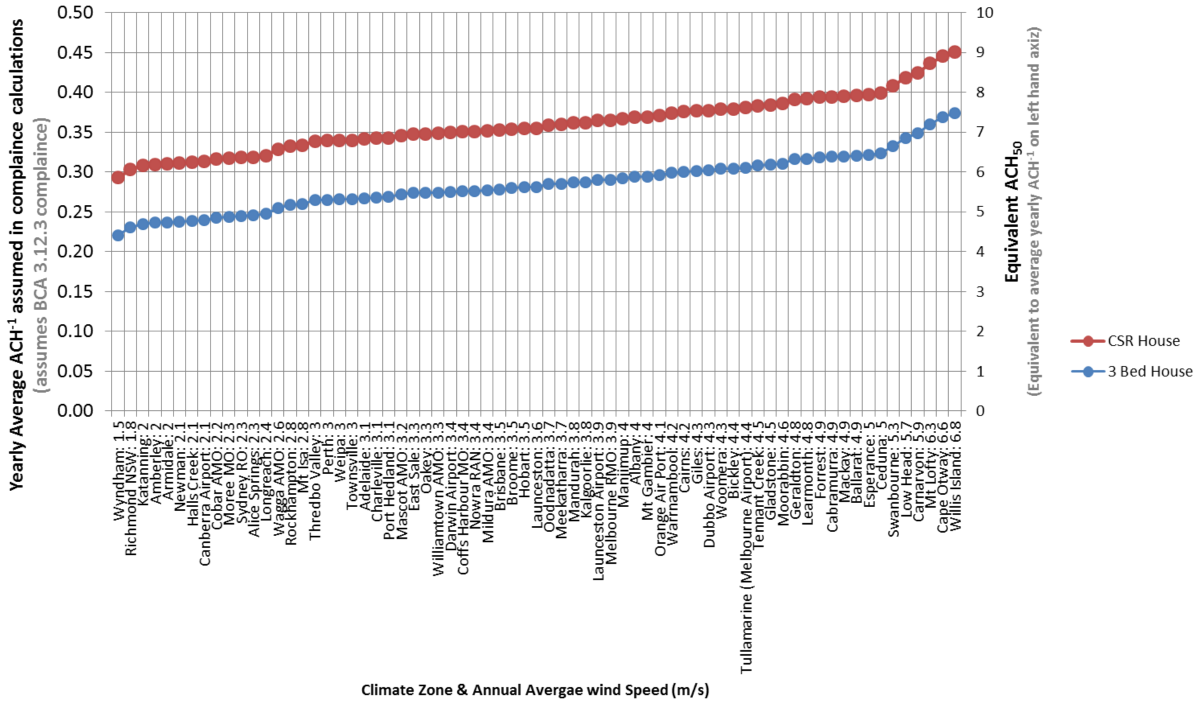
The influence of air infiltration on the calculated energy requirement for each of the 414 house specifications was determined at 6 different infiltration rates 10 ACH_{50} – 35 ACH_{50} at 5 ACH_{50} increments to determine the benefit of addressing excessive air infiltration in the portion of houses above 10 ACH_{50} identified in figure 7 (Section 3.3).

3.9.3 Air Infiltration Rate

Variations in the air permeability calculations were undertaken to determine the benefit of improving minimum industry practice to 10 ACH_{50} from the infiltration rates presented in Figure 7 in combination with the 6 star material specifications as per Appendix E.

The NatHERS tools currently do not give the user the ability to manually modify the air infiltration rate within the dwelling under consideration. The calculations within this study have modified the infiltration rate in the AccuRate simulation files by utilisation of the Advanced Comfort Index developed by the CRC for Low Carbon Living. This has modified algorithms which allow adaptations to the standard AccuRate infiltration assumptions by utilising the concepts and methodology outlined in 'Infiltration Calculations in AccuRate V2.0.2.13' (Chen, 2013).

Compliance calculations using the simulation method and NatHERS compliance path assume an air leakage rate based on user selections for windows, mechanical ventilation fans, down lights and other in-built electrical fittings and appliances in combination with the climatic wind conditions in which the building is located. The algorithms published by (Chen, 2013) assume a reasonable build standard which is compliant with BCA clause 3.12.3 acceptable construction practice and result in average annual infiltration rates comparable to international practice as shown in Figure 16 below. It should be noted that the AccuRate model was assumed to comply with BCA section 3.12.3.4 with sealed exhaust fan dampers and utilised sealed down lights or surface mounted down lights. In all cases the calculated annual average infiltration was below an equivalent benchmark of 10 ACH_{50} in a suburban setting.



Note: The ACH^{-1} compliance value was based on the AccuRate model for the House and the NatHERS TMY weather data for the location taking into account the wind and stack infiltration as published by Dong Chen, 2013.

Figure 16 Average yearly air change rate assumed in compliance calculations

The effect of infiltration on both the heating and cooling load was calculated at 5 ACH_{50} increments from 5 to 35 ACH_{50}; this forms the basis of the energy benefit in this study attributed to sealing leakier dwellings to a benchmark of 10 ACH_{50}. The effect of increasing air infiltration is shown in Figure 17 and 18 for each of the reference houses across 69 climate zones. Data points are plotted for 3 construction types; brick veneer, cavity brick and lightweight construction in each climate zone. It is apparent here that an extremely leaky 6 star house of 35 ACH_{50} or higher which is not effectively implementing the prescriptive air sealing requirements in section 3.12.3 of the building code may actually be achieving equivalent outcomes to 4 NatHERS stars or less in many climate regions.

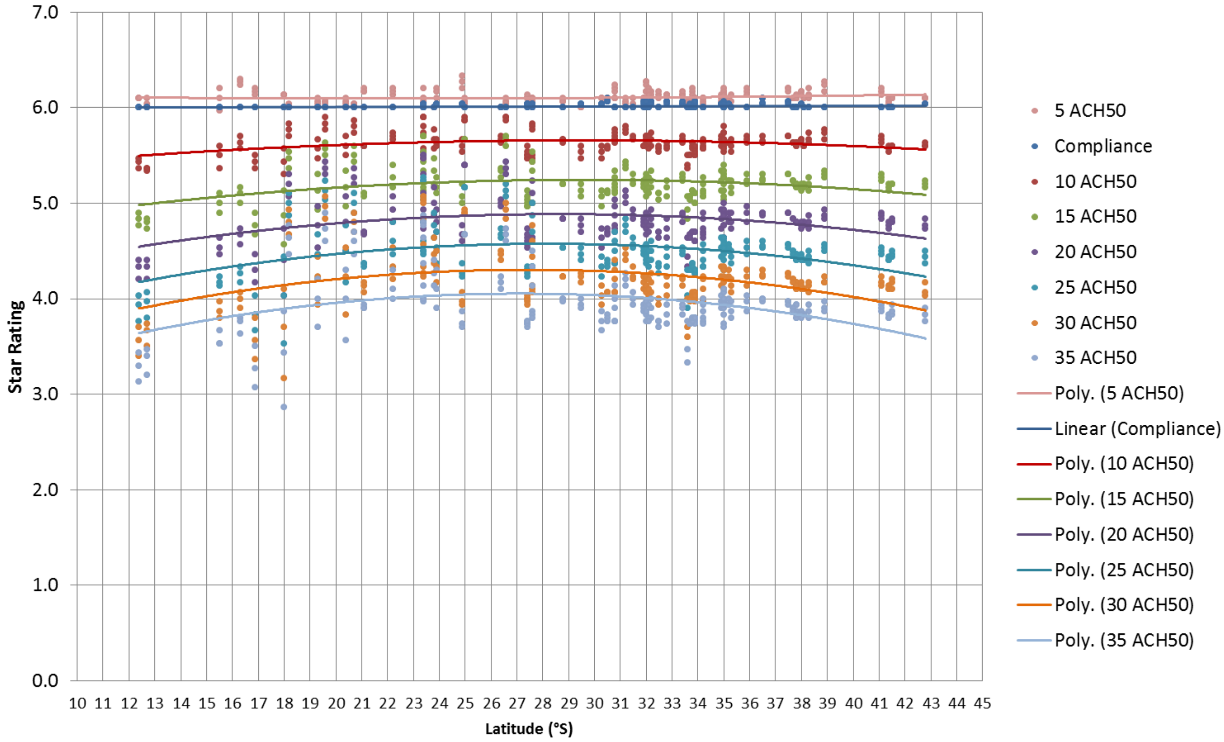


Figure 17 Loss of rating performance based on air change rate for 3 bed house

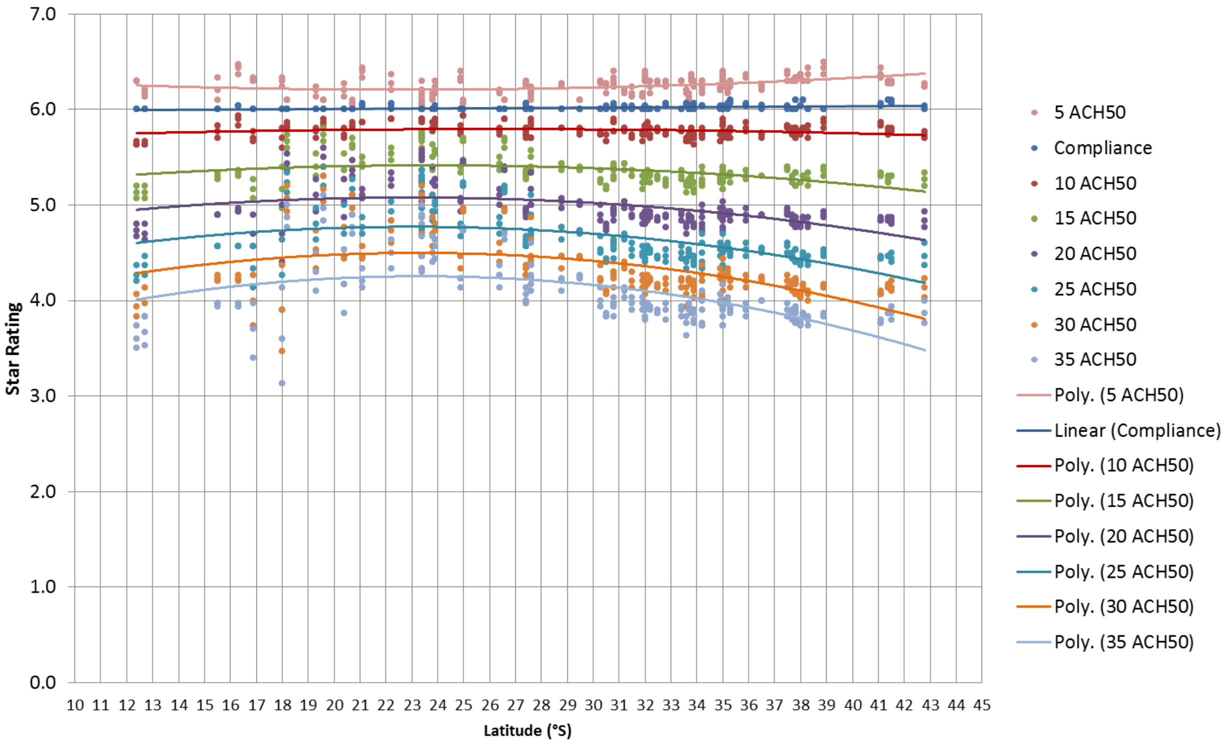


Figure 18 Loss of rating performance based on air change rate for The Research Facility

It is apparent that the climates that are most effected by inadequate air sealing are above 20°South (tropical climates) and below 40°S (cold climates). Figure 17 and 18 show the effects of air leakage on individual climates. However of more use to the regulatory approach is an understanding of how air leakage might affect the performance of houses in the eight BCA climate zones. Averaging the star penalty of all NatHERS climate zones within each BCA climate zone averaged between the two reference house types results in a star variation as per Figure19. Interestingly it is the hot and humid climate zone 1 which has the largest star rating penalty due to the conditioning energy required to extract moisture from the infiltration air.

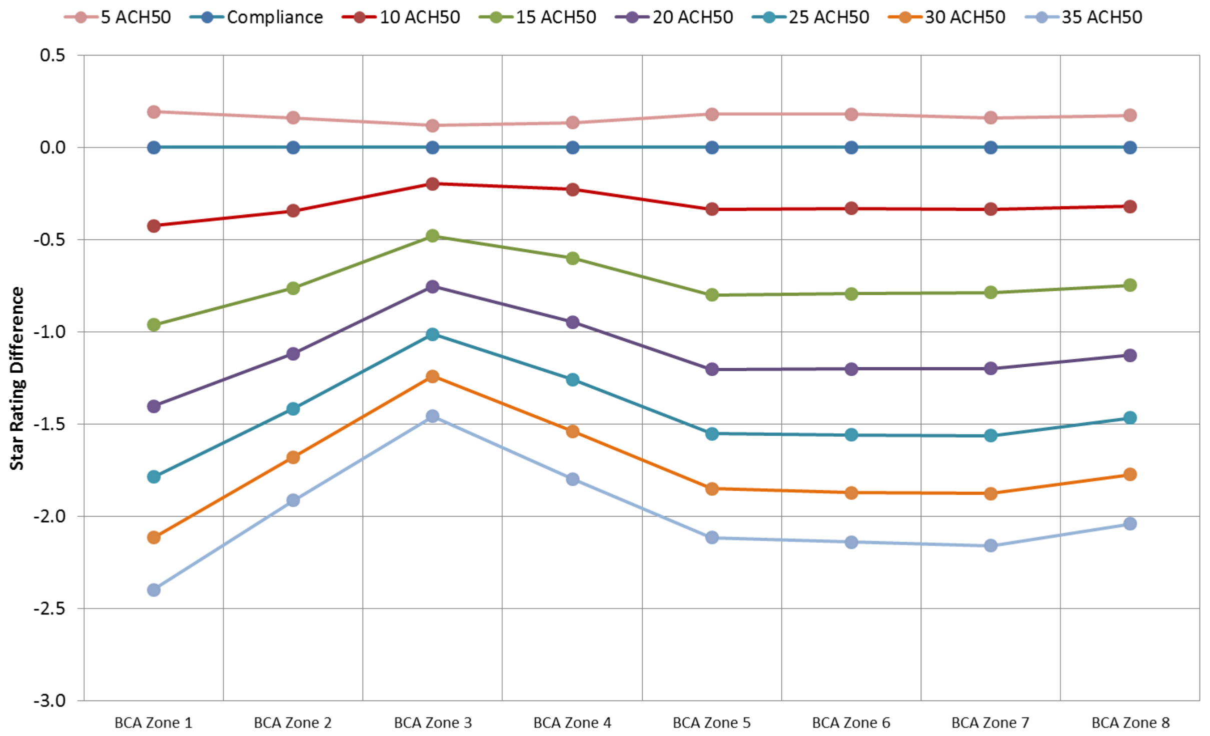


Figure 19 Loss of rating performance Vs Infiltration, averaged into BCA climate zones

Code based post construction performance verification using the fan pressurisation method described in AS/NZS ISO 9972:2006 will promote learning and innovation within industry to achieve energy outcomes within the carbon emission saving intent of the code. The ability to quantify the performance of air control measures will drive adoption of better construction techniques within industry to better align the design rating to the operational energy. The aim being to close the performance gap with current acceptable construction practice requirements compared to actual delivered outcomes achieved by performance based air sealing.

4 ECONOMIC COSTS

The cost of implementation of air control measures is estimated to be relatively minor ranging from \$163-\$1468 per dwelling arising from labour, sealants and potential use of air barrier membranes. The construction type, house size and current method of sarking will all determine how much additional cost will be imposed. The benefit is primarily achieved by better construction and installation practices and increased understanding resulting from industry learning.

Key air control measures are already partly addressed in the BCA Section 3.12.3 acceptable construction practice. Assuming current compliance with section 3.12.3.1 – 3.12.3.6 checklist then the following listed items have been assigned a zero additional cost for implementation:

- Chimneys and flues with dampers or flaps that can be closed to seal the chimney or flue (BCA 3.12.3.1)
- Roof lights are sealed or capable of being sealed (BCA 3.12.3.2).
- External windows and doors restrict air infiltration (BCA 3.12.3.3)
- Exhaust fans are fitted with sealing devices (BCA 3.12.3.4)
- Evaporative coolers are fitted with sealing devices (BCA 3.12.3.6)

The cost associated with improving and validating an air infiltration of 10 ACH_{50} for a single storey or double storey is outlined in table 3 and table 4. Various construction types and scenarios are presented as the cost of improving air sealing will vary depending on if the walls are of framed construction and if pliable building membranes for wall sarking are in use. The amount of newly constructed houses that incorporate wall sarking has been estimated from data received by the Pliable Building Membrane Association (PBMA, 2016) to enable aggregated state based costs for targeting 10 ACH_{50}. The portion of houses that do not currently incorporate wall sarking may need additional air barrier building wraps. These also happen to provide a sarking function and their use is generally recommended practice for this reason.

Part of the total cost is attributed to the post construction validation test using AS/NZS ISO 9972 method to quantify the air leakage through roofs, external walls, external floors and any opening such as a window frame, door frame or the like.

A recent study, "Assisting NatHERS Compliance Market Survey" found that the cost of providing a service for fan pressurisation was generally between \$400-500, with 57% of respondents saying that they charge \$400-\$500 for their standard test and report, while the other 43% said that they charge over \$500 (Sustainability House, 2013). For the purpose of this study $500 fee for service has been utilised in the calculations, justifiable by the economies of scale, competition and innovation generated by a code requirement.

The other portion of the cost goes into improving air sealing of the envelope. This cost can be achieved with minor modifications to design and construction practices, focusing on identifying areas which can be sealed during the construction phase with low cost sealants and tapes as shown in table 3 and 4. Appendix B outlines low cost opportunities for improving air sealing as identified by research undertaken at The Housing Research facility on which the costs in table 3 and 4 were based.

	Additional Air Barrier Required		Wall Sarking already used		
Cost (Material and Labour)	**Brick Veneer**	**Light Weight Cladding**	**Brick Veneer**	**Light Weight Cladding**	**Cavity Brick**
Blower door test	$500	$500	$500	$500	$500
Window and door reveal seals	$163	$163	$163	$163	$163
Bottom plate sealing mastic	$186	$186	$186	$186	N/A
Wall Wrap	$439	$439	$0	$0	N/A
Taping wrap overlaps and joints	$100	$100	$0	$0	N/A
Dampers on flues for gas fireplaces * (BCA 3.12.3.1)	$0	$0	$0	$0	$0
Adequate weather-stripping of doors and windows * *(BCA 3.12.3.3)*	$0	$0	$0	$0	$0
Exhaust fans with damper/seal * (BCA 3.12.3.4)	$0	$0	$0	$0	$0
Evaporative cooling systems with damper *(BCA 3.12.3.6)	$0	$0	$0	$0	$0
Ducted heating/cooling systems with continuous ductwork * *(BCA 3.12.5.3)*	$0	$0	$0	$0	$0
No Cavity sliding doors **	$0	$0	$0	$0	$0
No unsealed downlights **	$0	$0	$0	$0	$0
Total Costs	**$1,387**	**$1,387**	**$849**	**$849**	**$663**

* Compliance to current building code - No Cost Allocated

** Zero cost design decision

Table 3 Cost associated with achieveing 10 ACH_{50} – Single storey 3 bedroom

Cost (Material and Labour)	Additional Air Barrier Required: Brick Veneer	Additional Air Barrier Required: Light Weight Cladding	Wall Sarking already used: Brick Veneer	Wall Sarking already used: Light Weight Cladding	Cavity Brick
Blower door test	$500	$500	$500	$500	$500
Window and door reveal seals	$262	$262	$262	$262	$262
Bottom plate sealing mastic	$196	$196	$196	$196	N/A
Wall Wrap	$890	$890	$0	$0	N/A
Taping wrap overlaps and joints	$120	$120	$0	$0	N/A
Dampers on flues for gas fireplaces * (BCA 3.12.3.1)	$0	$0	$0	$0	$0
Adequate weather-stripping of doors and windows * *(BCA 3.12.3.3)*	$0	$0	$0	$0	$0
Exhaust fans with damper/seal * (BCA 3.12.3.4)	$0	$0	$0	$0	$0
Evaporative cooling systems with damper *(BCA 3.12.3.6)	$0	$0	$0	$0	$0
Ducted heating/cooling systems with continuous ductwork * *(BCA 3.12.5.3)*	$0	$0	$0	$0	$0
No Cavity sliding doors **	$0	$0	$0	$0	$0
No unsealed downlights **	$0	$0	$0	$0	$0
Total Costs	**$1,968**	**$1,968**	**$959**	**$959**	**$762**

* Compliance to current building code - No Cost Allocated

** Zero cost design decision

Table 4 Cost associated with achieveing 10 ACH_{50} – Housig Research Facility, 2 storey

Achieving 10 ACH_{50} is a realistic and achievable target based on current building practices. This is reflected in the fact that a significant portion of new buildings in Queensland, South Australia and Tasmania achieved below 10 ACH_{50} in the data set recorded by Ambrose and Syme (2015) (Table 5). This portion will not require additional building costs but this analysis assumes will impose a cost of $500 for a validation test to ensure compliance.

	Housing Approvals 2015 (Detached)	% of CSIRO Data < 10 ACH_{50}	Estimated Houses to Achieve < 10 ACH_{50}
NSW	30772	7%	2051
VIC	44972	5%	2249
QLD	31377	58%	18166
SA	8820	75%	6615
WA	23543	0%	0
TAS	2490	79%	1956
ACT	3514	21%	740

Table 5 Houses already achieving 10 ACH_{50}, based on Ambrose and Syme (CSIRO, 2015)

5 ECONOMIC BENEFITS

The benefits of improved air sealing are primarily in air conditioned buildings in very hot and humid climates and heated buildings in cooler climates. Generally most climates indicate favourable BCRs. The total BCR associated with performance based fan pressurisation testing is calculated to be 1.7 @ 7% discount rate, 2.1 @ 5% discount rate or 2.5 @ 3.5% discount rate (IPCC recommended) over a 25 year period. Figure 20 shows the associated present value of the future 25 year economic benefit as calculated to be $255 million, $314 million and $371 million respectively for 2015 housing approval numbers. The cost of implementing air control measures and validating using performance based fan pressurisation requirements for 2015 housing approvals is calculated to be $146.7 million as shown in Figure 20.

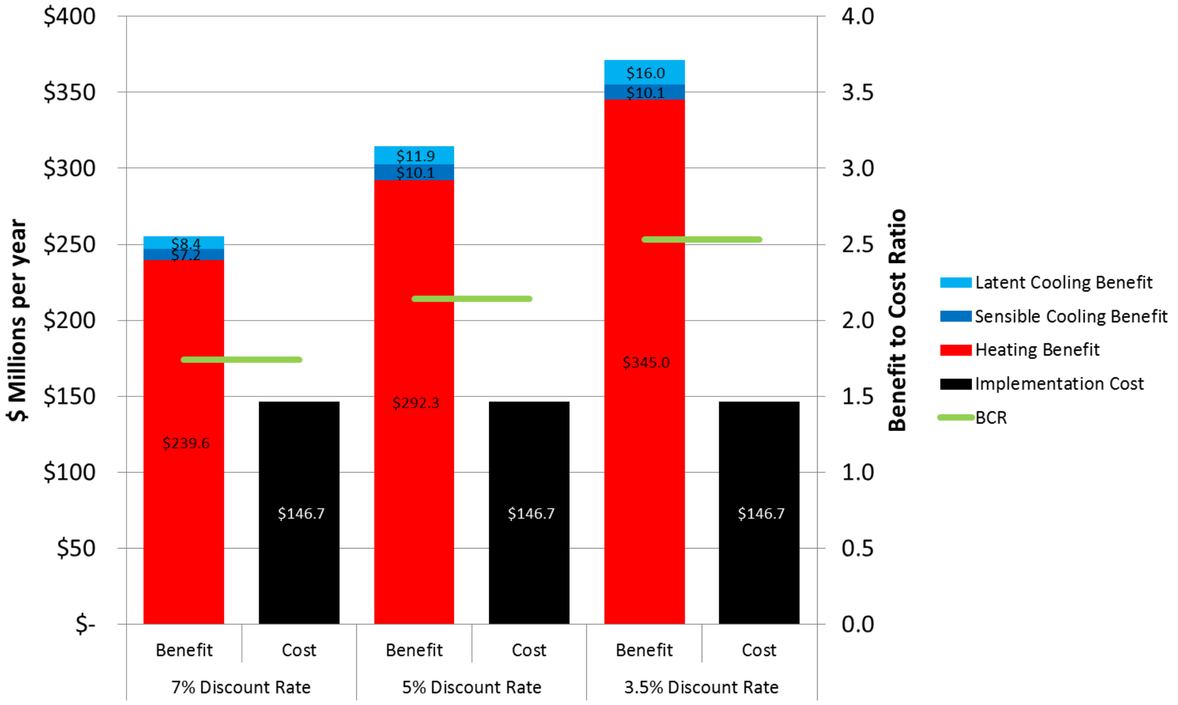


Figure 20 Present value benefits and costs of 10 ACH_{50} benchmark (2015 approval data)

The least benefit is seen in the mild BCA climate zone 2 with a 0.5 BCR ratio @ 5% discount rate a maximum of 0.6 @ 3.5% discount rate and just 0.4 @ 7% discount rate. The highest BCR is seen in BCA climate 8 with a 6.0 BCR ratio @ 5% discount rate a maximum of 7.0 @ 3.5% discount rate and 4.9 @ 7% discount rate. Figure 21 to 23 show the total cost and benefit in each BCA climate zone for a 7%, 5% and 3.5% discount rate. Housing approvals were aggregated into climate regions for purpose of calculations and the subsequent benefit and cost are based on total housing approvals in each BCA climate zone for the year 2015. The assumptions outlined in section 3 were used to calculate the benefits and the assumptions in section 4 used to determine the financial cost to society and form the basis of the numbers presented in Figures 21 to 23.

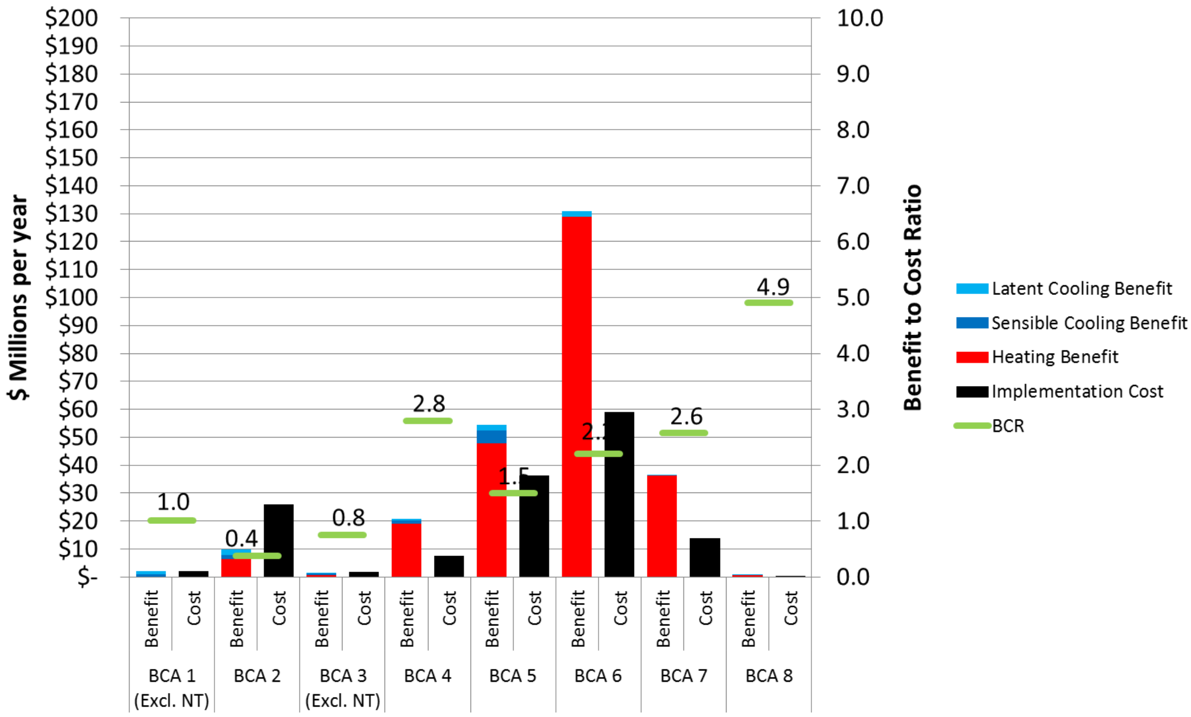


Figure 21 BCR for adopting air sealing (7% discount)

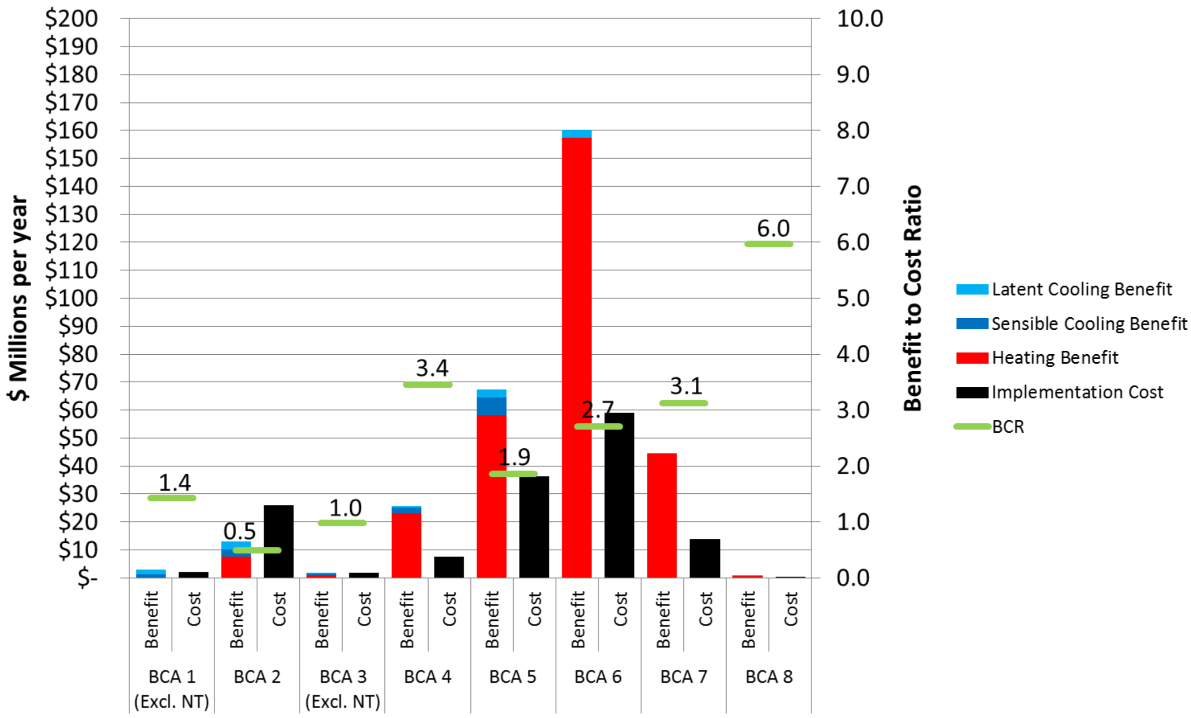


Figure 22 BCR for adopting air sealing (5% discount)

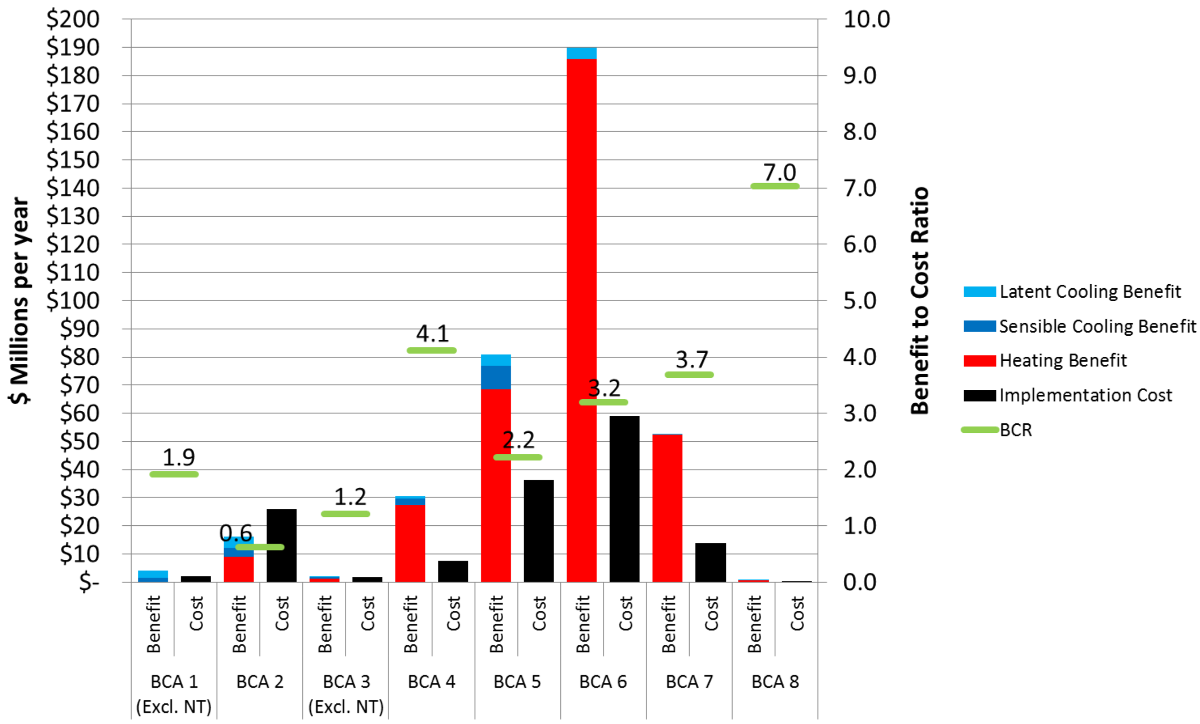


Figure 23 BCR for adopting air sealing (3.5% IPCC discount)

The housing development activity in each state and the related BCA climate zone are the key driver of the contribution to the overall benefit. The BCR for each BCA climate zone varies and is discussed in more detail for each zone on the following pages.

5.1 BCA Climate Zone 1 - Hot humid summer, warm winter

Source: http://www.yourhome.gov.au/

Climate Zone 1 stretches across the states of WA, NT and QLD. In the case of this analysis NT housing was excluded from the analysis due to no data being available for air sealing. So the relative air leakiness of houses in the hot humid parts of Australia is defined by WA and QLD housing.

With 2,433 houses approved in 2015 (Figure 24) the total benefit to Australia remains small however the total BCR is favourable with a 1.4 @ 5% discount rate. Due to the high humidity and large amounts of moisture in the external air energy is required to reduce indoor humidity to maintain comfort in this climate. A BCR of 1.01 @ 7% discount and 1.9 @ 3.5% discount rate show this climate is just favourable for air sealing in economic terms. All calculations are generally based on a NatHERS cooling temperature of 27°C (28°C Wyndham, 26°C Weipa) which in reality may be higher than actual operating temperatures in homes

(Saman, Oliphant, Mudge, & Halawa, 2008), this means that the cooling loads may be higher and the resulting benefits of air sealing in BCA zone 1 may actually be greater than stated here.

In addition BCRs calculated here are based on a 6 star benchmark for the reference houses. In reality houses in Climate Zone 1 may gain compliance with 5 - 5.5 stars due to allowable concessions, therefore the BCR may vary from the number stated in favour of a higher BCR.

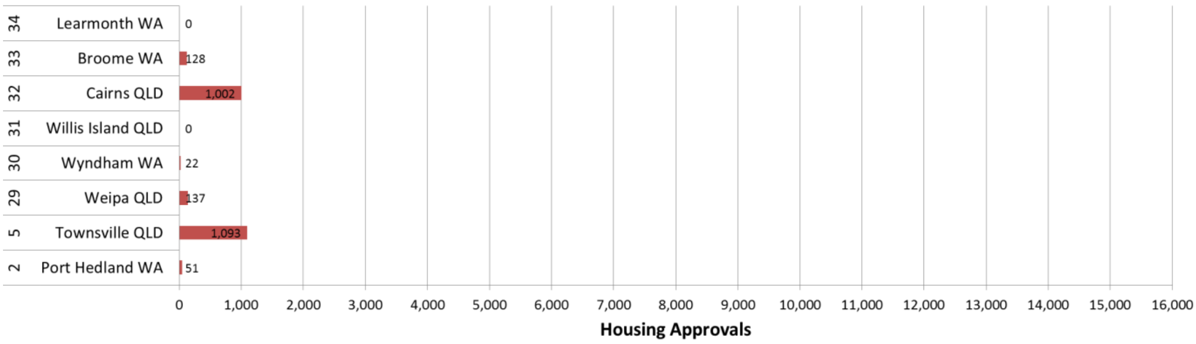


Figure 24 Housing approvals (2015) in BCA climate 1

Western Australia

The 2015 CSIRO data (Ambrose & Syme, 2015) indicated that WA has some of the leakiest houses in Australia which means air sealing is highly beneficial. The wide use of cavity brick construction in WA means that walls may be sealed relatively easily and cost effectively. The same ratio of construction types was used across all WA climate zones.

Queensland

The 2015 CSIRO data (Ambrose & Syme, 2015) indicated that 58% of QLD houses would already meet a 10 ACH_{50} benchmark (based on Brisbane data) and therefore these houses contributed a zero benefit to a code based performance requirement. This same portion was assumed in BCA climate zone 1. In the case of the already compliant houses no additional effort or costs for builders are imposed apart from the $500 fan pressurisation per house for performance validation. A further 29% are less than 15 ACH_{50} and only contribute a marginal benefit for improving air sealing.

5.2 BCA Climate Zone 2 - Warm humid summer, mild winter

Source: http://www.yourhome.gov.au/

Climate Zone 2 had a total of 28,385 housing approvals in 2015 (Figure 25) and is primarily located in SE Queensland, only 4% of housing approvals fall within NSW.

The 2015 CSIRO data (Ambrose & Syme, 2015) indicated that 58% of QLD houses (based on Brisbane data) would already meet a 10 ACH_{50} benchmark and therefore these houses contributed no benefit to a code based performance requirement. These already compliant houses would require no additional effort or costs for builders apart from the $500 test per house for performance validation. A further 29% in QLD are less than 15 ACH_{50} and only contribute a marginal benefit for improving air sealing. The relatively good air sealing performance in conjunction with a milder climate means that the benefit is limited to a BCR of 0.5 at 5% discount rate. The costs are calculated to be $26.03 million and the present value of the 25 year benefits to be $12.99 million (5% discount) for 2015 housing approvals.

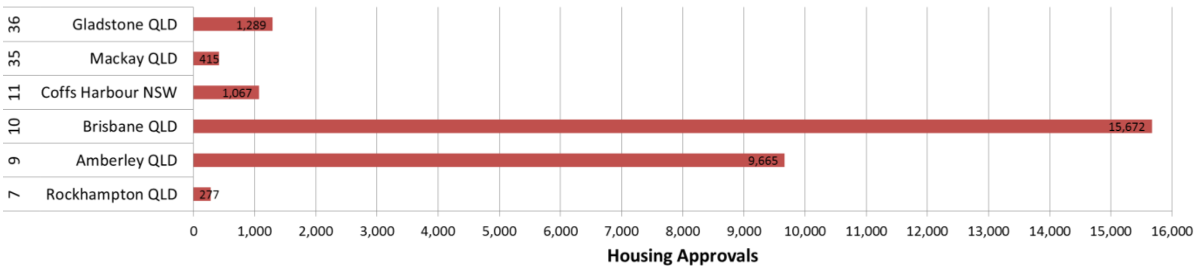


Figure 25 Housing approvals (2015) in BCA climate 2

It is recommended that further investigation into current performance of mainstream volume built homes in Queensland infiltration rates is required as the data presented by Ambrose and Syme indicates that houses are unusually well sealed compared to NSW and Victorian houses. All calculations are generally based on a NatHERS cooling temperature of 26°C which in reality may be higher than actual operating temperatures in homes (Saman, Oliphant, Mudge, & Halawa, 2008), this means that the resulting benefits may be increased. In addition BCRs calculated here are based on a 6 star benchmark for the reference houses. In reality houses in Climate Zone 2 may gain compliance with 5 - 5.5 stars due to allowable concessions, further increasing the BCR for air sealing.

5.3 BCA Climate Zone 3 - Hot dry summer, warm winter

Source: http://www.yourhome.gov.au/

Climate Zone 3 stretches across the states of WA, NT and QLD. In the case of this analysis NT housing was excluded from the analysis due to no data being available for air sealing of NT housing. So the relative air leakiness of houses in these hot dry parts of Australia is defined by WA and QLD housing.

There are only a relatively small number of houses, with 1,989 total approvals for climate zone 3 in 2015 (Figure 26). Within this inland region the only notable development area is within Oakey climate zone. The hot and dry climate may have high diurnal swings; this means that air leakage may not have such a large benefit in housing that has any significant level of heat capacity (thermal mass).

The implementation costs are calculated to be $1.76 million and will provide $1.72 million (5% discount) in savings over 25 years delivering a 1.0 BCR.

The BCR is calculated to be 0.8 @ 7% discount rate and 1.2 @ 3.5% discount rate meaning that the BCR is viable under IPCC guidelines but not under stringent economic terms.

All calculations are generally based on a NatHERS cooling temperature of 27°C which in reality may be higher than actual operating temperatures in homes (Saman, Oliphant, Mudge, & Halawa, 2008), this means that the cooling loads may be higher and the resulting benefits of air sealing in BCA zone 3 may actually be greater than stated here.

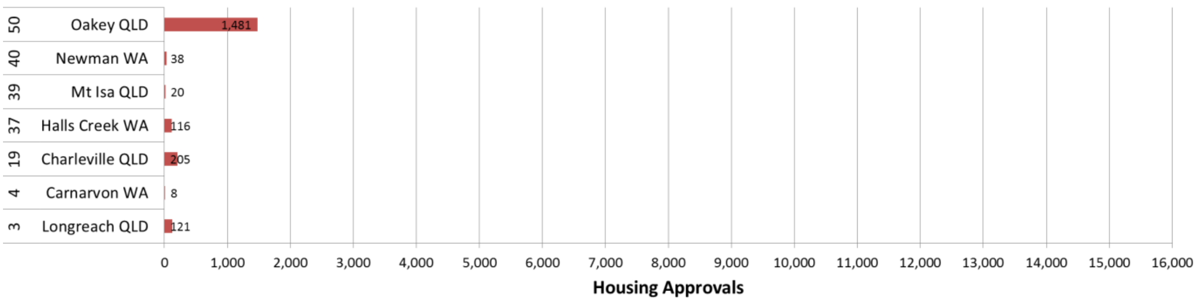


Figure 26 Housing approvals (2015) in BCA climate 3

5.4 BCA Climate Zone 4 - Hot dry summer, cool winter

Source: http://www.yourhome.gov.au/

Climate Zone 4 stretches across the states of WA, SA and NSW. This climate is both extremely hot and can get very cool in winter making the heating load more significant in which air sealing plays an important role.

There are only a relatively small number of houses, with 7,497 approvals for climate zone 4 in 2015. The hot and dry climate may have high diurnal swings; in these climates air leakage may not have such a large benefit in housing during the summer and mid seasons when any significant level of thermal mass is incorporated. The cool winters which may have prolonged periods of cool weather contribute most to the benefits of reducing air leakage.

The implementation costs are calculated to be $7.43 million and will provide $25.62 million (5% discount) in savings over 25 years delivering a 3.4 BCR.

The BCR is calculated to be 2.8 @ 7% discount rate and as high as 4.1 @ 3.5% discount rate meaning that climate zone 4 is valid for inclusion in the building code.

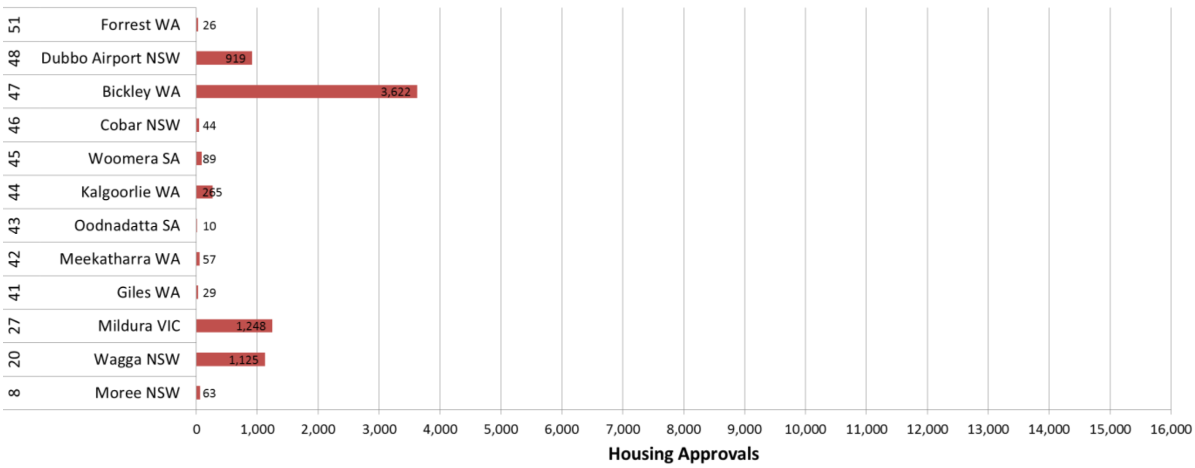


Figure 27 Housing approvals (2015) in BCA climate 4

5.5 BCA Climate Zone 5 - Warm temperate

Source: http://www.yourhome.gov.au/

Climate Zone 5 is predominantly coastal regions covering the capital cities of Sydney, Adelaide and Perth. There is significant housing development in this climate region with 36,077 houses approved in 2015. This means there is means there is a significant benefit to introduce performance based requirements for air sealing at a 10 ACH_{50} benchmark.

Due to the large number of housing development in this region it delivers a large benefit to Australia. The implementation costs are calculated to be $36.39 million and will provide $67.49 million (5% discount) in savings over 25 years delivering a 1.9 BCR.

The BCR is calculated to be 1.5 @ 7% discount rate and as high as 2.2 @ 3.5% discount rate meaning that climate zone 5 is valid for inclusion in the building code.

New South Wales

The 2015 CSIRO data (Ambrose & Syme, 2015) indicated that NSW houses are relative leaky with only 7% equal to or better than a 10 ACH_{50} benchmark. A high portion of houses in NSW are estimated to not have external wall wraps potentially increasing the cost to achieve a 10 ACH_{50} benchmark. Note that BCRs calculated here are based on a 6 star benchmark for the reference houses. In reality BASIX prescribes the current performance required for compliance which may be lower and more benefit to be gained for the same cost.

South Australia

The 2015 CSIRO data (Ambrose & Syme, 2015) indicated that 75% of SA houses already meet a 10 ACH_{50} benchmark and therefore contributed a zero benefit. In the case of the already compliant houses no additional effort or costs for builders are imposed apart from the $500 fan pressurisation per house for performance validation. It is recommended that further investigation into current performance of mainstream volume built homes in South Australia is undertaken as Ambrose and Syme (2015) concluded that their data suggests houses are unusually well sealed. Therefore the benefit may be greater than stated here.

Western Australia

The 2015 CSIRO data (Ambrose & Syme, 2015) indicated that WA has some of the leakiest houses in Australia which means air sealing is highly beneficial. The wide use of cavity brick construction in WA means that walls may be sealed relatively easily. The cost of implementation is reduced as additional air barriers are not necessarily required in walls.

Although BCA climate 5 in WA is often considered hot the leakiness of the houses and the relatively large number of approvals (17046 houses in 2015) means that the WA benefit makes a considerable contribution.

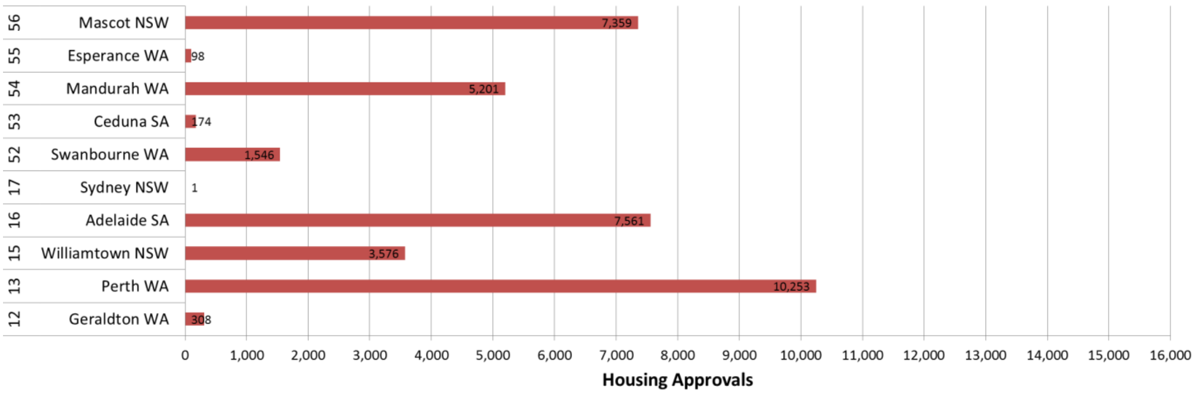


Figure 28 Housing approvals (2015) in BCA climate 5

5.6 BCA Climate Zone 6 - Mild temperate

Climate Zone 6 represents the cooler regions of WA, western Sydney stretching up to the Blue Mountains of NSW, Melbourne and the cool coastal regions of the Great Ocean Road in VIC. Incorporating western Sydney development fringes and Melbourne there is significant housing development in this climate region with 55,047 houses approved for climate zone 6 in 2015. The winter may have prolonged periods of cool weather where significant benefits are delivered by air sealing.

Source: http://www.yourhome.gov.au/

Due to the largest number of housing approvals in all Australia within this region coupled with cool winters it delivers a substantial benefit to Australia. The implementation costs are calculated to be $59.04 million and will provide $159.62 million (5% discount) in savings over 25 years delivering a 2.7 BCR.

The BCR is calculated to be 2.2 @ 7% discount rate and as high as 3.2 @ 3.5% discount rate meaning that climate zone 6 is valid for inclusion in the building code.

Victoria

With the housing approvals totalling 37,149 in climate zone 6 in 2015, some of the leakiest houses in Australia (Ambrose & Syme, 2015) and cool winters, Victoria shows significant benefit to introduce performance based requirements for air sealing at a 10 ACH_{50} benchmark in climate zone 6. The BCR is further enhanced by the fact that many builders in Victoria are already utilising wall wrap reducing the imposed cost of air sealing in Victorian housing.

New South Wales

The 2015 CSIRO data (Ambrose & Syme, 2015) indicated that NSW houses are relative leaky with only 7% equal to or better than a 10 ACH_{50} benchmark. With a total of 15,137 housing approvals per year in NSW climate zone 6 it means there is a significant benefit to introduce performance based requirements for air sealing at a 10 ACH_{50} benchmark. A high portion of houses in NSW are estimated to not have external wall wraps reducing the overall climate 6 BCR for a 10 ACH_{50} benchmark.

Note that BCRs calculated here are based on a 6 star benchmark for the reference houses. In reality BASIX prescribes the current performance required for compliance which may be lower than 6 stars, therefore the BCR may vary from the number stated.

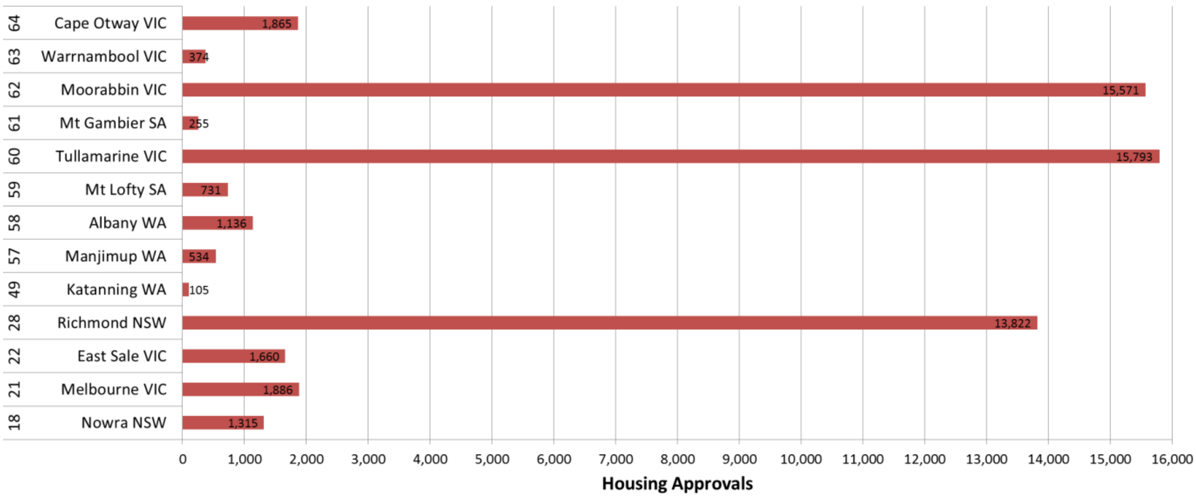


Figure 29 Housing approvals (2015) in BCA climate 6

5.7 BCA Climate Zone 7 - Cool temperate

Source: http://www.yourhome.gov.au/

Climate zone 7 is cool with prolonged winters. The higher regions of mainland Australia and the majority of Tasmania fall into this climate.

The winters are generally very cold and cool weather dominates for the majority of the year. Housing in this region totals 13,985 approvals in 2015 and the benefit of air sealing to Australia is enhanced by the large benefit gained in these regions.

The implementation costs are calculated to be $13.81 million and will provide $43.17 million (5% discount) in savings over 25 years delivering a 3.1 BCR.

The BCR is calculated to be 2.6 @ 7% discount rate and as high as 3.7 @ 3.5% discount rate meaning that climate zone 7 is valid for inclusion in the building code.

New South Wales

Note that BCRs calculated here are based on a 6 star benchmark for the reference houses. In reality BASIX prescribes the current performance required for compliance which may be lower than 6 stars, therefore the BCR may vary from the number stated.

Victoria

With the largest number of housing approvals in climate zone 7 totalling 6,575 in 2015, some of the leakiest houses in Australia (Ambrose & Syme, 2015) and relatively cool winters, Victoria shows significant benefit to introduce performance based requirements for air sealing at a 10 ACH_{50} benchmark. The BCR is further enhanced by the fact that many builders in Victoria are already utilising wall wrap reducing the imposed cost of air sealing in Victorian housing.

Tasmania

The 2015 CSIRO data (Ambrose & Syme, 2015) indicated that Tasmania has some of the best air sealed houses in Australia. This may be attributed to Tasmania almost entirely covered by climate zone 7 where the natural response is to conserve warm air within the homes. With 79% of houses in Tasmania already meeting or exceeding a 10 ACH_{50} performance benchmark the cost of compliance is small with only a $500 test imposed to validate performance. The 21% of houses above 10 ACH_{50} show significant ongoing energy benefits to be brought in line with the 79% of already compliant homes. The overall contribution to Australia's benefit is small due to the relatively small number of housing approvals.

It is recommended that further investigation into the current performance of mainstream volume built homes in Tasmania is undertaken as Ambrose and Syme (2015) concluded that their data suggests houses are unusually well sealed. Therefore the benefit may actually be greater than stated here.

Australian Capital Territory

The 2015 CSIRO data (Ambrose & Syme, 2015) indicated that 79% of houses are leakier than 10 ACH_{50}. This combined with the predominantly heating climate in Canberra conducive to air sealing allows for large benefits.

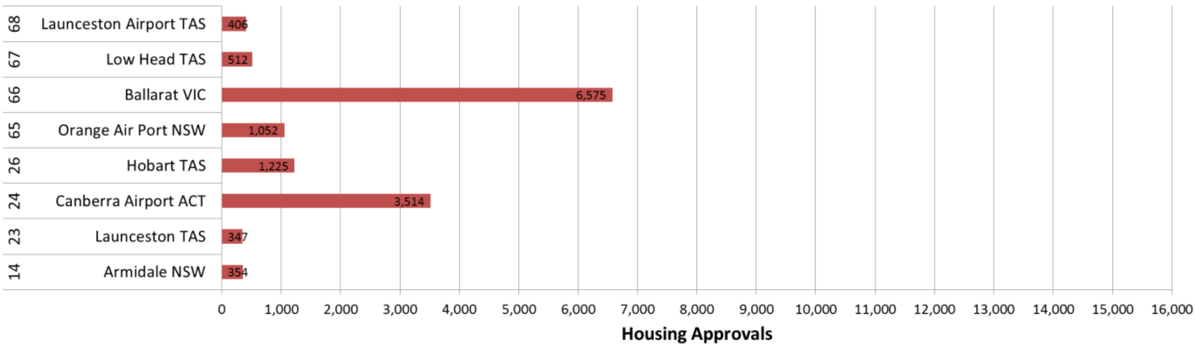


Figure 30 Housing approvals (2015) in BCA climate 7

5.8 BCA Climate Zone 8 – Alpine

Source: http://www.yourhome.gov.au/

Climate zone 8 contains the coldest regions of Australia with winter snowfall. The alpine regions of the Great Dividing Range fall into this climate.

Housing in this region totalled 75 approvals in 2015 therefore the overall benefit to Australia is limited. However on an individual household level the benefit is substantial.

The implementation costs are calculated to be $110,000 and will provide $650,000 (5% discount) in savings over 25 years delivering a 6.0 BCR.

The BCR is calculated to be 4.9 @ 7% discount rate and as high as 7.0 @ 3.5% discount rate meaning that climate zone 8 is valid for inclusion in the building code.

Note that BCRs calculated here are based on a 6 star benchmark for the reference houses. In reality BASIX prescribes the current performance required for compliance which may be lower than 6 stars, therefore the BCR may vary from the number stated.

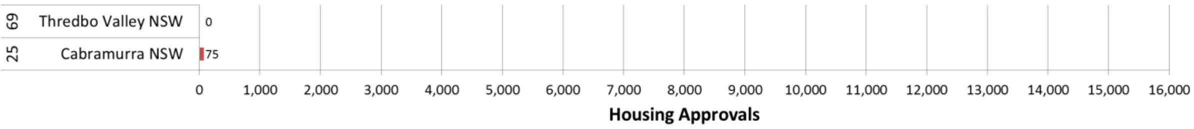


Figure 31 Housing approvals (2015) in BCA climate 8

6 PUBLIC HEALTH AND AMENTIY

In 2011 Axel Berge identified many issues which arise from poor air sealing in buildings which generally fall into the categories as identified by Figure 32 with cross references to the Australian building code volume 2. Enhancing air sealing can reduce moisture related issues, increase air quality, improve fire safety, improve acoustics, enhance weatherproofing and improve thermal comfort with associated energy and carbon emission savings in Australian housing.

The discussion outlined in this section identifies the use of code based verification for delivering the benefits of the health and safety objectives of the BCA volume 2. Through driving an emphasis on better design and more improved detailing of construction methods air sealing will:

1. Provide better performing homes in extreme heatwaves and cold snaps reducing thermal stress on the occupants.
2. Help safeguard occupants from illness or loss of amenity as a result of undue sound being transmitted from outside or between adjoining dwellings (BCA O2.4.6)
3. Enhance the ability to safeguard occupants from illness or injury and protect the building from damage caused by external humidity entering a building (BCA O2.2)
4. Allow highly effective low cost balanced mechanical ventilation strategies to:
    a. Safeguard occupants from illness or loss of amenity due to lack of air freshness (BCA O 2.4.5)
    b. Safeguard occupants from illness or injury and protect the building from damage caused by the accumulation of internal moisture in a building (BCA O2.2)
5. Improve the ability to prevent the penetration of water in walling systems that could cause unhealthy or dangerous conditions, or loss of amenity for occupants; and undue dampness or deterioration of building elements (BCA P2.2.2)
6. Help to avoid the spread of fire (BCA O2.3)

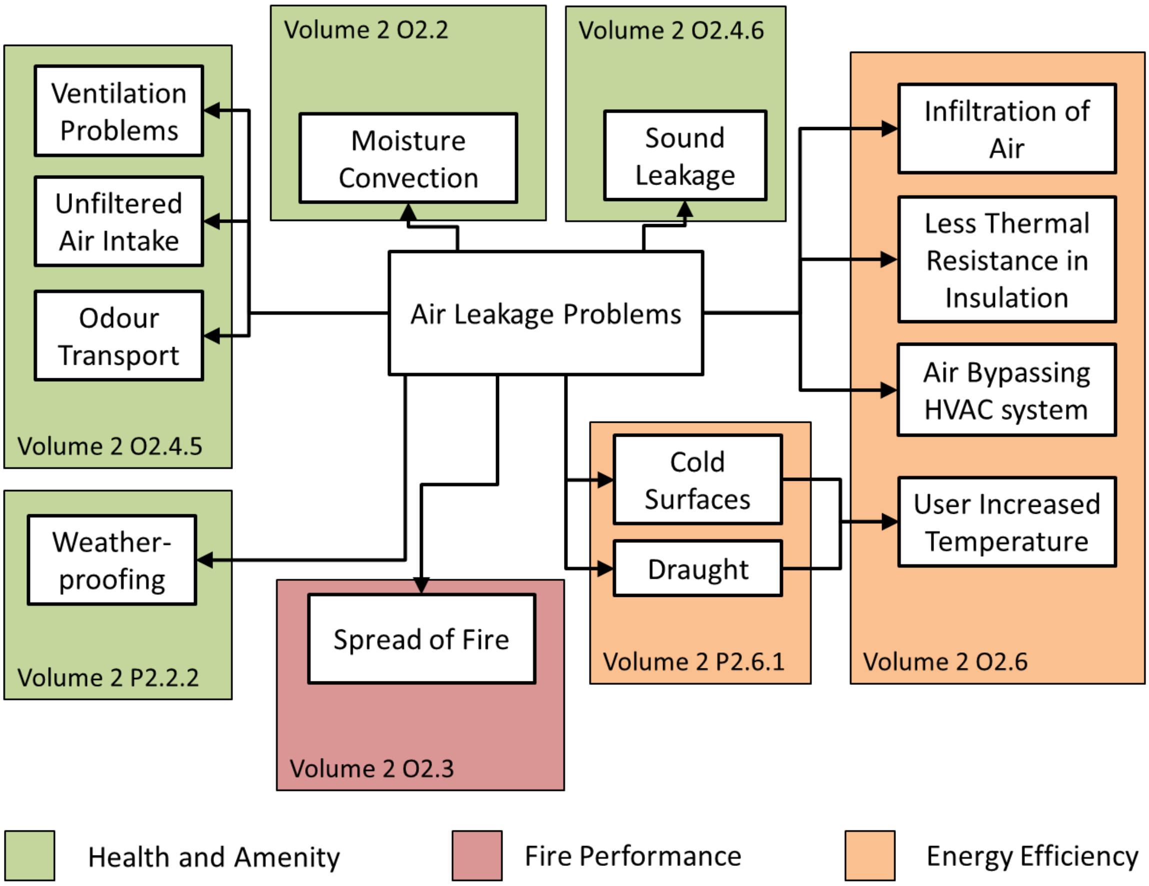


Figure 32 The ability of fan pressurisation verification to enhance BCA Vol. 2 objectives

6.1 Indoor Thermal Stability

The primary benefit of air sealing is gained through thermal comfort benefits to the community and associated reduction in energy requirements. From a health aspect this includes reduced heat stress for the extremely young, the elderly and the frail in extreme cold and/or extreme hot conditions reducing morbidity and mortality rates in these extreme events.

In January 2014 Melbourne experienced a heat wave in which more than 203 deaths were reported to the coroner, more than twice the average. In 2009 Victoria experienced a heat wave which was reported to have killed more than 370 (ABC, 2014). A four-day heatwave in Victoria in January 2014 resulted in a 24 per cent increase in the number of deaths and a 97 per cent increase in emergency calls for cardiac issues (ABC, 2014). An additional 167 people died that week compared to previous years. Housing provides a refuge for many people during peak temperatures and it is essential that the building and services are able to operate effectively in these periods for the health and safety of vulnerable demographic groups.

Chapter 8 discusses the implications air sealing has on summer peak load. The ability of improved air sealing is synonymous with the improved ability to maintain comfort in extreme hot weather.

A recent study found that cold contributes to about 3.69 per cent of deaths in Sweden, but 6.5 per cent in Australia (Gasparrini, et al., 2015). In addition cold weather claims more lives than hot weather in Australia. The same study concluded that heat contributed to only 0.5 per cent of deaths in Australia. The author Dr Adrian Barnett believes this is attributed to the lack of performance based housing in Australia.

The main driver that causes increased mortality is not extreme events like blizzards that cause the most deaths from cold. Rather, it's stress caused by increased blood pressure from constant exposure to low temperatures (Roberts, 2015).

These deaths are largely preventable as the main reason countries such as Sweden have colder weather but fewer lives lost can be attributed to the quality of their housing.

Professor Adrian Barnett described many Australian homes as nothing more than "glorified tents", exposing us to much lower temperatures than the Scandinavians endure (Roberts, 2015).

Gasparrini et al. found that the Relative Risk (RR) of mortality in Australia (Represented by Sydney, Figure 33) increased at a much higher rate as the outdoor temperature deviated from a comfortable 22.5°C. When compared to other countries such as Canada (Toronto, Figure 34) or Sweden (Stockholm, Figure 35). Despite the far colder climates and sub zero temperatures in Sweden and Canada the relative risk of mortality is much lower across the entire temperature range in these countries than the mild temperature range in Australia.

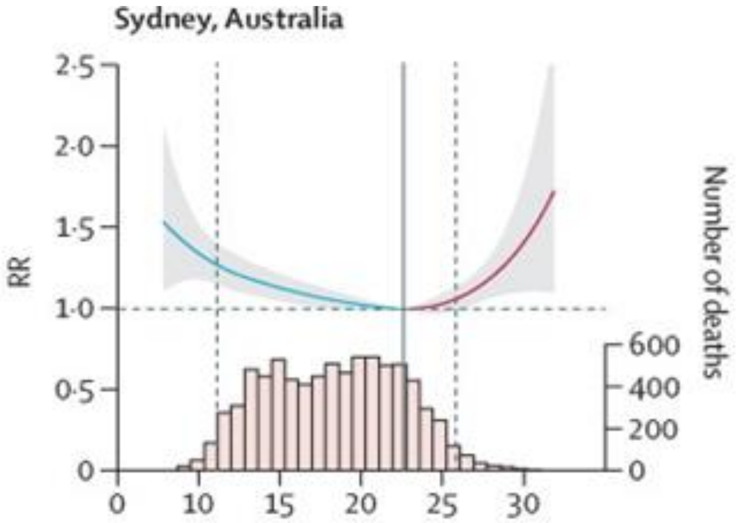


Figure 33 Relative Risk (RR) of mortaility vs temeprature in Sydney, Gasparrini et al. 2015

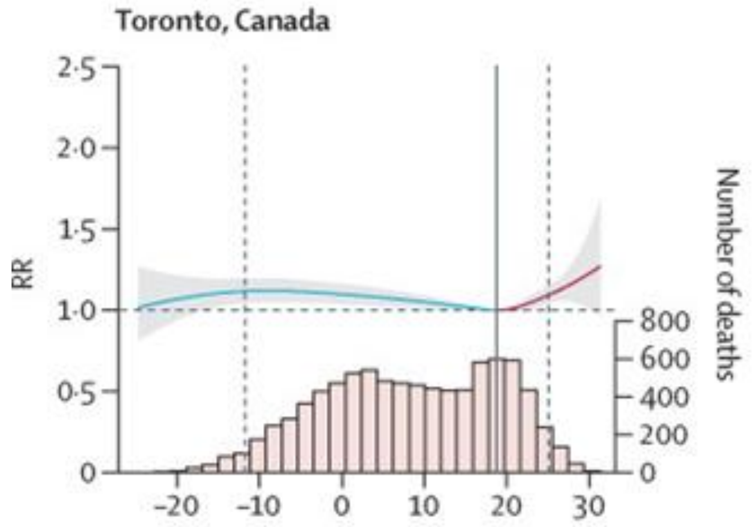


Figure 34 Relative Risk (RR) of mortaility vs temeprature in Canada, Gasparrini et al. 2015

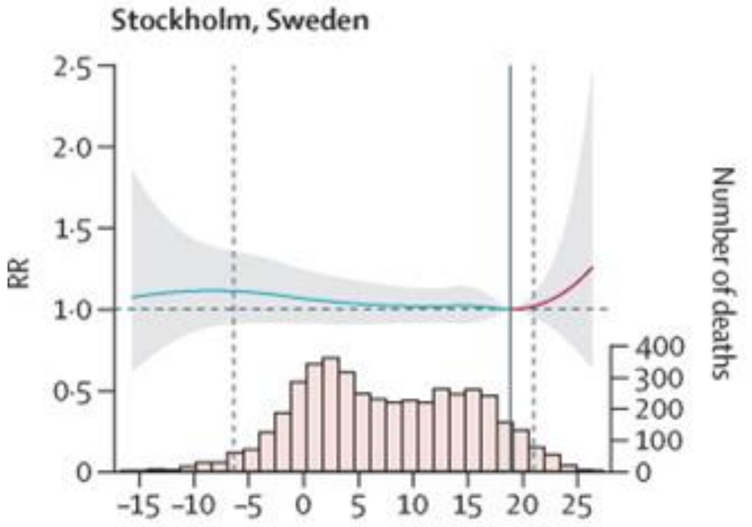


Figure 35 Relative Risk (RR) of mortaility vs temeprature in Sweden, Gasparrini et al. 2015

Generally speaking building envelope integrity in both Sweden and Canada is superior to Australian housing. Both these countries were early pioneers of building sealing with the idea originating in Sweden in 1977 and widespread use began in Canada in the 1980s (Anderson, 1995). This early adoption means that with over 30 years of implementation of air sealing a much higher portion of the existing housing stock can be effectively and efficiently heated with a uniform temperature to reduce the relative risk of mortality.

Australian research in the 1980s found that a sample of Australian houses had much higher air infiltration rates than both Swedish and Canadian houses of the same era as shown in Figure 36 (Biggs, Bennie, & Michell, 1986). The legacy of the buildings of this era is still apparent in today's existing housing stock and little industry learning has occurred as reflected in Ambrose and Syme results recorded in 2015 with 26% of houses tested having leakage rates recorded in excess of 20 ACH_{50}. This is equivalent to all the air in a house leaking out in just 1 hour under normal operation where it is then required to be completely heated or cooled again.

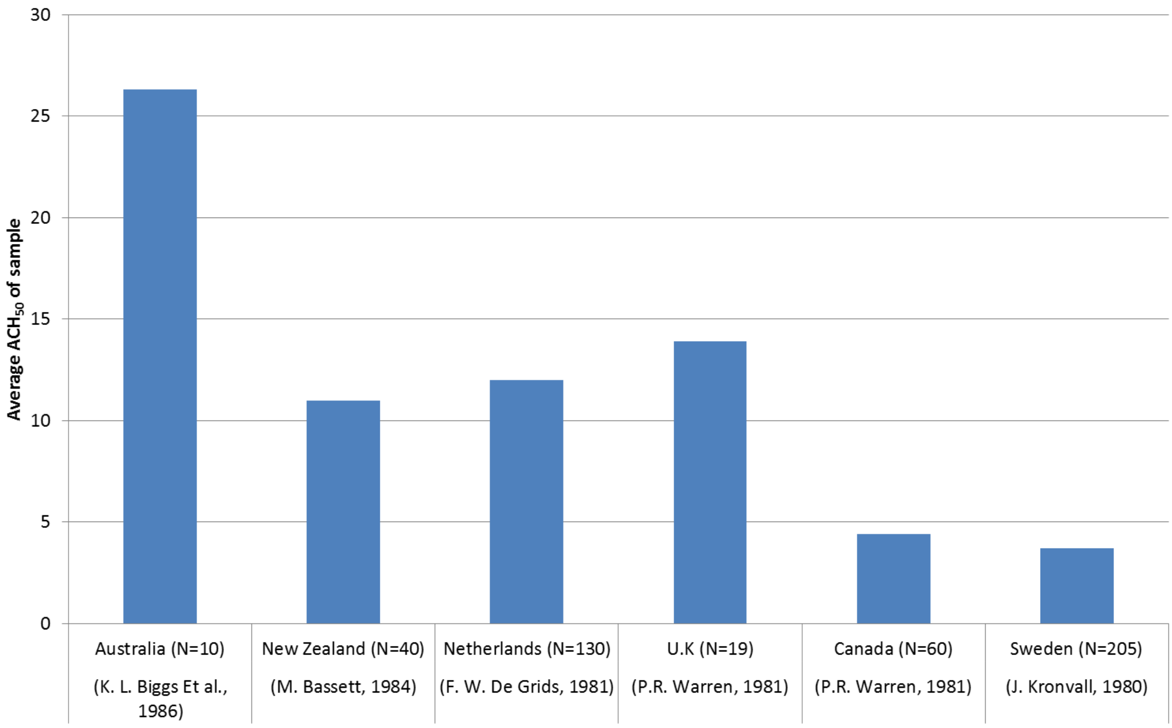


Figure 36 Indicative air sealing of buildings in various countries in the 1980's

High infiltration rates mean houses will be difficult to heat and cool, increased draughts occur, and temperature variance in the living spaces becomes high. The ability of the thermal envelope to enhance the "natural comfort" without the use of air conditioning is generally improved through making a dwelling more air tight. Peeters et al. used adaptive temperature limit guidelines and developed an adaptive thermal comfort guideline for residential buildings (Peeters, 2009). For the purpose of this study this comfort model has been used to determine the "natural comfort" level of both the single storey 3 bedroom house and double storey Housing Research Facility in all climate zones when no heating or cooling is applied and only relying on controlled natural ventilation operated according to the NatHERS protocol. Figure 37 and 38 shows the enhancement in the comfort level achieved by improving the air sealing from 35 ACH_{50} to 10 ACH_{50} in both the houses. The green bars indicate the improvement air sealing can have on the ability of the thermal space to passively maintain comfort and reduce the likelihood of exacerbated cold spells within the habitable space and associated morbidity and mortality. The improvement to the "natural comfort" level in warmer climates of northern Queensland, northern territory and Western Australia is limited. Although air sealing will have implications for energy use when mechanical cooling is used as shown in the cost benefit chart in (Figure 20). In particular Latent cooling loads in Darwin would see potentially large benefits from air sealing air conditioned homes, however the Northern Territory has been excluded due to lack of availability of current housing performance data.

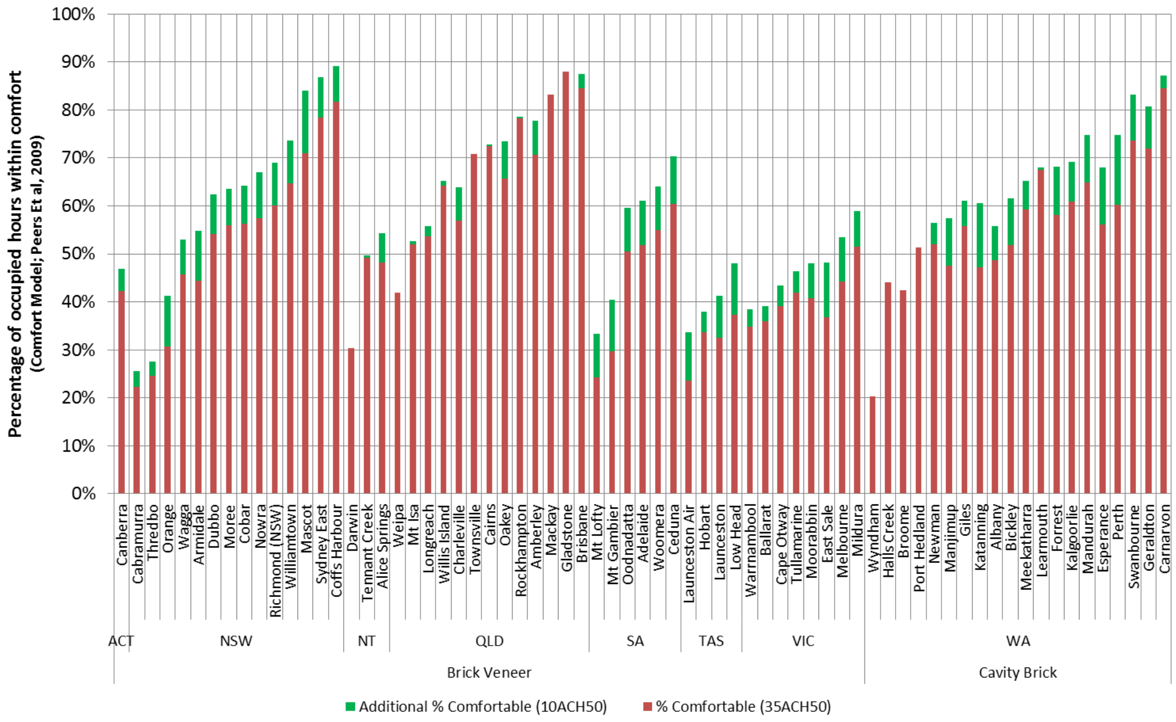


Figure 37 Natural Comfort(Free Running Mode) for typical 3 bedroom House 6 Star

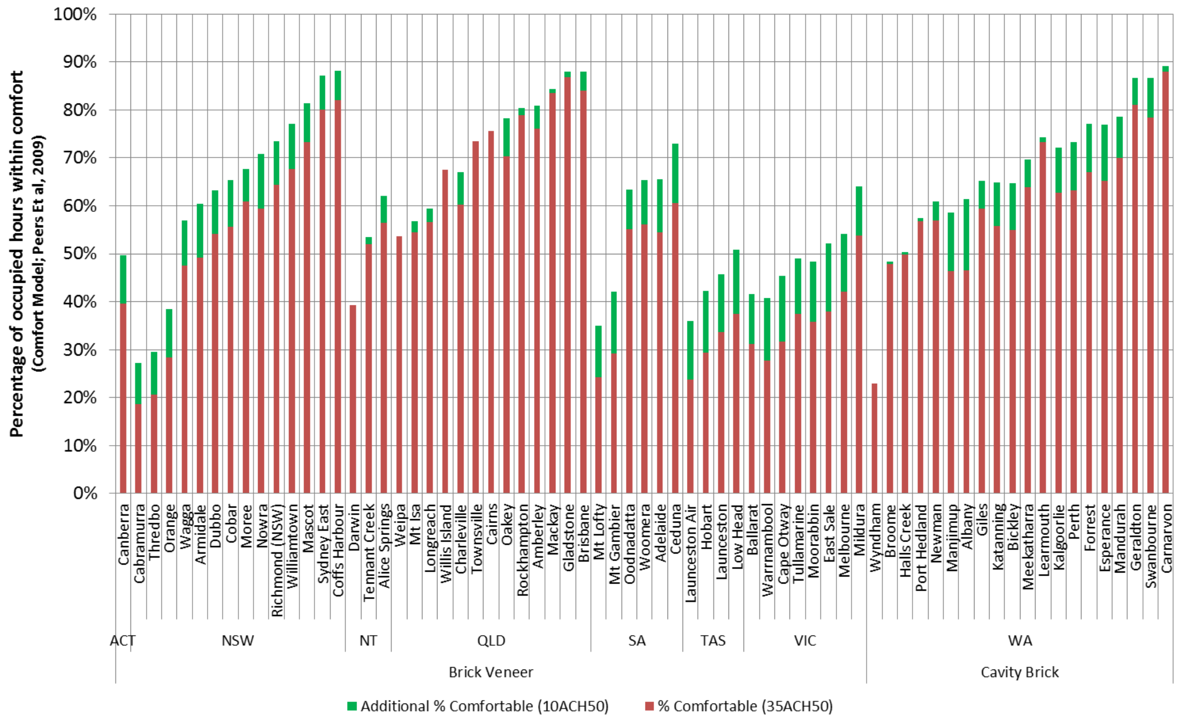


Figure 38 Natural Comfort (Free Running Mode) for The Housing Research Facility, 6 Star

In the long term implementation of code based requirements; adequate air sealing is likely to reduce the relative risk of mortality and sickness by increasing the ability of the building to naturally maintain comfort conditions.

6.2 Acoustic Performance

Sound is readily transported through air. If there are air leaks through sound barriers, the sound will shortcut through these and will not reduce as much as for a completely airtight barrier. Thus leakages will also affect the disturbance from sound leaking into the building, and good air sealing increases the indoor acoustic amenity.

The acoustic performance of wall systems is measured as a sound reduction in either R_w or may include an adaption factor (C_{tr}) for low frequency noise, which becomes $R_w + C_{tr}$. The BCA specifies acoustic rating of wall systems based on laboratory test results. When tested in laboratories it is essential that good seals around the perimeter of the test rig are maintained to limit the amount of noise bypassing the construction system and lowering the acoustic rating as shown in Figure 39. The same attention to air sealing in the field is required to achieve acoustic ratings for internal partitions between occupancies and for external to indoor noise transmission.

Figure 39 Air sealing at perimeter of acoustic laboratory test rig

Figure 40 highlights the acoustic benefits limiting the air leakage paths in construction systems (Long, 2014). A 10m² brick veneer wall with an R_w 60, and an effective leakage area of 1 cm² (0.001%) will reduce the rating to R_w 50, or with a 10cm² (0.01%) effective leakage area reduced to R_w 40 greatly limiting the benefit of the external wall system to prevent external to internal noise transmission.

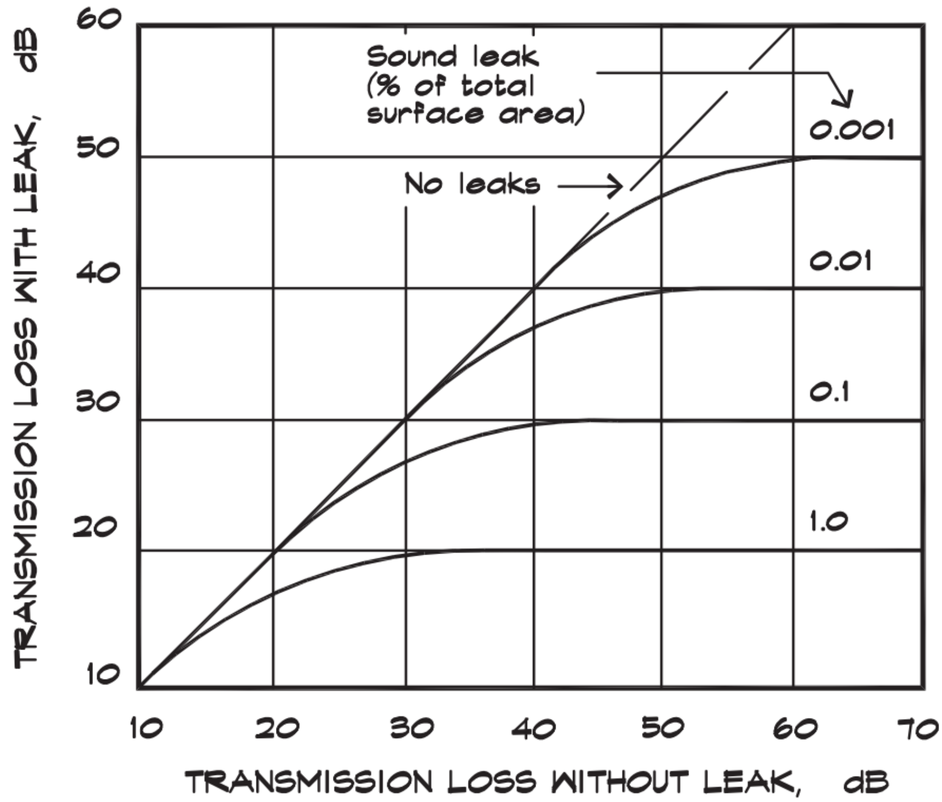


Figure 40 Composite loss of a leaky panel as a function of the total percentage of leaks

Air sealing is beneficial in restricting outdoor to indoor noise transmission and is essential to achieving adequate sound isolation between semi-detached dwellings to meet performance requirement P2.4.6, "Walls separating dwellings must provide insulation against the transmission of airborne sound sufficient to prevent illness or loss of amenity to the occupants."

Post construction fan pressurisation with diagnostic techniques such as smoke sticks; infra sound or infra-red thermography to identify air leakage paths provide a means of identifying poor or insufficient performance for sound attenuation between habitable spaces.

6.3 Moisture Management

Air pressure differential between conditioned spaces and the surroundings, as well as between building assemblies and rooms can have implications for health, safety and durability of the building enclosure. Infiltration of humid air during cooling periods is a concern as is the exfiltration of interior heated, moist air during heating periods.

Moisture related issues in buildings can be largely attributed to uncontrolled air flows. Any reduction in the transfer of moisture laden air through the envelope will reduce the amount of free moisture in insulated cavities such as stud bays. This will reduce the risk for air transported moisture causing condensation and moisture related issues such as wood rot and mould. As the ABCB suggests

> "Water vapour can form at everyday temperatures, travel freely in air and condense in parts of a building where a sustained presence of liquid water or frost might be dangerous or damaging" (ABCB, 2014),

This is also confirmed by The Building Science Corporation

> "Stopping air is the second-most-important job of a building enclosure. Next to rain, air leaks through walls, roofs, and floors can have the most damaging effect on the durability of a house. Uncontrolled airflow through the shell not only carries moisture into framing cavities, causing mould and rot, but it also can account for a huge portion of a home's energy use and can cause indoor-air-quality problems." (Straube, Energy Leaks How They Waste Energy and Rot Houses, 2012)

This highlights the benefit of mitigating uncontrolled air transport through the building envelope and containing air movement to purpose built drying cavities. Although difficult to quantify this benefit of adopting AS/NZS ISO 9972 as a reference in the BCA it provides the basis to be able to start addressing these issues by limiting air transported water vapour in the building envelope.

Figure 41 highlights the extent of latent heat (humidity) ingress into the housing research facility when modelled in all major capital cities and how this varies with the air leakage rate. Clearly the outstanding location here is Darwin in which the tropical weather has high external temperatures with high humidity. This raises particular health concerns with leaky air conditioned buildings and microbial growth.

> "Moisture is a special class of contaminant because it commonly exists in both liquid and vapour form and is a limiting factor in the growth of moulds and fungus. Poor air tightness that allows damp air to come in contact with cool surfaces is quite likely to lead to the growth of micro biologicals." (Sherman & Chan, 2004)

In Figure 41 it can be seen that latent heat loads in Darwin increase dramatically with air leakage. If the moisture laden air is transferring into the building increasing the air conditioning loads then it is transferring through the building envelope at unknown locations. This poses large risks for interstitial condensation, mould and fungus growth. This is of concern in air conditioned buildings which are likely to have cooler internal construction linings or structural framing increasing the risk of condensation on these cooler surfaces and likely to be hidden within cavities. These issues provide a widespread health concern in tropical climates.

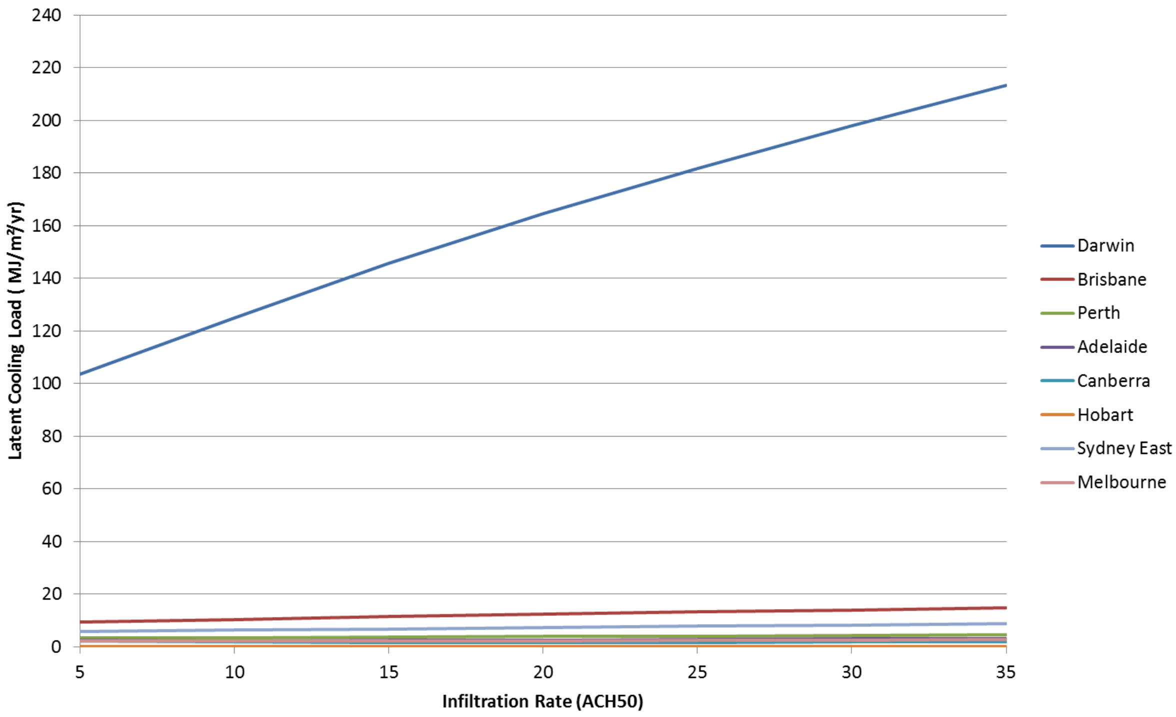


Figure 41 Latent Cooling loads vs air leakage rate, Housing Research Facility

Brisbane and Sydney also show increases in latent heat loads, however to a lesser extent. This also implies additional moisture laden air travelling through the envelope of houses in these cities increases condensation risk during the warmer more humid summer, albeit to a lesser extent and duration than Darwin.

6.4 Ventilation and Infiltration

Existing Australian homes rely on infiltration through a porous building envelope for background ventilation with operable windows to provide increased natural ventilation when needed. Natural climatic forces create differences in air pressure between the outside and inside of the building that can cause infiltration in a building. Pressure differences depend on changes in temperature and wind speed as mirrored in the infiltration model used in NatHERS tools. Wind causes a positive pressure on the windward side of the building and a negative pressure on the leeward side of the building. The resulting amount of infiltration is dependent on the placement and number of gaps and cracks in the building envelope and on wind direction and speed. Relying on infiltration as ventilation makes the air flow rate unpredictable and uncontrollable since the driving mechanism is variable over the year and the flow paths are diffused over the building envelope (Allard & Ghiaus, 2005).

This most basic fresh air supply system (infiltration) has no extra construction costs or explicit operating costs; however, there is poor control over fresh air rates when the envelope is leaky. The energy implications arise almost exclusively from the need to condition the outdoor air. The system relies on the occupants to open and close windows to provide adequate fresh air when the envelope is tight. The lack of control can result in energy loss due to high air change rates especially in winter when temperature differences and wind speeds are high (Russell, Sherman, & Rudd , 2005). Alternatively, this method may under-supply fresh air during the hot summer months. When climatic conditions are favourable, natural ventilation (through windows and doors) can be used for cooling and can replace air conditioning systems for part of the year.

The Building Code of Australia currently specifies when mechanical ventilation is required in domestic dwellings but there are no quantifiable performance requirements to ensure that the ventilation achieves its purpose. The purpose as set out in P2.4.5 is to maintain adequate air quality free of odour, micro-organisms, pathogens or toxins.

The current acceptable construction practice to meet P2.4.5 does not currently promote effective ventilation. Habitable rooms, sanitary compartments, bathrooms, shower rooms, laundries require only external operable openings of pre-determined size to allow occupants to purge contaminants (natural ventilation). Mechanical ventilation (exhaust fans) is also acceptable for sanitary compartments, laundries or bathrooms which exhaust to outside or into the roof space. The key issues with this approach are:

1. Reliance on the occupants to manage indoor contaminates by purging air from rooms
2. Mechanical exhaust fans have no performance specifications and therefore may not be correctly sized or located.

To protect health and amenity it is necessary to have a constant flow of fresh air delivered at a minimum performance flow rate. AS 1668.2 sets permissible mechanical ventilation rates having consideration to health and ventilation amenity (Standards Australia, 2012). The specified ventilation rates are intended to maintain general contaminants (e.g. body odours, volatile organic compounds and the like) at concentrations below exposures that have the potential to cause adverse health effects to a majority of occupants.

6.4.1 Ventilation Strategies

Air quality can correspond positively to ventilation and ventilation can be made more effective by having sealed envelopes to enable purposeful ventilation paths. There are four key aspects of maintaining air quality and reducing the risk of the build-up of micro-organisms, pathogens or toxins (commonly mould) in well-sealed buildings:

1. Reduce the quantity of pollutants through appropriate selection of furnishings and products (i.e. low or zero VOC products). Currently no provisions exist in the Australian building code for this.
2. Ensure source extract ventilation is always direct to the outside for bathrooms, laundries and kitchens to remove water vapour and odours at the source. The extract ventilation must have minimum performance targets for extract ventilation rates.
3. Utilise low volume continuous ventilation of rooms or spaces to dilute and flush out pollutants and water vapour that may not be removed by operation of extract ventilation in accordance with (2). Currently there are no provisions for this in the BCA but is essential for high integrity well sealed building envelopes.
4. Utilise purge ventilation, or manually controlled ventilation of rooms and spaces at a high rate to rapidly dilute pollutants and water vapour (i.e. open windows and doors on a daily basis). Currently the BCA addresses this by specifying minimum operable areas for habitable spaces in accordance with the acceptable construction practice in Vol 2 Clause 3.8.5.2.

6.4.2 Extract Ventilation

In general the best approach to manage indoor air quality is source control of pollutants and water vapour. This is the removal of the contaminant and/or moisture where they are generated. Intermittent extract ventilation as specified in AS 1668.2 can be effective in kitchen, toilets, bathroom and sanitary compartments as shown in Table 6. The UK Part F Building Regulations (HM Government, 2010) specifies minimum flow rates for kitchen exhaust required for effective removal of contaminants.

	Kitchen Extract	Laundry		Bathroom / Toilet / Sanitary Compartment
		No Dryer/Condensing Dryer	Non-Condensing Dryer	
Minimum Exhaust ventilation flow rates (L/s)	30 (adjacent hob)* 60 (elsewhere)*	20#	40#	25#
*UK Part F Ventilation Requirement # AS 1668.2 Ventilation Requirement				

Table 6 Minimum intermittent source extract ventilation rates

6.4.3 Continuous Ventilation

The “whole building” ventilation is the minimum continuous ventilation of rooms or spaces at a relatively low rate to dilute and flush out pollutants and water vapour, which otherwise not removed by operation of extract ventilation, purge ventilation or infiltration (uncontrolled air leakage through the envelope).

While doing their source removal job, local exhaust fans may also increase the overall ventilation of the building and in that sense is incidental ventilation. For example, a high capacity kitchen exhaust of 200L/s assures that the overall ventilation rate will be (temporarily) at least 200L/s which are well above international fresh air requirements. Because the duty cycle of these local exhaust fans is determined by the occupants and presumably related to a source-generating activity, one cannot count on them towards meeting minimum ventilation requirements. (Russell, Sherman, & Rudd , 2005).

AS 1668.2 recommends minimum continuous outdoor air flow rate in residential buildings which works out to be 0.35L/s/m² for larger dwellings and 10L/s/person for small dwellings.

6.4.4 Balanced Ventilation

Air change rates (ACH_{50}) as measured by Ambrose and Syme (2015) are closely linked with air quality; very well sealed buildings can lead to a build-up of contaminants if the source of the contamination is located within the home.

In very well sealed homes (below 7 ACH_{50}), supply fans and extract fans with equal flow rates will need to be incorporated to maintain adequate fresh air supply rates (Sherman M. , The

Use of Blower Door Data, 1998). This is known as a balanced ventilation system. A balanced ventilation system controls the air flows for the exhaust air and fresh air supply ensuring the relative internal air pressure is equivalent to the external air pressure.

An unbalanced system however, only provides:

a. Fresh air supply in to the building resulting in a slightly pressurised internal environment, exhaust air is expected to naturally "leak" out of the building, or
b. Exhaust stale air out of the building resulting in a slightly de-pressurised internal environment, fresh supply air is expected to naturally "leak" into the building.

An unbalanced system relies on leakage through gaps and cracks in the construction, around window frames and other leakage points. This is the currently preferred method of ventilation in Australian homes and a benchmark of 10 ACH_{50} does not restrict this practice.

In 1998 Max Sherman from the university of California published guidelines on the type of ventilation system required based on the envelope air infiltration rate (ACH_{50}). Table 7 outlines the type of ventilation supply and extract setup required to achieve effective ventilation for contaminant and moisture removal.

Leakage Class	Typical ACH_{50}	Continuous Ventilation Required	Ventilation Supply/Exhaust
A	≤1	YES	Balanced
B	≤2	YES	Balanced
C	≤3	YES	Balanced or Unbalanced
D	≤5	YES	Balanced or Unbalanced
E	≤7	YES	Unbalanced
F	≤10	OPTIONAL	Unbalanced
G	≤14	NO	Buildings in this range are too loose
H	≤20	NO	Buildings in this range are too loose
I	≤27	NO	Buildings in this range are too loose

(Sherman M. , The Use of Blower Door Data, 1998)

Table 7 Ventilation strategies required based on ACH_{50} Infiltration Measurement

6.4.5 Fresh Air and Effective Ventilation

An analysis of the US ventilation benchmarks (ASHRAE, 2010) showed that for typical indoor pollutant generation the required ventilation rate may need to be as high as 470% of the ASHRAE 62.2 benchmark level when an in-effective extract only ventilation system in a building with 7 ACH_{50} envelope is used (Rudd, Lstiburek, & Townsend, 2009). This study also showed that by the simple placement of inlet vents above windows ventilation effectiveness will be greatly enhanced.

ASHRAE requires ventilation rates based on ASHRAE 62.2 utilising the following relationship,

$$Q\ (L/s) = 0.05 * A_{floor} + 3.5\ (N+1)$$

Where:

- A_{floor} is floor area in m²
- N is number of bedrooms

Comparatively, the Australian Standard 1668.2-2012 "The use of ventilation and air conditioning in buildings" recommends minimum outdoor air flow rate in buildings. For residential buildings, the minimum amount of introduced outdoor air should be the greater value of area-based minimum and the occupancy based minimum, which are:

a. Area based minimum,

$$q_{min} = 0.35 \times A$$

Where:

- q_{min} is minimum ventilation rate (in L/s)
- A is floor area

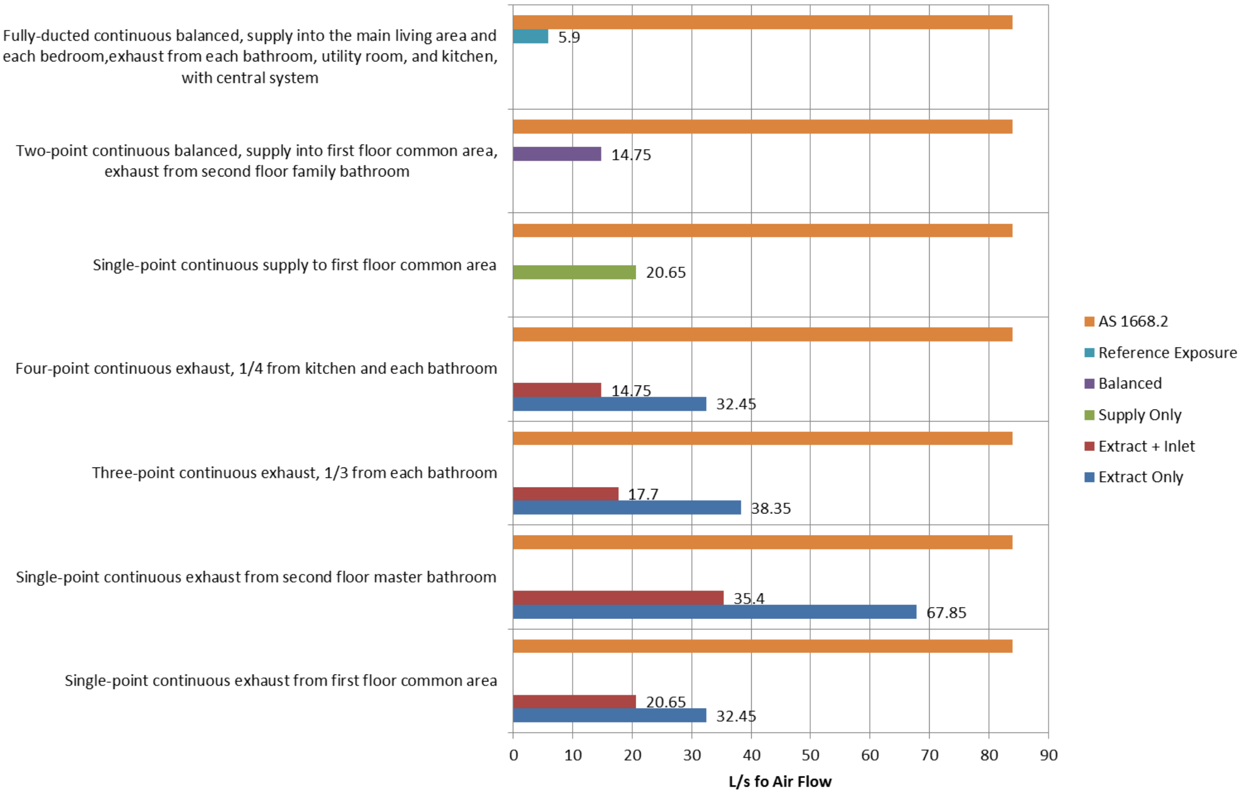
b. Occupancy based minimum:

$$q_{min} = 10 \times N$$

Where:

- q_{min} is minimum ventilation rate (in L/s)
- N is number of people in the space

Interestingly when compared to the requirements under ASHRAE the requirement in AS 1668.2 yields much higher air flow rates, in addition the way the air is supplied and the effectiveness of the air exchange may affect the amount of air required to achieve the same indoor air quality objectives (Rudd, Lstiburek, & Townsend, 2009). Figure 42 shows the relative air volume rate to achieve suitable air quality in a 4 bedroom 240m² house as studied by Rudd et al. in 2009 (See Appendix F). The AS 1668.2 volumetric air requirement for the same house has been overlayed in Figure 42. Under the contaminant scenario shown (50% from building, 50% from occupants) the AS 1668.2 requirement is more than enough even in the least effective case utilising a single extract fan from the master bathroom to attain an equivalent level of air quality as a fully ducted, balanced ventilation system. This implies that the Australian standard is more than sufficient to allow adequate fresh air rates in Australian homes utilising standard extract fans in bathrooms and/or laundries as long as a continuous flow rate is maintained in accordance with AS 1668.2.



Notes:

1. *Reference Exposure: A fully-ducted continuous balanced, supply into the main living area and each bedroom with exhaust from each bathroom, utility room, and kitchen utilising a central HVAC system*
2. *Zones emit 1/2 of total contaminants weighted by zone volume, occupants emit 1/2 of total contaminants in the zone that they occupy according to their daily schedule; occupants are exposed according to their daily schedule; consider the occupant with the highest yearly exposure*

Figure 42 Fresh air rates under ventilation scenarios for equivalent air quality (@ 7ACH$_{50}$)

Suppling fresh air is aimed at addressing an air quality issue. On the other hand it is important to understand how supplying outdoor air can affect the energy use in a home. If a direct axial fan system is used to deliver a volume of outdoor air then there will be energy implications for both heating and cooling the home.

Figure 43 and Figure 44 show the resulting star rating when a 7 ACH$_{50}$ (Leakage class E, from Table 7) single storey 3 bed house and double storey 3 bed Housing Research Facility is fitted with a continuous fresh air supply direct from outside delivering either AS 1668.2 or ASHRAE 62.2 recommended flow rates. Each data point represents the average of brick veneer, cavity brick and lightweight clad scenarios. Some of the more sensitive climates with high external humidity above 20°South; Broome, Weipa and Darwin show significant star rating penalties when introducing direct fresh air supply.

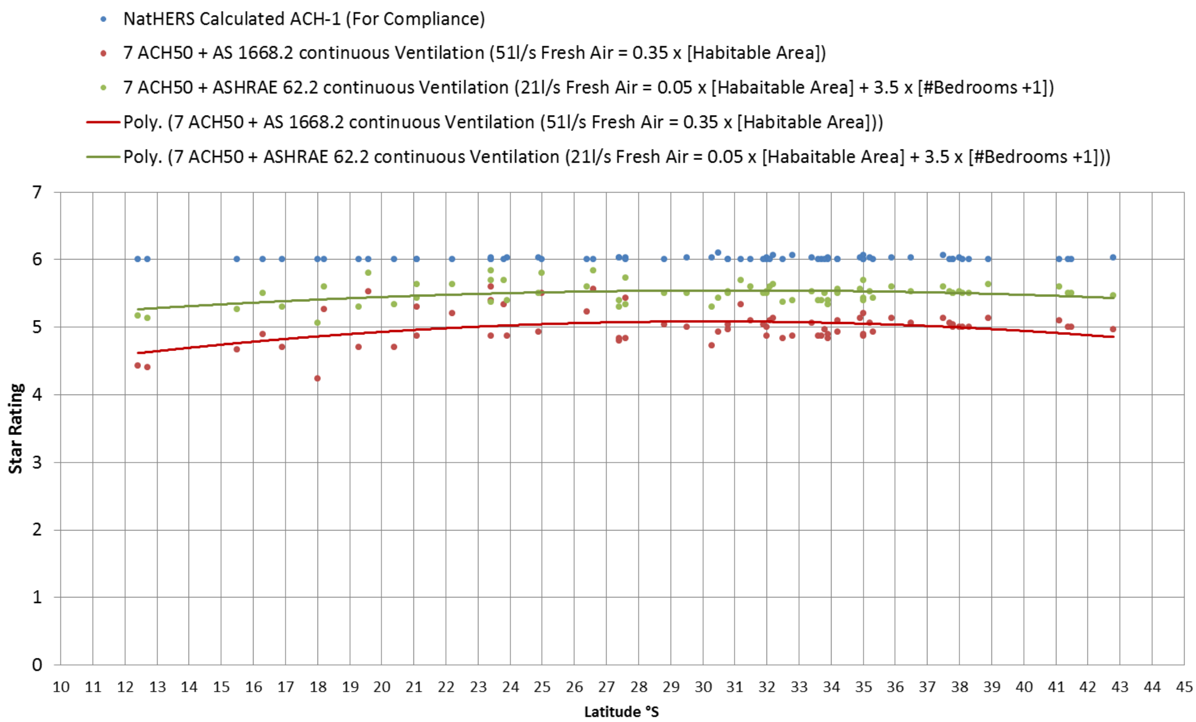


Figure 43 Star rating versus fresh air rates single storey house (@ 7ACH$_{50}$ Envelope)

The double storey Housing Research Facility shows a significantly lesser energy penalty under ASHRAE required fresh air volumes (Figure 44) as it has a larger habitable volume for the same number of bedrooms compared to the smaller footprint house. This means that the occupancy is the same as the smaller reference house and it results in less volume of outside air per cubic meter of habitable volume being delivered resulting in an overall lesser energy penalty. The AS 1668.2 required flow rate also has a lesser energy penalty; this is likely due to the taller ceilings in The Housing Research Facility at 2.7m which creates a larger habitable volume such that the supply air based on square meter has less adverse effect.

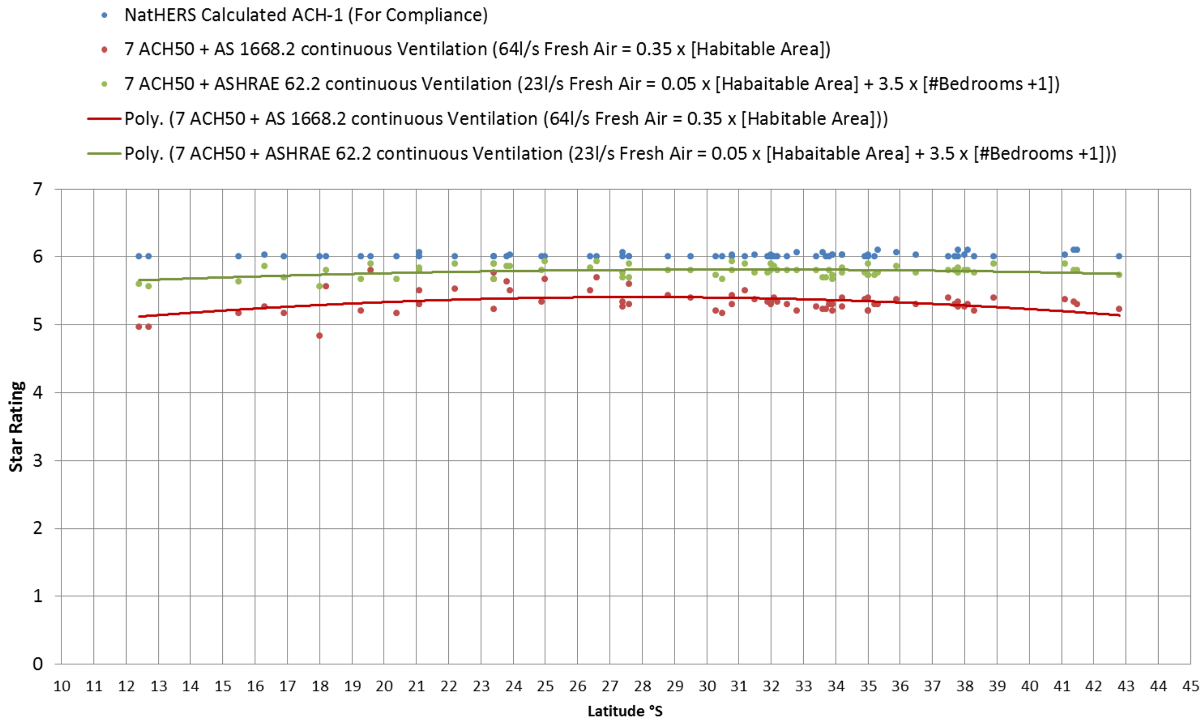


Figure 44 Star rting versus fresh air rates housing research facility (@ 7ACH$_{50}$ Envelope)

Averaging the star rating penalty of all NatHERS climate zones within each BCA climate zone and averaged between the two reference house types the results in a star variation under varying fresh air supply rates are presented in Figure 45. It is recommended further investigation into managing moisture in BCA zone 1 (tropical climates) needs to be undertaken before implementing ventilation requirements in BCA zone 1.

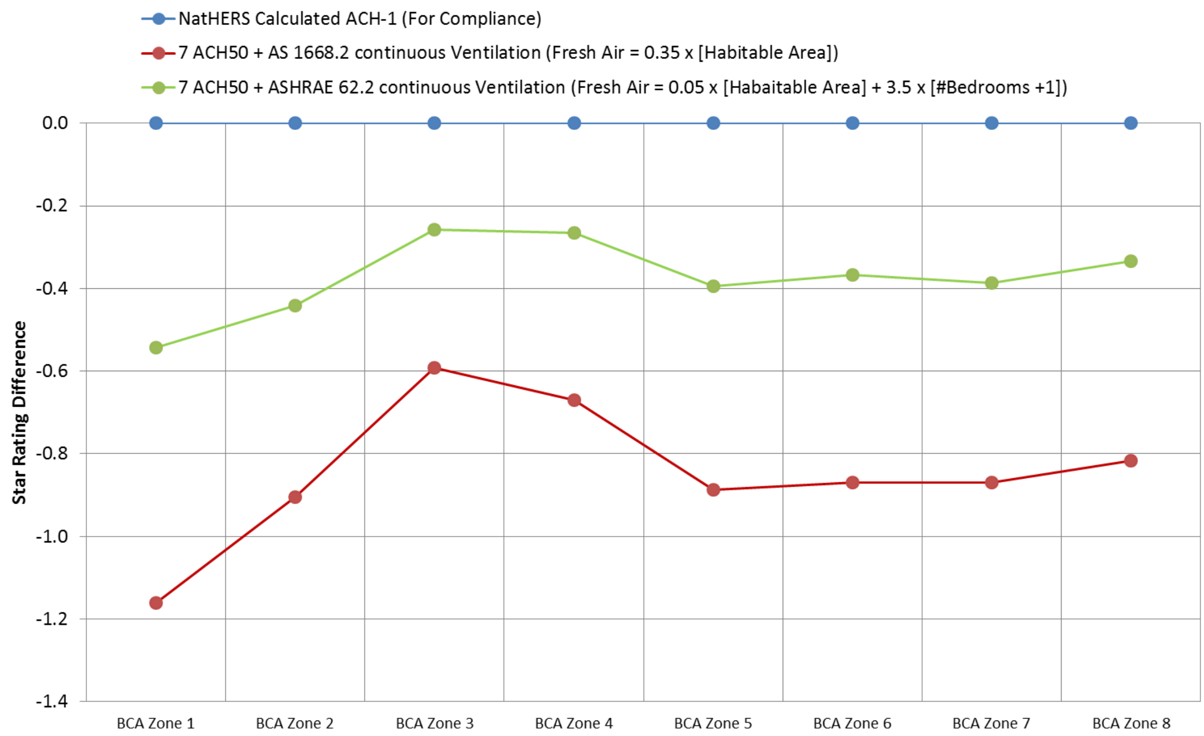


Figure 45 Loss of rating performance Vs fresh air rate, averaged into BCA climate zones

6.5 Limiting Health and Amenity Risks

In 2004 a study commissioned by the Natural Heritage Trust into the effects of gas heating concluded:

> *"When un-flued gas heaters are operating, indoor air generally exhibits substantially higher levels of nitrogen dioxide, carbon dioxide and carbon monoxide than the highest concentrations measured in ambient air in Australia. The measured average peak 1 hour nitrogen dioxide levels were over 10 times higher than the equivalent measured outdoor values. These levels, especially for nitrogen dioxide, were often significantly above health based indoor air quality criteria."* (AWN Consultants and Team Ferrari, 2004).

This health concern is currently covered by BCA clause 3.12.3 (b)(ii) which states that building sealing is not required for "A permanent building ventilation opening that is necessary for the safe operation of a gas appliance," however this conflicts with performance requirement 2.6.1 to facilitate the efficient use of energy.

AS/NZS 5601 currently prohibits the installation of gas hose fittings for non-flued gas heaters in bedrooms, bathrooms, saunas, toilets, hallways and garages. However it does not restrict the use from habitable living spaces, dining spaces and kitchens. AS/NZS 5601 will need to be addressed in the building code and Plumbing code (Clause E1.2) in conjunction with AS/NZS ISO 9972 performance benchmarks incorporated into the BCA.

State requirements that currently conflict with P2.6.1 to facilitate the efficient use of energy can be found in AS/NZS 5601 as referenced in the Plumbing Code of Australia as follows:

Energy Safety Division of the Department of Commerce, Western Australia

> *"Where a quick-connect device socket is installed indoors, for the future connection of a flueless space heater, the room is required to have two permanent ventilation openings direct to outside. The openings are required to be provided at high and low levels, with a minimum vertical separation of 1.5 m. Each opening is required to have an aggregated minimum free area of 25,000 mm^2." (AS/NZS 5601.1)*

Office of the Technical Regulator, South Australia

> *"Two permanent ventilation openings are required to be provided directly to outside, one at a high level and one at a low level, each having a minimum free area of 1,000*

mm^2 per MJ/h. Where a quick connect device socket is installed for the future connection of a flueless heater and the capacity is unknown, the room is required to have two ventilation openings installed, one at high level and one at low level. Each opening is required to have a minimum free area of 25,000 mm^2." (AS/NZS 5601.1)

It is recommended that the building code is updated to ensure all new buildings in Australia should meet the intent of **Energy Safe Victoria** requirements as outlined in AS/NZS 5601.1 and be adopted within the building code:

> *"A person cannot install any flueless space heater as a new installation in residential premises (including a caravan or boat). A person is required not to install or locate for use a connection device (quick connect, bayonet connection) for a flueless space heater in residential premises including a caravan or boat."*
>
> *However a person is permitted to replace an existing flueless space heater with a new flueless space heater if the new flueless heater meets the following requirements:*
>
> *(a) The heater being replaced operated on LP Gas; and*
>
> *(b) The new heater operates on LP Gas; and*
>
> *(c) The emission of oxides of nitrogen from the new heater does not exceed 2.5 ng/J; and*
>
> *(d) The carbon monoxide/carbon dioxide ratio of the new heater does not exceed 0.002.*

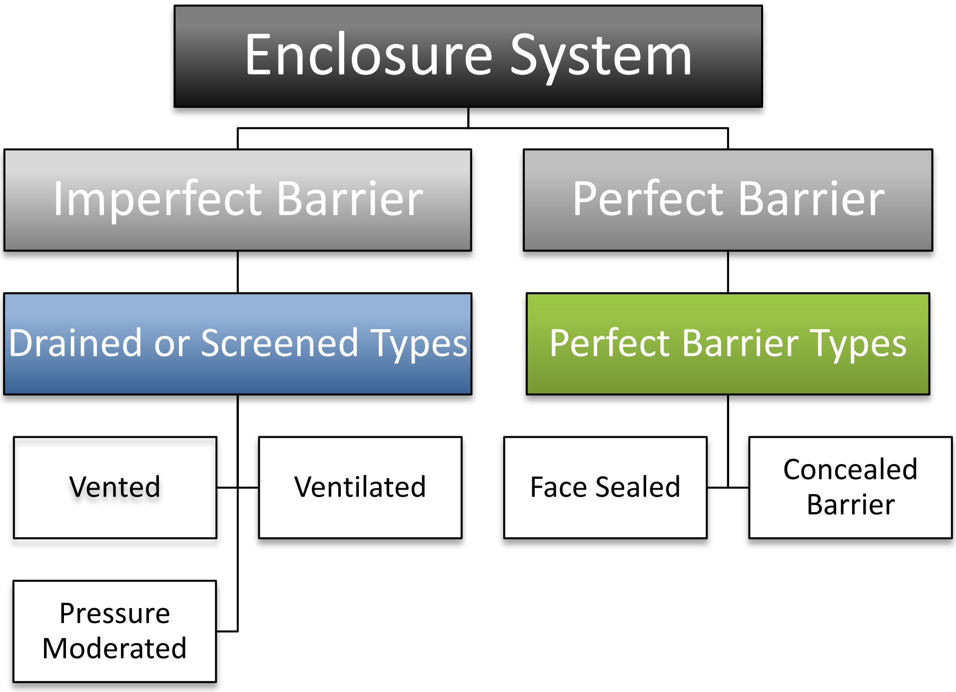
6.6 Weather-Proofing

Controlling air leaks in wall systems is critical to achieving weather-proofing in accordance with BCA. The Building Research Association of New Zealand (BRANZ) identified through many years of research that:

> *"Wind acting on a building creates a pressure difference between the higher pressure outside and the lower pressure inside. The design of a wall system must incorporate an undamaged barrier to resist these wind pressures and to avoid any air leakage paths to the interior of the building. If an air leakage path exists, water can be carried along it into the wall assembly. If not provided with effective air seals, any gaps, joints and junctions in the wall cladding can become air leakage paths that can carry water when present."* (BRANZ, 2010)

This effect is apparent in the BCA verification method V2.2.1 Weatherproofing. This verification method utilises AS/NZS 4284 Testing of Building Facades (Standards Australia, 2008) as the basis of the verification in which a cyclic pressure is applied to the wall system to induce water leaks due to isolated air flow paths in the walling system. The integrity of the air seals in the water-proof layer will provide ultimate determination of a pass or fail result.

The fundamental scientific approaches to achieving a weather-proof system (Straube, 2010) is described in figure 46 below.



Notes: Classification is made on actual behaviour, not necessarily design intent. For the purpose of this classification system, the following definitions are necessary:

1. *Drained: the large majority of the water that penetrates the screen is removed by gravity.*
2. *Cavity: a clear space or a filled space that facilitates gravity drainage and air flow and resists the lateral transfer of water (a capillary break)*
3. *Ventilated: allows some degree of water vapour diffusion through vent and redistribution within the cavity by air mixing and vapour diffusion.*
4. *Pressure-moderated: an approach that moderates air pressure differences across the screen. If perfect moderation is achieved, a theoretical condition, it is termed “pressure equalised”*

Figure 46 Enclosure system types (Straube, 2010) for compliance with BCA V2.2.1

Testing undertaken for both drained screen type cladding systems and perfect barrier systems was carried out at CSIRO testing facilities in 2015 as shown in Figure 47 and 48. The testing for compliance in accordance with BCA V2.2.1 and AS/NZS 4284 validated the concept as published by BRANZ (BRANZ, 2010) that an effectively sealed air barrier is the basis of weather-proofing.

All system types require an airtight water barrier; the only difference is the location of the air barrier within the system and the material which constitutes the air barrier. The correlation between air control and weatherproofing as identified by BRANZ means that air tight envelopes actually deliver superior rain control. AS/NZS ISO 9972 provides a basis to verify the holistic level of integrity which incorporates this enhanced rain control function.

Perfect barrier type systems require air seals in the water-proof external surface and window junctions as shown in figure 47. If an air leakage path exists, water can be carried along it into the wall assembly.

Figure 47 Masonry veneer face sealed system under test (air sealed cladding)

Drained or screen type systems require air sealing at the water barrier sarking membrane with careful integration into window and door reveals using appropriate flashings as shown in figure 48. If an air leakage path through the sarking membrane exists, water can be carried along it into the wall assembly. Research undertaken by a leading product manufacturer has shown properly taped and sealed sarking can reduce air leakage by 82% (Appendix C) which will in turn increase overall weather tightness in drained and screen type systems.

Figure 48 Weatherboard pressure moderated system under test (air sealed membrane)

Performance based requirements for air leakage utilising AS/NZS ISO 9972 will allow for holistic validation of the enclosure integrity and provide some security that air sealing for weatherisation has been undertaken to a reasonable degree.

7 FIRE SAFETY

Sealing of constructions also improves fire safety. Fire Rating Levels (FRL) are specified by the building code and measured in accordance with AS 1530.4. Unsealed paths through the building component can deteriorate its performance in terms of the structural adequacy rating, integrity rating and insulation rating in the event of a fire as well as allowing hot gases and fumes to migrate between compartments. Adequate sealing at ceiling, wall and floor junctions is necessary in fire rated walls to achieve performance as well as fire rated sealants around penetrations through fire rated construction systems. Figure 49 shows the laboratory testing procedure incorporating seals around a pipe penetration required to achieve the Fire Rating Level (FRL).

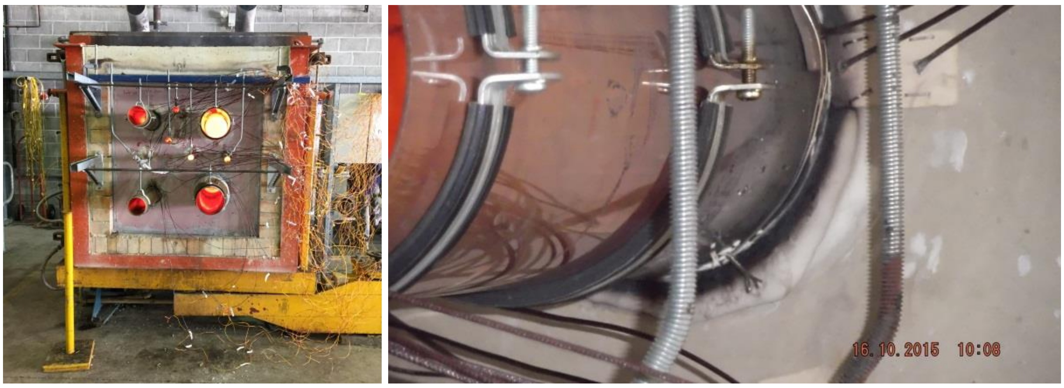


Figure 49 Fire Rated Wall with pipe pentration under Test

Integrity failure occurs in a fire test when a structural element develops spaces or openings through which hot flames or gases can pass; air leakage paths can expedite this process. Ultimately early failure in the integrity will result and a speedier decline to structural failure and collapse of the system under load. Good air sealing allows the laboratory tested FRL values for constructions to be better implemented in practice and to some extent pressurisation testing can act as an indicator for a fire safe building.

Diagnostic tools are commonly used when fan pressurisation testing is carried out to allow for the air leakage paths to be identified. These tools may consist of smoke sticks, thermography or ultrasound devices to locate non-sealed gaps in the construction. The use of these tools for locating and rectifying gaps for energy efficiency purposes also increases the likelihood of identifying fire rated construction systems which may be undermined by poor air sealing. Figure 50 shows the fire rated method of installing cabling and pipe penetrations in walls as per AS 1530.4 laboratory testing. Figure 51 shows non-compliant installations of penetrations in fire rated walls in a class 2 development. Poor air leakage test results and/or air leakage path detection techniques in any building type can allow for enhanced identification of non-visible fire integrity issues.

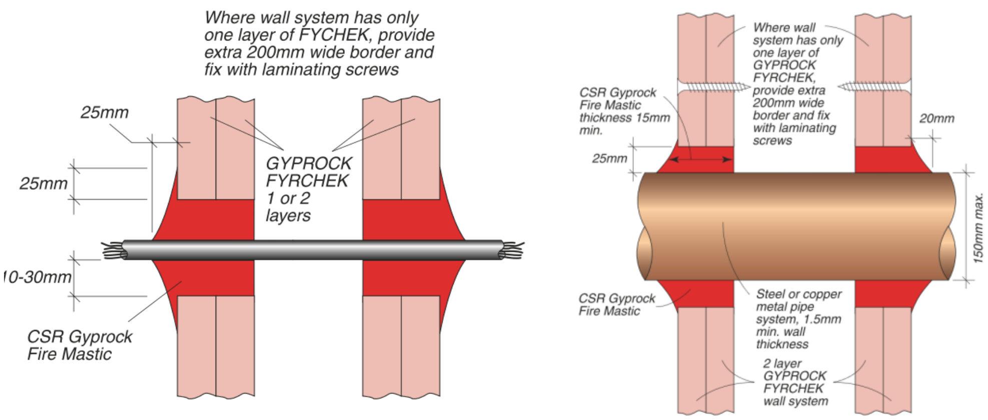


Figure 50 Fire rated cabling (-/120/60) and pipe (-/120/-) sealing

Figure 51 Non-sealed cable and pipe pentration in fire rated wall (BCA Logic, 2015)

8 PEAK LOAD REDUCTION

Peak load on the electricity grid is a growing concern in many parts of Australia. Investigations into the relationship between the peak load of the heating and cooling systems and air sealing show that heating and cooling peak load will reduce. Depending on the climate peak heating load can be reduced by 21-32% in capital cities (Table 8) for the single storey house and 24-26% (Table 11) for the double storey Housing Research Facility when a leaky home ($35ACH_{50}$) is sealed to a “fair” level ($10\ ACH_{50}$). In summer the sensible cooling peak load was estimated to reduce by 7-22% in capital cities (Table 9) for the single storey and 9-16% (Table 12) for the double storey Housing Research Facility when adequate air sealing is implemented. It should be noted that Brisbane shows a slight increase in the sensible cooling load of 6% in The Housing Research Facility model however this is offset by larger gains in the latent cooling load reduction.

Peak latent cooling load reduction due to air sealing is largely due to the prevention of infiltration of humid air. In warmer tropical climates this has the largest effect. Latent cooling peak load was estimated to reduce by 1-43% in capital cities (Table 10) for the single storey and 8-37% (Table 13) for the double storey Housing Research Facility when adequate air sealing is implemented.

Figure 52 – 57 show the peak heating, peak sensible cooling and peak latent cooling plotted for 69 climates based on heating degree days (HDD, 18°C) Cooling Degree Days (CCD, 24°C) including data points for three construction types; brick veneer, cavity brick and lightweight for each single storey and double storey reference house. It is clear that in cooler climates with increased HDD there is significantly more benefit to the peak heating load when houses are well sealed when compared to cooling peak load Vs CDD relationship. The data suggests the benefit of air sealing is more beneficial to peak heating load in general than compared to peak cooling loads.

Reducing air infiltration also reduces the likelihood that houses will fail to maintain acceptable temperature in extreme heat and extreme cold weather, due to either grid failure or limited capacity of installed heating and cooling systems. This improves public safety in these extreme weather events as discussed in section 6.1.

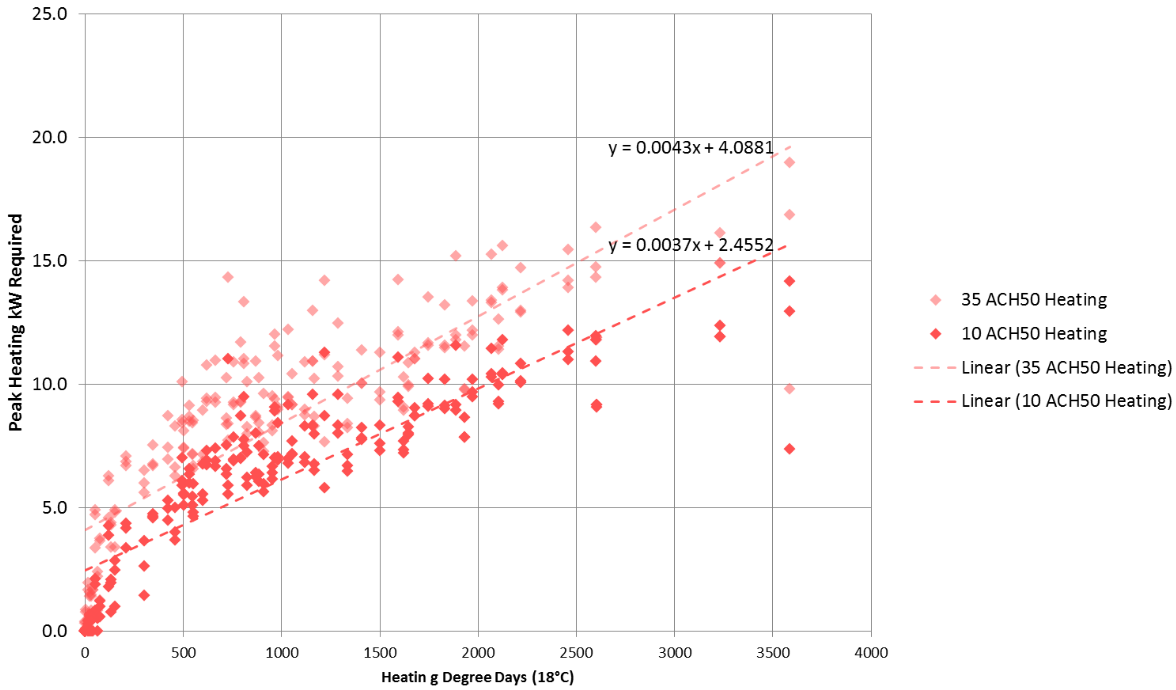


Figure 52 Single storey house peak heating load Vs HDD, 10 ACH_{50} Vs 35ACH_{50}

Figure 52 shows a clear distinction between the peak heating loads of a leaky 35ACH_{50} single storey 3 bed house compared to being properly sealed at 10 ACH_{50}. The cooler the climate gets the greater the benefit to the total reduction in heating peak load. This means that the trend is for the benefit to be roughly similar across all climate zones in the vicinity of 25% reduction. As a percentage load reduction the number in the warmer climate of Brisbane may look impressive (Table 8) but the overall benefit to grid load reduction will not be as great due to the lower baseline energy required at 35ACH_{50}.

	HDD (18°C)	kW Heating @ 35 ACH_{50}	kW Heating @ 10 ACH_{50}	Peak Load Reduction
Brisbane	346	6.7	4.6	32%
Perth	759	9.2	6.9	25%
Richmond (West Sydney)	1036	12.2	9.2	25%
Adelaide	1055	9.2	7.2	22%
Tullamarine (Melbourne)	1746	11.7	9.2	21%
Hobart	2071	13.3	10.3	23%
Canberra	2128	13.9	10.5	25%

Table 8 Single storey house peak heating load reduction in capital cities

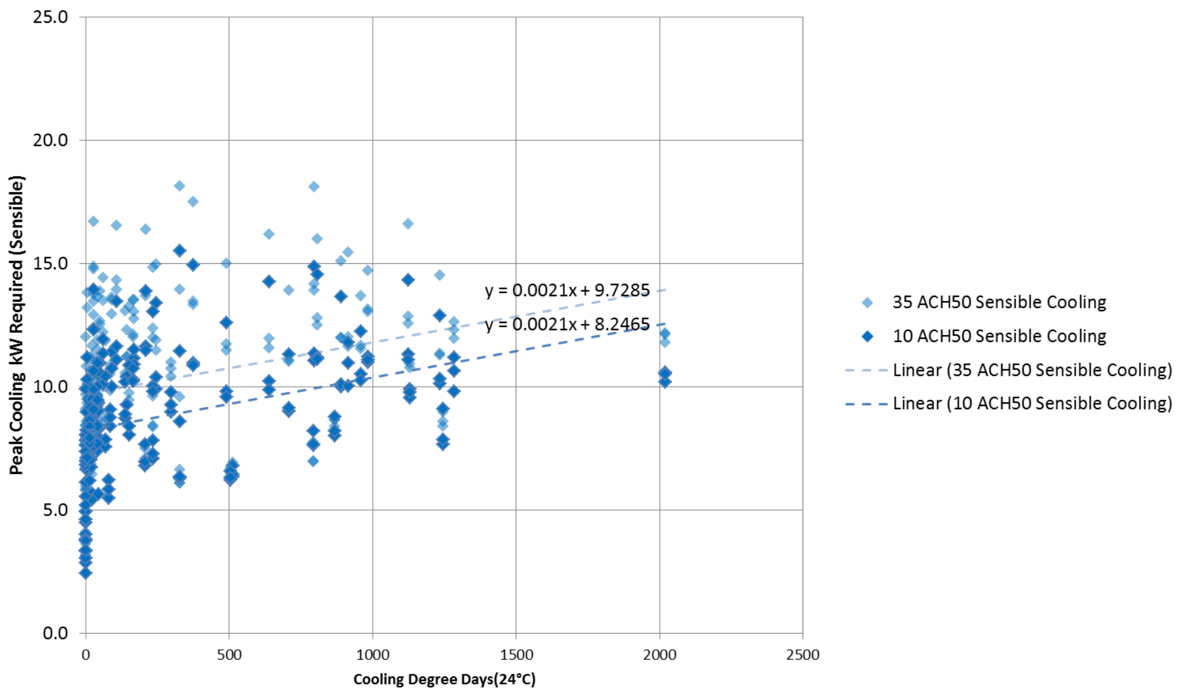


Figure 53 Single storey house peak sensible cooling load Vs CDD, 10 ACH$_{50}$ Vs 35ACH$_{50}$

Figure 53 shows a clear distinction between the peak sensible cooling loads of a leaky 35ACH$_{50}$ single storey 3 bed house compared to being properly sealed at 10 ACH$_{50}$. As expected for Australia, the chart indicates that all climates have some sensible cooling load requirement and that there is a notable benefit across all climate types. The difference between the trend lines indicate an expectation for 1.5kW less peak load across all climate types when a house is well sealed compared to leaky.

	CDD (24°C)	kW Cooling @ 35 ACH$_{50}$	kW Cooling @ 10 ACH$_{50}$	Peak Load Reduction
Adelaide	210	13.8	11.6	16%
Perth	138	10.5	8.9	16%
Brisbane	80	5.9	5.5	7%
Richmond (West Sydney)	61	13.5	11.4	16%
Tullamarine (Melbourne)	18	10.2	8.7	15%
Canberra	7	13.2	10.3	22%
Hobart	1	9.1	7.4	19%

Table 9 Single storey house peak sensible cooling load reduction in capital cities

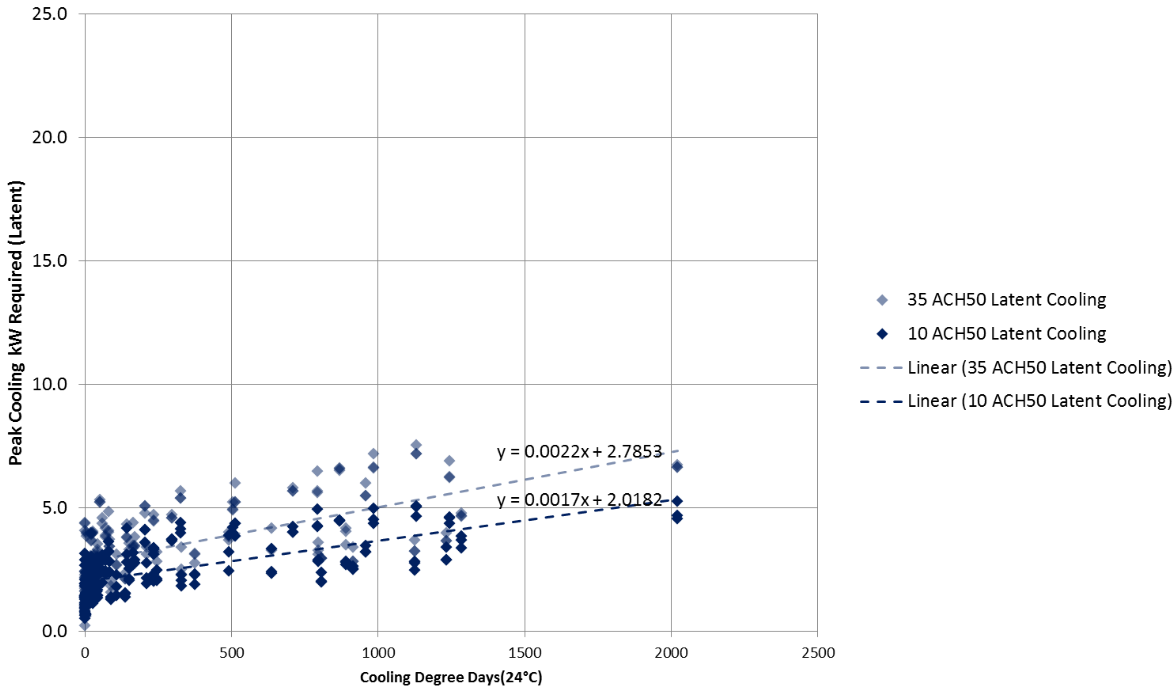


Figure 54 Single storey house peak latent cooling load Vs CDD, 10 ACH_{50} Vs 35ACH_{50}

Albeit a much smaller portion of the overall load, latent cooling peak loads benefit from better air sealing. Figure 54 shows a clear distinction between the peak latent cooling loads of a leaky 35ACH_{50} single storey 3 bed house compared to properly seal at 10 ACH_{50}. The difference between the trend lines indicate in warmer climates (tropical) there may be as much as 2.5kW less peak load across all climate types when a house is well sealed. The drier climates like Perth may yield a large overall percentage reduction in peak latent cooling but this arises from having a small latent cooling requirement due to low humidity climate.

	CDD (24°C)	kW Cooling @ 35 ACH_{50}	kW Cooling @ 10 ACH_{50}	Peak Load Reduction
Adelaide	210	3.4	1.9	43%
Perth	138	2.1	1.5	29%
Brisbane	80	4.1	3.2	20%
Richmond (West Sydney)	61	4.6	3.0	34%
Tullamarine (Melbourne)	18	2.1	1.6	25%
Canberra	7	1.8	1.4	20%
Hobart	1	0.9	0.9	1%

Table 10 Single storey house peak latent cooling load reduction in capital cities

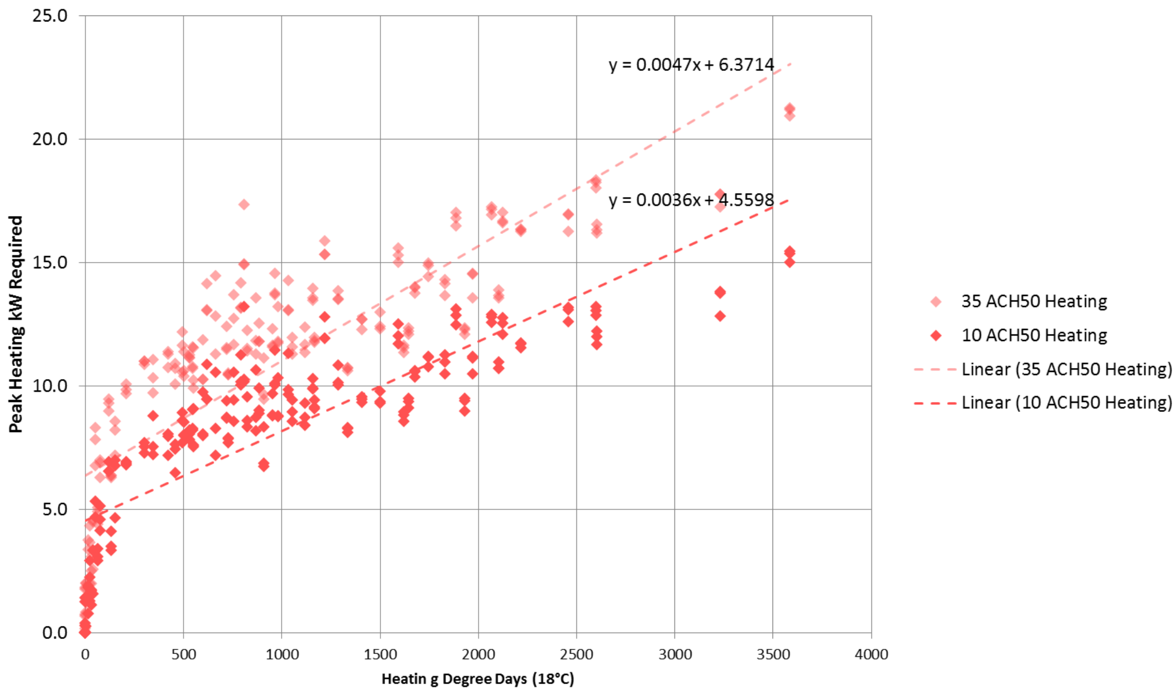


Figure 55 The Housing Research Facility peak heating load Vs HDD, 10 ACH_{50} Vs $35ACH_{50}$

Figure 55 shows a clear distinction between the peak heating loads of the leaky $35ACH_{50}$ double storey, 3 bedroom Housing Research Facility compared to being properly sealed to 10 ACH_{50}. The cooler the climate gets the greater the benefit to the total reduction in heating peak load. As the climate gets cooler the peak load benefit increases maintaining a more constant percentage benefit across all climates in the range of 24-26%. Significant overall reduction in peak load can be as much as 5kW for this house in cooler climates with 2500 HDD or more.

	HDD (18°C)	kW Heating @ 35 ACH_{50}	kW Heating @ 10 ACH_{50}	Peak Load Reduction
Brisbane	346	9.7	7.2	26%
Perth	759	12.7	9.4	26%
Richmond (West Sydney)	1036	13.1	9.7	26%
Adelaide	1055	11.3	8.5	24%
Tullamarine (Melbourne)	1746	15.0	11.2	25%
Hobart	2071	17.1	12.8	25%
Canberra	2128	16.7	12.5	25%

Table 11 Housing Research Facility peak heating load reduction in capital cities

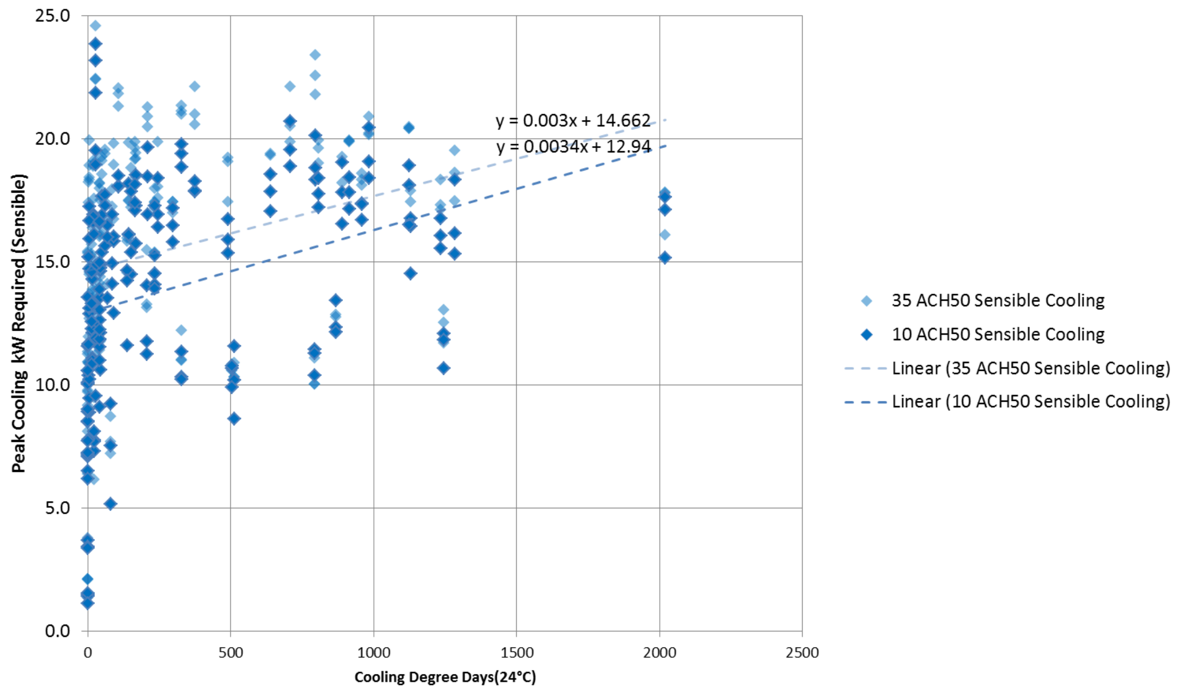


Figure 56 Housing Research Facility peak sensible cooling load Vs CDD, 10 ACH_{50} Vs 35ACH_{50}

Figure 56 shows a clear distinction between the peak sensible cooling loads of the leaky 35ACH_{50} double storey, 3 bedroom Housing Research Facility compared to being properly sealed at 10 ACH_{50}. As expected for Australia, the chart indicates that all climates have some sensible cooling load requirement and that there is a notable benefit across all climate types. The difference between the trend lines indicate an expectation for 1.7kW less peak load across all climate types when a house is well sealed compared to leaky. The percentage load reduction is then is primarily dependent on the baseline 35ACH_{50} sensible cooling peak load.

	CDD (24°C)	kW Cooling @ 35 ACH_{50}	kW Cooling @ 10 ACH_{50}	Peak Load Reduction
Adelaide	210	20.5	18.5	10%
Perth	138	15.8	14.2	10%
Brisbane	80	8.7	9.2	-6%
Richmond (West Sydney)	61	19.4	17.7	9%
Tullamarine (Melbourne)	18	16.4	14.3	13%
Canberra	7	18.9	15.9	16%
Hobart	1	15.4	13.6	12%

Table 12 Housing Research Facility peak sensible cooling load reduction in capital cities

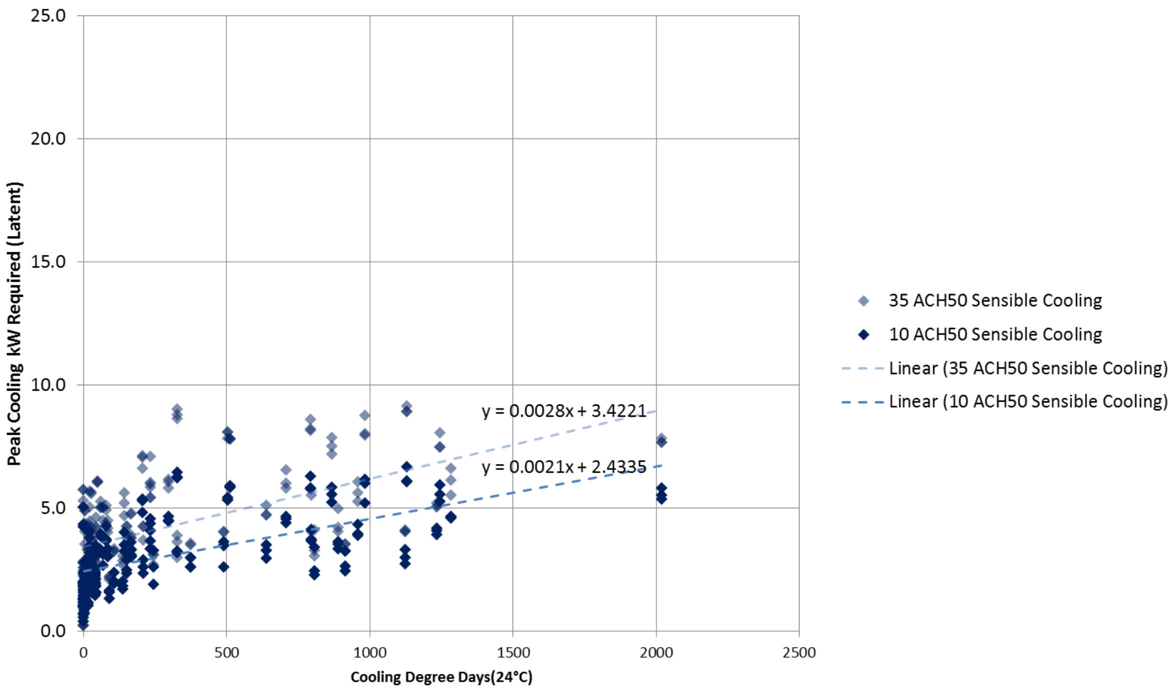


Figure 57 Housing Research Facility peak latent cooling load Vs CDD, 10 ACH_{50} Vs 35ACH_{50}

Albeit a much smaller portion of the overall load latent cooling peak loads benefit from better air sealing. Figure 57 shows a clear distinction between the peak latent cooling loads of a leaky 35ACH_{50} single storey 3 bed house compared to being properly sealed to 10 ACH_{50}. The difference between the trend lines indicate in warmer climates (tropical) there may be as much as 3.0kW less peak load across all climate types when a house is well sealed. The drier climates like Perth and Canberra may yield a large overall percentage reduction in peak latent cooling but this arises from having a small latent cooling requirement due to low humidity climate.

	CDD (24°C)	kW Cooling @ 35 ACH_{50}	kW Cooling @ 10 ACH_{50}	Peak Load Reduction
Adelaide	210	3.7	2.9	22%
Perth	138	2.9	2.0	29%
Brisbane	80	5.1	3.7	27%
Richmond (West Sydney)	61	5.3	3.3	37%
Tullamarine (Melbourne)	18	2.5	2.0	17%
Canberra	7	2.3	1.6	29%
Hobart	1	1.3	1.2	8%

Table 13 The Housing Research Facility peak latent cooling load reduction in capital cities

The correlation between air leakage and peak energy load for heating, sensible cooling and latent cooling shows that in general there is a reduction of peak load in winter and summer for all Australian climate zones. Specific climatic factors such as diurnal temperature swing and construction factors such as building type will affect the overall outcome. The calculations indicate that in a 6 star rated NatHERS house in any climate zone peak heating load may be reduced by 21 – 32%, peak sensible cooling by 7 – 22% and peak latent cooling by 1-43% depending on the external humidity. In specific cases such as double storey buildings (in Brisbane) which suffer from hot air trapped at the upper level may result in increased cooling on the upper level, in the particular case of The Housing Research Facility this is outweighed by reduction in latent peak load reduction.

9 IMPACTS

9.1 Social and Community Impact

The consumer federation supported the adoption of this AS/NZS ISO 9972 standard to enable consumers to be given further information about the effectiveness of the long term operation of their homes and associated financial benefits. It will lead to better home performance in extreme weather events and reduce the likelihood of the elderly or frail from suffering undue heat related illness and stress, improve fire safety and health and amenity within homes.

A home is often the biggest financial purchase many people will make. Having a standardised post construction compliance test for air sealing of a home allows build quality testing to be performed for homes in which they are looking to purchase. This provides certainty that they are purchasing at least the minimum requirements for construction integrity. The intangible benefits associated with increased comfort and well-being is synonymous with the energy savings.

Air sealing any building is essential for obtaining reliable outcomes for improved health, amenity and energy performance along with preventing misleading claims made by developers or builders in regards to energy savings or comfort, both of which can be both severely undermined and highly variable due to uncontrolled air transfer.

9.2 Carbon Reduction Impact

Air sealing is aimed at improving compliance with the energy provisions and closing the gap between claimed energy performance and real energy performance. The performance based verification of compliance with P2.6.1 with an emphasis on as-built performance will achieve the calculated energy demand equivalent to 6 star NatHERS rated designs in new housing stock leading to long term carbon savings. Figure 58 shows the yearly carbon emission savings by state if all houses approved in 2015 were to comply with a 10 ACH_{50} performance benchmark. A performance based fan pressurisation target of 10 ACH_{50} has potential to mitigate an estimated 33360 Tonnes of CO_2 savings per year.

All calculations were based on the 2014 national greenhouse factors (Department of Environment, 2014) where the metropolitan gas emission rate was used for gas heating appliances as per table 14.

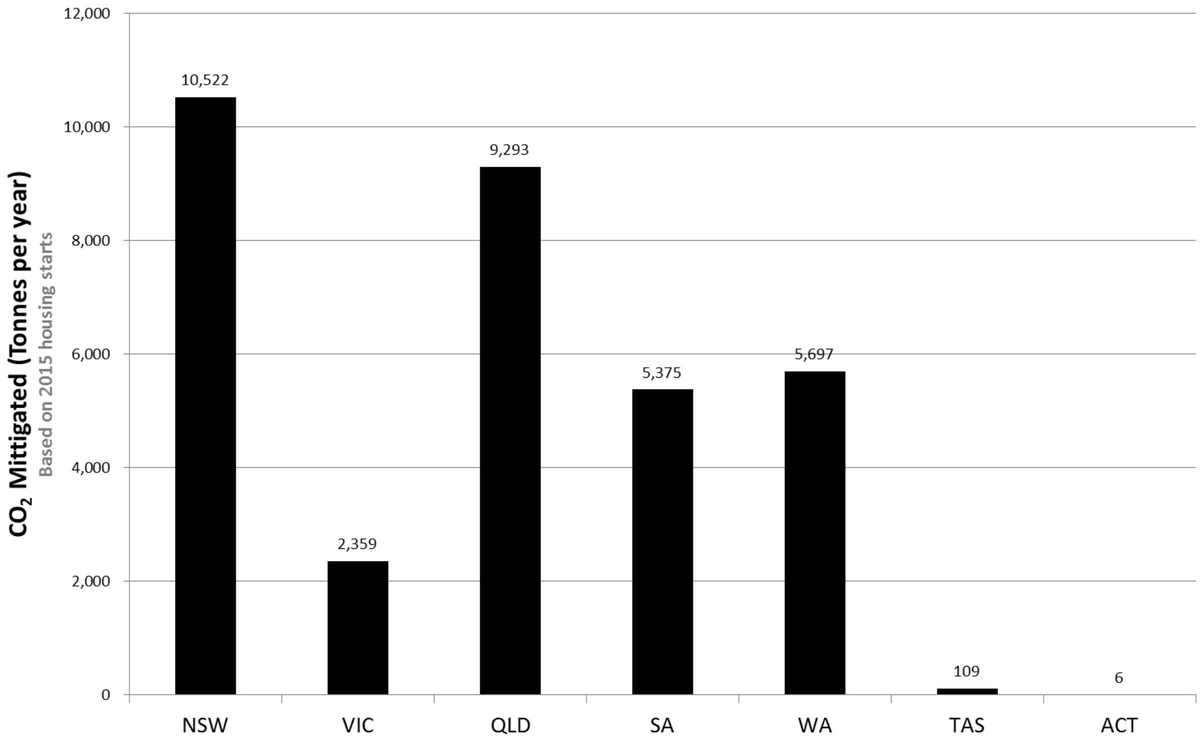


Figure 58 Potential tonnes of CO2 mitigated by air sealing new houses built in 2015

	Electricity		Gas kg $CO_{2\text{-e}}$ /GJ	
	kg.CO2/kWh	kg.CO2/GJ	Metro	Non-Metro
NSW	0.99	275	12.8	13.5
ACT	0.99	275	12.8	13.5
VIC	1.34	371	3.9	3.9
QLD	0.93	260	8.7	7.6
SA	0.72	199	10.4	10.2
WA	0.83	230	4	3.9
TAS	0.23	63	3.9	3.9

Table 14 National Greenhouse Accounts Factors, Department of Environment, 2014

9.3 Competition

ISO 9972 forms the basis of most international pressurisation testing standards including the European Norm, EN 13829, the British ATTMA standards and AS/NZS ISO 9972. This aligns Australia with all European countries currently using pressure testing to meet the energy efficiency requirements of the European directive. The tools and apparatuses used in the fan pressurisation of buildings are well developed and established in European and North American countries. The equipment can be operated to meet any test protocol, the products and services required to undertake the testing and deliver higher performance in air sealing are all available in Australia.

A performance based benchmark within the Building Code of Australia incorporating AS/NZS ISO 9972 target of 10 ACH_{50} is not restrictive to competition as it requires knowledge and building techniques which are commonly available in Australia and worldwide to achieve better building outcomes aligned with BCA objectives. The test equipment can be designed and manufactured using commercially available techniques and equipment available anywhere in the world as long as it meets the tolerances as specified in the standard.

The adoption of AS/NZS ISO 9972 in the BCA is likely to drive the development of new construction measures and innovations to improve the air sealing of buildings to enhance the compliance with the BCA energy efficiency provisions as has been experienced in all countries that have codified this technique.

Ideally a building has a zero air leakage factor (0 ACH_{50}) to provide highest energy efficiency and optimal ventilation systems for water vapour management. To achieve this future tightening of the performance benchmarks will drive the need for further products, services and construction methods to be developed along with innovation and upskilling within the trades sector to realise increased stringency below 10 ACH_{50}. Additionally the development and commercialisation of new technologies will be required to address evolving issues associated with air sealing as we further learn to build high performance near Zero Energy buildings in Australia.

Technology in building products required to drive air sealing to more appropriate levels is already widely available but not necessarily correctly applied in practice. It is innovation and technological advancement of construction practices which will be driven mostly by performance based post construction validation techniques such as fan pressurisation. This will enable better ways of assembling products together for optimal energy efficiency, health, amenity, and fire safety outcomes for consumers. This may help to drive both manufacturing and service based innovation.

Construction techniques in Australia have similarities to some parts of the world but Australia will need to evolve its construction techniques in its own way using domestic knowledge and innovative products as well as international knowledge and innovation to improve the air leakage of Australian buildings.

Overall innovation in manufacturing and construction sectors will be driven by performance based benchmarks incorporated into section 3.12.3 of the BCA volume 2.

9.4 Economic Impact

The savings are largely gained by the end users of buildings with lower energy and running costs that are closer to the intended National Construction Code 6 star energy performance benchmark, as well as healthier indoor environments. As consumers begin to value the tangible and intangible benefits they may begin to increasing expenditure on better products, better services and better construction techniques in which manufacturers, builders and consultants could increase revenue.

However, there is an additional cost of testing buildings after they are complete. This cost will be borne by the builder to gain compliance in which the capital costs will be passed on to the consumers who will be rewarded with ongoing energy savings

A growth in the service based industry is likely to evolve to enable future increase in the demand for testing technicians to be met. This may be seen as a growth in consulting and service based companies as they extend operations within this emerging field.

The overall economic impact is unquestionably positive, saving money for consumers, increasing job opportunities, increasing building quality, improving energy performance, improving moisture resilience, improving acoustic performance, reducing associated carbon dioxide emissions and improving the overall health and well-being of occupants living in these buildings.

10 CONCLUSIONS

- Air sealing to a "Fair" level of 10 ACH_{50} is realistic and achievable with standard Australian construction practice.
- A building code target of value of 10 ACH_{50} would effectively bring 65% of new houses tested to a "Fair" level of performance.
- AS/NZS ISO 9972 provides a standardised method for industry to verify the performance of air sealing and in economic terms is valid for inclusion in the building code.
- The energy penalty for high infiltration rates ranges from the equivalent of 1.5 stars (BCA Zone 3) - 2.4 stars (BCA Zone 1) for extreme infiltration rates of ≥ 35 ACH_{50}.
- $255 - 371 million of economic benefit can be gained by $146.7 Million per year investment in air sealing technologies and practices.
- The cost of implementation of air control measures is estimated to be relatively minor ranging from $163-$1468 per house.
- Air sealing will deliver an economic BCR of 1.7 @ 7% discount rate, 2.1 @ 5% discount rate or 2.5 @ the IPCC recommended 3.5% discount rate for 25 year projections.
- A code target of 10 ACH_{50} has potential to mitigate an estimated 33360 Tonnes of CO_2/year.
- Overall innovation in manufacturing and construction sectors will be driven by performance based benchmarks incorporated into section 3.12.3 of the BCA.
- Through driving an emphasis on better design and more improved detailing of construction methods air sealing will:
    - Reduce the longer term relative risk of mortality and sickness by increasing the ability of the building to naturally maintain comfort conditions.
    - Help safeguard occupants from illness or loss of amenity as a result of undue sound being transmitted from outside or between adjoining dwellings improving compliance with BCA O2.4.6.
    - Enhance the ability to safeguard occupants from illness or injury and protect the building from damage caused by external humidity entering a building improving compliance with BCA O2.2.
    - Allow highly effective low cost balanced ventilation strategies to:

        - Safeguard occupants from illness or loss of amenity due to lack of air freshness improving compliance with BCA O 2.4.5.
        - Safeguard occupants from illness or injury and protect the building from damage caused by the accumulation of internal moisture in a building improving compliance with BCA O2.2.
    - Improve the ability to prevent the penetration of water in walling systems that could cause unhealthy or dangerous conditions or loss of amenity for occupants; and undue dampness or deterioration of building elements improving compliance with BCA P2.2.2. The correlation between air control and weatherproofing means that an air tight envelope actually delivers superior weatherproofing.
    - Help to avoid the spread of fire improving compliance with BCA O2.3 by utilising assessment tools to determine gaps in construction through identification of air leakage paths.
- When a leaky home (35ACH_{50}) is sealed to a "fair" level (10 ACH_{50}) and operated with effective controlled natural ventilation strategies:
    - Peak heating load can be reduced by 21-32% in capital cities.
    - Peak sensible cooling load can be reduced by 7-22% in capital cities.
    - Peak latent cooling peak load can be reduced by 1-43% in capital cities.
    - Peak latent cooling load reduction due to air sealing is largely due to the prevention of infiltration of humid air, in warmer tropical climates this has the largest effect.
- International practice suggests that a continuous ventilation requirement is necessary for houses that are sealed below 7 ACH_{50}.
- Existing Australian standard AS 1668.2 for ventilation is suitable for reference in conjunction with AS/NZS ISO 9972 having consideration to managing energy efficiency with health and amenity objectives of the BCA.
- Health concerns exist for the operation of un-flued gas heaters in well-sealed buildings.

11 RECOMMENDATIONS

- A performance target of 10 ACH_{50} is implemented as a performance based measure in parallel with acceptable construction practice in 2019 code revision.
- AS/NZS ISO 9972 is used as the standard test methodology to validate the performance.
- A performance based benchmark is in parallel with acceptable construction practice until 2022 building code update where performance verification becomes the only option.
- Continuous ventilation rates for houses less than 7 ACH_{50} should have flow rates as specified in AS 1668.2.
    - AS 1668.2 should be listed for review to optimise the flow rate to minimise energy penalty while maintaining indoor air quality in line with international research.
- The 2019 building code incorporates requirements for the ventilation system configuration required to achieve air change effectiveness when performance based measurements below 7 ACH_{50} are achieved.
- Continuous outdoor air supply in BCA zone 1 (tropical climates) should be implemented with caution due to the high external humidity.
- The building code is updated to ensure all new buildings in Australia meet the intent of Energy Safe Victoria requirements as outlined in AS/NZS 5601.1.
- AS/NZS 5601.1 will need to be addressed in the Plumbing Code of Australia (Clause E1.2) in conjunction with AS/NZS ISO 9972 performance benchmarks incorporated into the BCA.

12 Further Investigations

- Further investigation into managing moisture in BCA zone 1 (tropical climates) needs to be undertaken before implementing ventilation requirements in BCA zone 1.
- The current performance of Queensland homes as indicated by CSIRO data are unusually well sealed compared to NSW and Victorian houses and extension of this data set would be beneficial.
- Options for only verifying a portion of buildings; say 50% or 25% of newly constructed buildings would reduce the financial impost and thereby increasing the BCR in mild

climates such as Brisbane. The ability to deliver the desired compliance outcome would need to be evaluated.

- Fan pressurisation testing in Northern Territory be undertaken to understand the air sealing performance in air conditioned homes. Due to the latent cooling loads air sealing stands to provide the largest per house benefit out of all states.
- Investigations in to the infiltration rates in Tasmanian and South Australian homes is undertaken to extend the CSIRO data set in these states.
- Research is undertaken on integration of evaporative air conditioners in adequately sealed homes to include these homes within section 3.12.3. Many states that utilise large portions of evaporative air conditioners in hot dry summers; Victoria, South Australia, Australian Capital Territory and Western Australia also have cold winters.
- Development of Australian design guidance to aid in the selection of building materials and construction types to prevent the accumulation of internal moisture by managing water vapour diffusion.

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APPENDIX A – PREDICTING ENERGY USE FROM ACH_{50} RESULTS

There are two different approaches which are possible for utilising pressure testing results for the prediction of energy in individual buildings, physical and statistical. In a physical model the building component characteristics are put together into a calculation model with which the leakages can be simulated. A statistical model sets up a combination of variables which can be seen to correlate to the airtightness. In Australia little data exists to generate statistical models for Australian housing leakage characteristics and therefore are not deemed suitable at this stage. The lack of existing data and research in the Australian context is the primary reason why the kronvall and Persily (Sherman M. , The Use of Blower Door Data, 1998) rule of thumb has been used to convert between test results and annual average operational building air leakage. In this section a discussion of the validity of the Kronvall and Persily estimation method in Australia is presented and compared to other estimation models.

Internationally the primary existing physical models for conversion between pressure test results and actual operational air infiltration are:

a) Persily-Kronvall estimation model
b) LBL Infiltration Model
c) Sherman Infiltration Estimation Model
d) ASHARAE enhanced infiltration model

The pressure testing results give an indication of individual building behaviour based on the characteristics of the leakage paths in the building. Every building will be slightly different in the pressure flow characteristics and the overall quantities of air which leak through the envelope. The actual air leakage at any given time is based on temperature differential between inside and outside and site wind conditions.

AS/NZS ISO 9972 describes the total envelope leakage using the power law seen in Equation (1). With the power law, the total flow is considered to be somewhere between laminar and turbulent. As the flow takes different forms at different leakage paths and at different pressure differences, this is an approximation.

$$\dot{V} = C_L \cdot (\Delta P)^n \tag{1}$$

Where,

$\dot{V}$ is the infiltration air flow [m^3 /s]
C_L is a constant [m^3 /s·Pa]
n is an exponent [-]

From the characteristics and mathematical relationship between air leakage and pressure it is possible to utilise known calculation methodologies to determine how the building will leak under any given set of temperature and wind conditions. This allows energy use to be calculated based on a variable infiltration model in the energy prediction models such as those used in NatHERS.

Persily-Kronvall estimation model

The Persily-Kronvall estimation model is the simplest possible model. It is shown in Equation (1) and Equation 2. It assumes that there is a linear relation between the q_{50} value and the annual infiltration.

$$q_{inf} = \frac{q_{50}}{20} \qquad (2)$$

Where

q_{inf} is the average airflow over the year $[l/(s \cdot m^2)]$

q_{50} is the permeability at 50Pa pressure difference $[l/(s \cdot m^2)]$

This is directly transferable to air change rates.

$$ACH^{-1} = \frac{ACH_{50}}{20} \qquad (3)$$

Where

ACH^{-1} is the average air flow over the year [ACH]
ACH_{50} is the air change rate at 50Pa [ACH_{50}]

This is a climate independent model and allows for average infiltration energy modelling using annual average infiltration rate that is assumed to remain constant throughout the year.

LBL Infiltration Model

The LBL Infiltration Model was developed at Lawrence Berkley Laboratories in the early eighties. The total flow through the envelope is calculated by superposition of the contributions from wind and stack, shown in Equation (4).

To describe the building the model uses the equivalent leakage area which can be obtained from a fan pressurization test. The rest of the flow terms are separated into a constant and a variable part, see Equation (5). For the flow from wind, the variable part is the wind speed and the constant part contains information about sheltering and terrain, see Equation (6). For flow from stack the variable part is the temperature difference between indoor and outdoor and the constant contains information on leakage distribution and building height, see

Equation (7) (Sherman M. , The Use of Blower Door Data, 1998)The equation follows the climate data time step and for each step the infiltration is calculated from the actual wind speed and temperature.

$$\dot{V} = \sqrt{\dot{V}_w{}^2 + \dot{V}_s{}^2} \tag{4}$$

$$\dot{V} = ELA \cdot \sqrt{f_w{}^2 \cdot U^2 + f_s{}^2 \cdot \Delta T} \tag{5}$$

$$f_w = C' \cdot (1-R)^{1/3} \cdot A \cdot \left(\frac{H}{10}\right)^B \tag{6}$$

$$f_s = \frac{\left(1-\frac{R}{2}\right)^{1/3}}{3} \cdot \left(1-\frac{x^2 H}{(2-R^2)}\right)^{3/2} \cdot \sqrt{\left(\frac{g \cdot H}{T_i}\right)} \tag{7}$$

$$R = \frac{ELA_C + ELA_f}{ELA} \tag{8}$$

$$x = \frac{ELA_C - ELA_f}{ELA} \tag{9}$$

Where

$\dot{V}$ is the infiltration air flow [m³ /s]
$\dot{V}_w$ is the infiltration air flow induced by wind [m³ /s]
$\dot{V}_s$ is the infiltration air flow induced by the stack effect [m³ /s]
ELA is the equivalent leakage area [cm²]
U is the wind speed at a nearby weather station [m/s]
ΔT is the temperature difference [°C]
C' is the shielding coefficient [-]
A and B are terrain coefficients [-]
H is the building height [m]
g is the gravitational constant [m/s²]
T_i is the indoor temperature[K]
ELA_c is the leakage through the ceiling [cm²]
ELA_f is the leakage through the floor [cm²]

The model uses the Equivalent leakage area, ELA, at a 4 Pa pressure difference to describe the leakages. The infiltration is governed by the transient weather data which generates transient leakage rate information. Thus, the energy usage can also be calculated for transient conditions. The ELA is calculated according to ASTM E779 with a discharge co-efficient, C_d of 1.0 and ΔP of 4Pa. The flow rate at 4Pa, $Q_{\Delta P}$, is estimated from the air change rate and the n exponent from equation (1). Equation (10) describes the relationship between ELA, pressure and flow rate.

$$ELA = \frac{Q_{\Delta P}}{C_d} \cdot \sqrt{\left(\frac{\rho}{2 \cdot \Delta P}\right)}$$

Where,

ELA is the Equivalent Leakage Area [m²]
ΔP is the pressure difference [Pa]
$Q_{\Delta P}$ is the airflow rate per unit area at pressure difference ΔP (ASTM E779 states 4Pa) [m³/s]
C_d is the discharge coefficient (ASTM E779 states 1.0) [dimensionless]
ρ is the density of air [kg/m³]

Sherman Infiltration Estimation Model

Sherman (1987) has made a development of the Kronvall Persily estimation model using a simplification from the LBL Infiltration Method. The model assumes a linear relation between the infiltration and the leakage at 50Pa pressure difference, see Equation (10). The difference from the Persily Kronvall estimation model is that the constant depends on local data of the analysed object, see Equation (11). Averaged local weather data is used for the specific infiltration, s_{avg} [m/s], in Equation (12) and the correction factors cf_1 -cf_3 are corrections for crack type, building height and shelter conditions.

$$q_{inf} = \frac{q_{50}}{N} \tag{10}$$

$$N = \frac{14}{S_a} \cdot cf_1 \cdot cf_2 \cdot cf_3 \tag{11}$$

$$S_{avg} = \sqrt{{f_w}^2 \cdot {U_{avg}}^2 + {f_s}^2 \cdot |\Delta T_{avg}|} \tag{12}$$

Where

q_{inf} is the average infiltration flow over the year [l/(s·m^2)]
q_{50} is the permeability at 50 Pa reference pressure [l/(s·m^2)]
N is a constant [-]
S_{avg} is the average specific infiltration [m/s]
cf_1, cf_2 and cf_3 are correction factors [-]
f_w is the wind factor and is set to 0.13 [-]
U_{avg} is the average annual wind speed [m/s]
U_{avg} is the stack factor and is set to 0.12 [m/(s·K$^{1/2}$)

ΔT_{avg} is the annual average temperature difference [^{0}C]

The model uses the permeability at 50Pa pressure difference as leakage description. For infiltration the average values of temperature and wind speed is used which makes it unnecessary to use anything more specific than an averaged model to calculate the energy.

ASHARAE enhanced infiltration model

The ASHRAE Enhanced Infiltration model is used in the ASHRAE 62.2 standard developed for utilising ventilation to protect indoor air quality in residential buildings.

A Lawrence Berkley Laboratories publication (Sherman, Turner, & Walker, Infiltration as Ventilation: Weather Induced Dilution, 2011) states that:

> "The enhanced infiltration model and shelter class selection used for the calculations resulted in conservative values of infiltration……..These assumptions make the use of the derived values directly appropriate for applying to equivalent ventilation calculations and IAQ, but they would significantly underestimate energy impacts and so are not appropriate."

For this reason this model has not been considered for validation against the rule of thumb.

LBL model VS Persily-Kronvall model

Calculations were carried out to compare the time and weather dependent LBL model against the Kronvall and Persily model. The infiltration in the LBL model is governed by the transient weather data which generates transient leakage rate information. This makes it possible to determine if the annual average infiltration for typical house assumptions in Australian climate conditions (wind and temperature) is likely to obey the Kronvall and Persily model.

Kronval and Persily model simply states that the annual average air infiltration is 1/20th or 5% of the ACH_{50} test result as shown in equation (2).

Following the procedure outlined in Figure 59 for a typical 200m² single storey and double storey house then the divisor is able to be calculated and compared to the denominator of 20. This enables the calculation of an "N" value as per equation (10) in the Sherman Infiltration Estimation Model, however based on the time dependent climatic conditions.

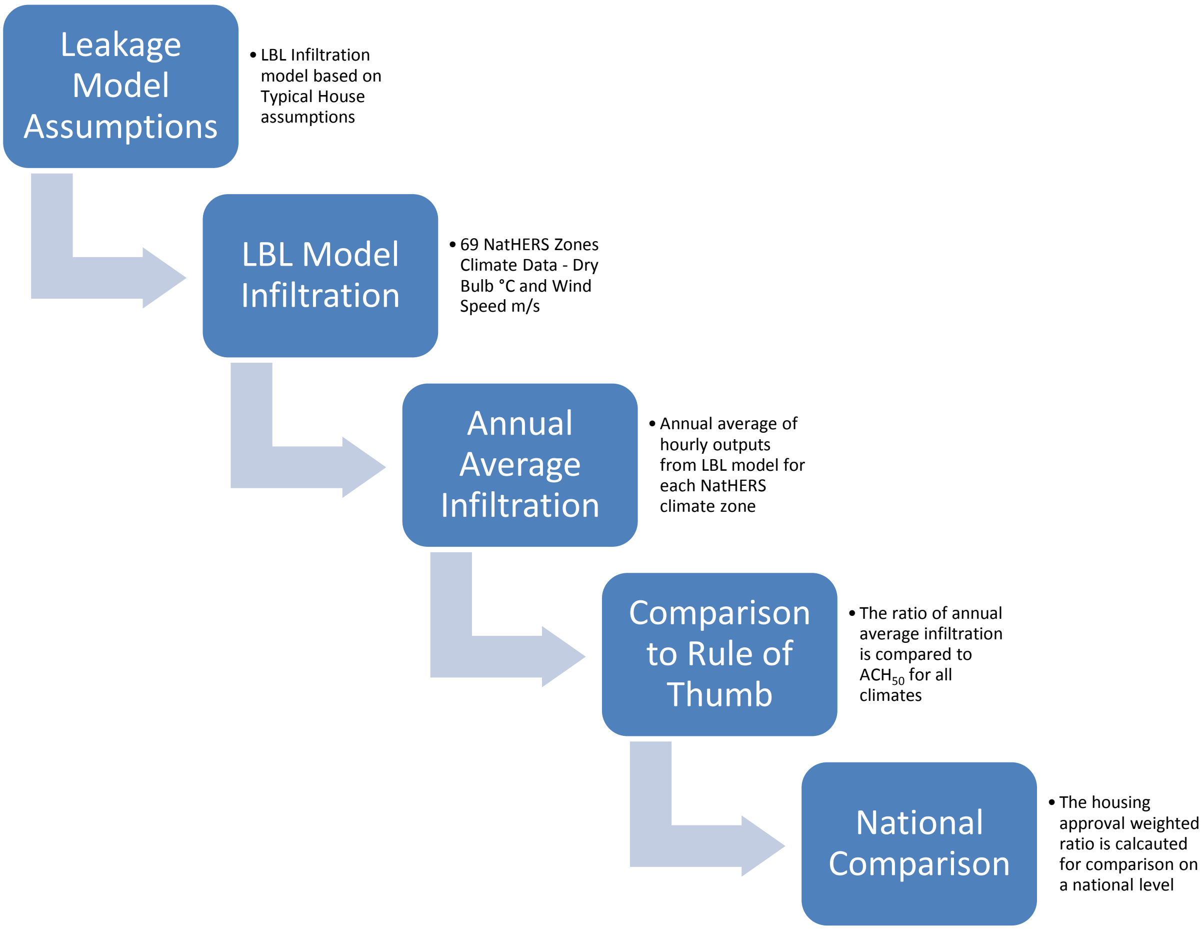


Figure 59 Calculation check for Kronval and Persily Rule of Thumb

If for any given climate the denominator "N" is less than 20 then Kronval and Persily method will be underestimating the energy benefits. If the denominator "N" is greater than 20 then Kronval and Persily is likely to be overestimating the energy benefits.

For the purpose of this analysis some assumptions need to be made concerning the terrain and the leakage locations within the building. The terrain is considered to be suburban as the majority of new houses are built within suburban areas. This means that the terrain factors A and B are 0.67 and 0.25 respectively as shown in table 15 (Sherman M. , The Use of Blower Door Data, 1998) & (Chen, 2013).

Terrain Coefficients				
	Exposed	Open	Suburban	Urban
A	1	0.85	0.67	0.47
B	0.15	0.2	0.25	0.35

Table 15 Terrain coefficients

The shielding factors are based on the shielding class which are divided into 5 categories (Sherman M. , The Use of Blower Door Data, 1998). For the purposes of this analysis no-shielding has been assumed with a factor of 0.3 as shown in table 16.

Shielding Class	Description
0.34	No obstructions or local shielding
0.3	Light local shielding with few obstructions within two building heights
0.25	Local shielding with many large obstructions within two building heights
0.19	Heavily shielded, many large obstructions within one building height
0.11	Complete shielding with large buildings immediately adjacent

Table 16 buidling shielding class (Sherman M. , The Use of Blower Door Data, 1998)

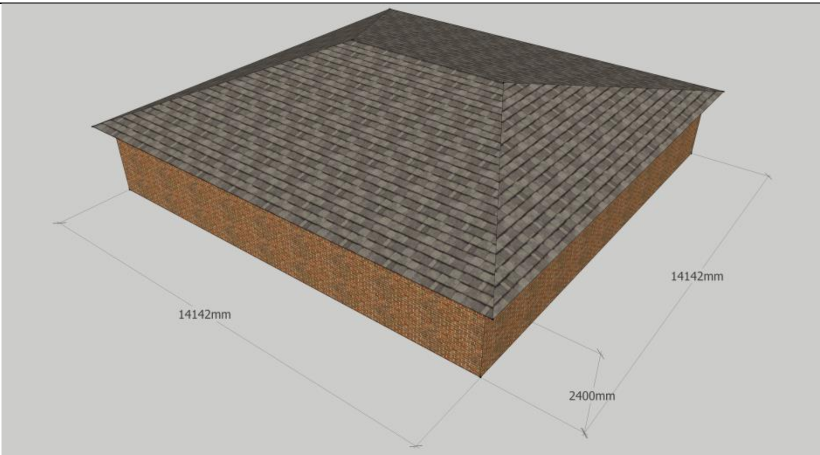
The LBL infiltration model requires R and X to be calculated based on leakage distribution between walls, ceiling and floors. For the purpose of this analysis percentage leakage rates published by LBL in 2011 have been used as shown in table 17 (Sherman, Turner, & Walker, Infiltration as Ventilation: Weather Induced Dilution, 2011)

Envelope Leakage Distribution			
Number of Stories	1	2	3
Fraction of the leakage in the Walls	0.5	0.67	0.75
Fraction of the leakage in the Ceiling [ELA_C]	0.25	0.165	0.125
Fraction of the leakage in the Floor Level [ELA_F]	0.25	0.165	0.125

Table 17 Enelope leakage fractions; walls, floors; ceilings (Sherman, 2011)

Table 18 and 19 show the building descriptions and assumptions which were used to calculate the annual infiltration rate using the LBL model for transient weather data from the 69 NatHERS climate zone data.

Single Storey House



	Single Storey House
N_{storey}	1
House Volume [m³]	480
Floor-Ceiling Height [m]	2.4
Floor Area [m²]	200
Building Floor Plate Width [m]	14
Building Floor Plate Length [m]	14
Envelope Area [m²]	536
Terrain Category	Suburban
Coefficeint A Eq^{n} 6	0.67
Coefficeint B Eq^{n} 6	0.25
Shielding Parameter	None
Shielding Co-efficeint, [C'] Eq^{n} 6	0.34
Constant, [C_L] Eq^{n} 1	441.4
Exponent, n Eq^{n} 1	0.61
C_d, Coefficient of discharge Eq^{n} 10	1
ACH_{50} Eq^{n} 3	10.0
Permeability, q_{50} Eq^{n} 2	9.0
Reference Pressure Eq^{n} 10	4.0
ELA @ 4Pa Eq^{n} 10	0.258
% of leakage in Ceiling [ELA_C] Eq^{n} 8 & 9	0.25
% of leakage at Floor [ELA_F] Eq^{n} 8 & 9	0.25
R Eq^{n} 6, 7 & 8	0.50
x Eq^{n} 7 & 9	0

Table 18 Single Storey House description and input parameters (LBL Model)

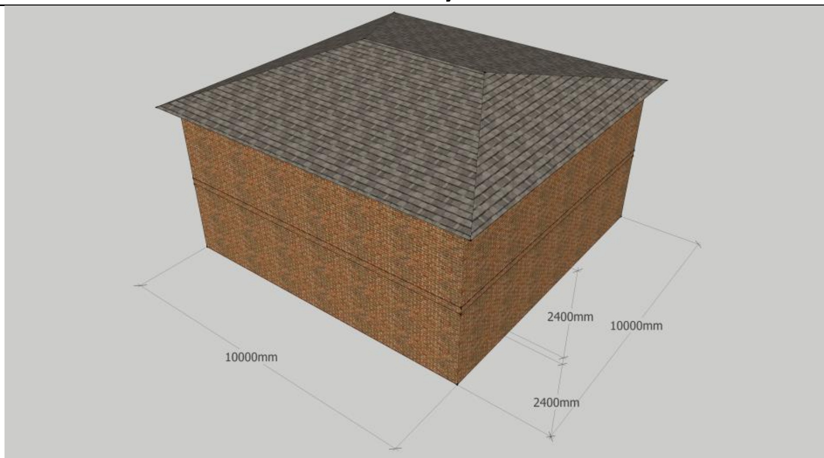
		Double Storey House
		
N_{storey}		2
House Volume [m³]		480
Floor-Ceiling Height [m]		2.4
Floor Area [m²]		200
Building Floor Plate Width [m]		10
Building Floor Plate Length [m]		10
Envelope Area [m²]		392
Terrain Category		Suburban
Coefficeint A	Eq^n 6	0.67
Coefficeint B	Eq^n 6	0.25
Shielding Parameter		None
Shielding Co-efficeint, [C']	Eq^n 6	0.34
Constant, [C_L]	Eq^n 1	441.4
Exponent, n	Eq^n 1	0.61
C_d, Coefficient of discharge	Eq^n 10	1
ACH_{50}	Eq^n 3	10.0
Permeability, q_{50}	Eq^n 2	12.2
Reference Pressure	Eq^n 10	4.0
ELA @ 4Pa	Eq^n 10	0.258
% of leakage in Ceiling [ELA_C]	Eq^n 8 & 9	0.165
% of leakage at Floor [ELA_F]	Eq^n 8 & 9	0.165
R	Eq^n 6, 7 & 8	0.33
x	Eq^n 7 & 9	0

Table 19 Double Storey House description and input parameters (LBL Model)

Figure 60 shows an example of the estimated hourly air change rate for Canberra climate based on the 2 storey assumptions which results in highly variable hourly ratios of air change rate at 50Pa compared to climate induced air infiltration. The ACH_{50} value varies from 4.6 to 310 times the climate induced air infiltration resulting in an annual average which is 19.7.

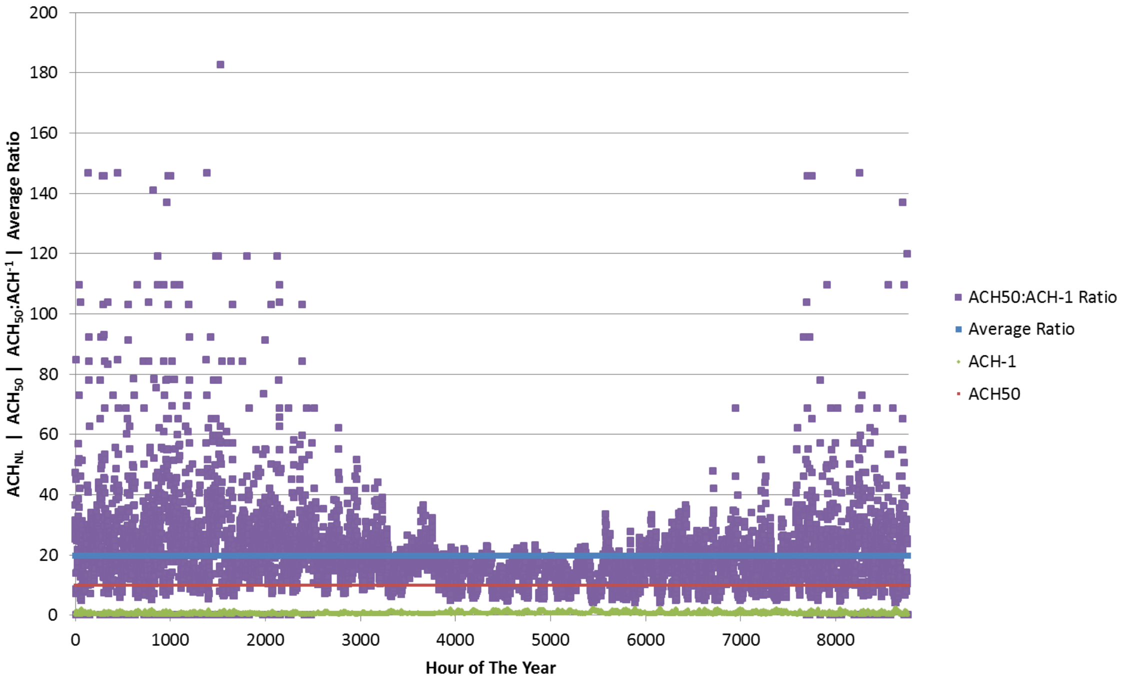


Figure 60 Estimated ACH^{-1} vs ACH_{50} for 2 storey house in Canberra

Table 20 outlines the ratio of ACH_{50} to ACH^{-1} for all 69 NatHERS climates zones for the 1 storey and two storey assumptions. Interesting the annual average and the annual average weighted by housing activity (2015) both result in a “N” number close to 20. The single storey was calculated to have a weighted ratio of 25.2 meaning the rule of thumb may slight overestimate the energy savings on a national scale. However, the double story resulted in a weighted ratio of 17.4 meaning the energy savings may be slightly underestimated on a national level.

It is considered that the kronvall and Persily estimation using N=20 is a respectable approximation on a national level.

The annual average infiltration rate in any of the 69 climates could be estimated by utilising equation (10) and an “N” value lookup from table 20. Specific house geometry will influence the house volume to external envelope area which will vary the outcomes for any specific house, but as a general guide this may be useful for relative climatic differences.

$$q_{inf} = \frac{q_{50}}{N} \tag{10}$$

NatHERS Climate	Housing Approvals (2015)	Annual Av. Wind Pressure (Pa)	Single Storey House N Factor	Double Storey House N Factor
Darwin Airport	1039	8.7	31.5	20.7
Port Hedland	51	3.1	39.2	26.5
Longreach	121	2.4	36.7	25.4
Carnarvon	8	5.9	17.4	11.5
Townsville	1093	3.0	38.2	25.9
Alice Springs	45	2.3	33.2	23.2
Rockhampton	277	2.8	33.5	22.8
Moree MO	63	2.3	33.2	23.1
Amberley	9665	2.0	37.8	26.3
Brisbane	15672	3.5	28.2	19.1
Coffs Harbour MO	1067	3.4	28.9	19.8
Geraldton	308	4.8	20.6	14.0
Perth	10253	3.0	28.0	19.7
Armidale	354	2.0	29.7	20.9
Williamtown AMO	3576	3.3	29.7	21.0
Adelaide	7561	3.1	25.0	17.2
Sydney RO	1	2.3	37.4	26.2
Nowra RAN	1315	3.4	26.9	18.5
Charleville	205	3.1	25.7	17.4
Wagga AMO	1125	2.6	26.0	18.3
Melbourne RMO	1886	3.9	23.2	16.3
East Sale	1660	3.3	23.2	16.4
Launceston	347	3.6	20.5	14.4
Canberra Airport	3514	2.1	27.2	19.7
Cabramurra	75	4.9	16.0	11.0
Hobart	1225	3.5	20.7	14.5
Mildura AMO	1248	3.4	24.6	16.9
Richmond NSW	13822	1.8	34.0	24.3
Weipa	137	3.0	38.4	25.5
Wyndham	22	1.5	45.2	32.8
Willis Island	0	6.8	16.8	11.1
Cairns	1002	4.2	26.8	17.6
Broome	128	3.5	28.6	19.2
Learmonth	0	4.8	21.5	14.2
Mackay	415	4.9	22.9	15.0
Gladstone	1289	4.5	21.6	14.2
Halls Creek	116	2.1	41.2	28.7
Tennant Creek	14	4.5	21.6	14.3

Table 20 Annual average infiltration Vs ACH_{50} test results by NatHERS climate

Mt Isa	20	2.8	31.5	21.6
Newman	38	2.1	39.4	27.0
Giles	29	4.3	21.2	14.1
Meekatharra	57	3.7	25.4	17.2
Oodnadatta	10	3.7	26.2	18.1
Kalgoorlie	265	3.8	22.4	15.1
Woomera	89	4.3	21.8	14.9
Cobar AMO	44	2.2	32.9	22.9
Bickley	3622	4.4	18.9	12.7
Dubbo Airport	919	4.3	19.6	13.2
Katanning	105	2.0	31.9	23.0
Oakey	1481	3.3	25.4	17.6
Forrest	26	4.9	19.0	12.9
Swanbourne	1546	5.3	17.4	11.5
Ceduna	174	5.0	17.5	11.8
Mandurah	5201	3.8	22.4	15.1
Esperance	98	5.0	18.1	12.3
Mascot AMO	7359	3.2	31.2	21.7
Manjimup	534	4.0	19.3	13.1
Albany	1136	4.0	21.4	15.0
Mt Lofty	731	6.3	21.4	15.0
Tullamarine	15793	4.4	14.7	9.9
Mt Gambier	255	4.0	20.1	14.0
Moorabbin	15571	4.6	18.9	13.2
Warrnambool	374	4.2	18.6	12.8
Cape Otway	1865	6.6	19.3	13.5
Orange Air Port	1052	4.1	14.6	9.8
Ballarat	6575	4.9	18.7	13.0
Low Head	512	5.7	17.0	11.7
Launceston Airport	406	3.9	17.4	12.0
Thredbo Valley	0	3.0	18.6	12.9
Average ACH50:ACHNL		**3.8**	**25.6**	**17.6**
Weighted Av. (Housing Approvals)		**3.6**	**25.2**	**17.4**

Table 20 Annual average infiltration Vs ACH_{50} test results by NatHERS climate

APPENDIX B - AIR SEALING PROCEDURES

Research undertaken at The Housing Research Facility in Schofields, Western Sydney has identified the simple construction techniques required to achieve a benchmark of 10 ACH_{50}. The following appendix outlines the general air sealing requirements used in The Housing Research Facility and representative of the practices that may be used to achieve the proposed 10 ACH_{50} benchmark measured in accordance with AS/NZS ISO 9972.

External Walls – Ground Level & Suspended Floor

1. Apply acoustic rated sealant to external wall bottom plate connection to slab and/or flooring substrate.

Figure 61 sealing under bottom plate

2. Assess air gaps surrounding window frames, between window and wall studs:

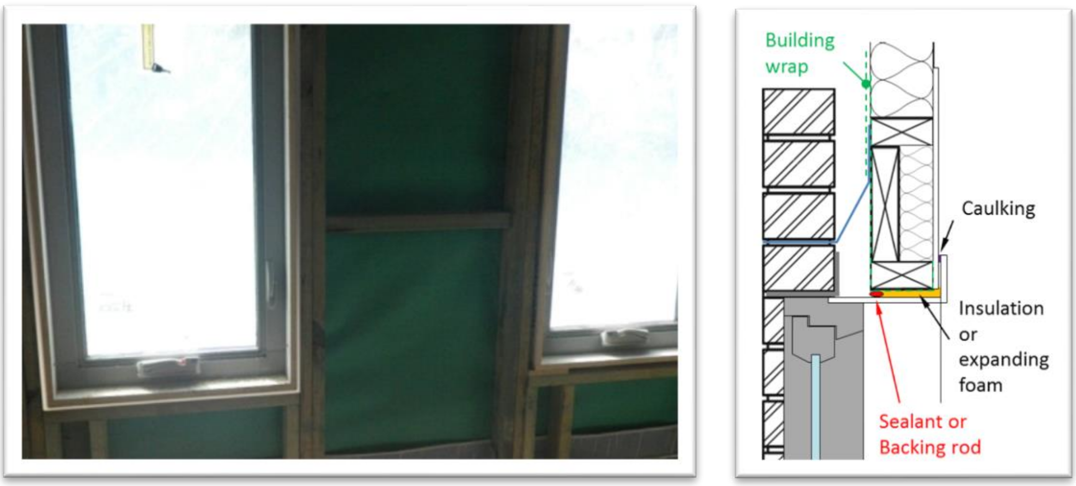


Figure 62 sealing around windows

   a. If gap >10mm

      Insert insulation off-cuts (or foam backing rod) into gap between window jamb and wall frame, apply acoustic rated sealant to perimeter of window gap to a depth of min 10mm.

b. If gap < 10mm

Apply acoustic rated sealant to perimeter of window sub-frame to a depth of 5-10 mm.

3. Prior to wall wrap and/or external cladding being applied an inspection of external to internal wall junctions is required, where external facing cavities are present, insulation is required to be cut and packed into the cavities from the outside.
4. External wall wrap joints will drastically improve air control when tape sealed, any penetrations through the wall wrap (for brick ties, brackets, nails etc.) can be taped to minimise air leakage. (See Appendix C for wall wrap benefits)

Figure 63 Taping and sealing membranes

Mid Floor – For 2 Storey Constructions

1. Focus on either Carpentry or Internal Linings.
2. Install Rim boards around perimeter of mid floor to close off and provide a seal to the joist ends.
3. Alternate to this is to ensure plaster lining is air tight at the Cornice and ceiling, minimal ceiling penetrations required, only sealed down lights (with ceiling flange gasket) are recommended.

Internal Linings

1. Penetrations through internal linings should be minimised and where necessary a snug fit for the service (cable, pipe or fitting) should be made and sealed upon completion.
2. All wall insulation (where installed) shall fit snug into the wall frames and be cut to the shape of any penetrating service.

Figure 64 Snug fitting insulation increase airflow resistance

3. Where electrical cables penetrate the lining, the insulation should not be dislodged or be deformed to create large voids.
4. Ensure plaster or cement sheet lining is air tight at the penetration and ceiling junction.
5. In wet areas apply a water proof sealant to the junction between the wall lining and flooring substrate.

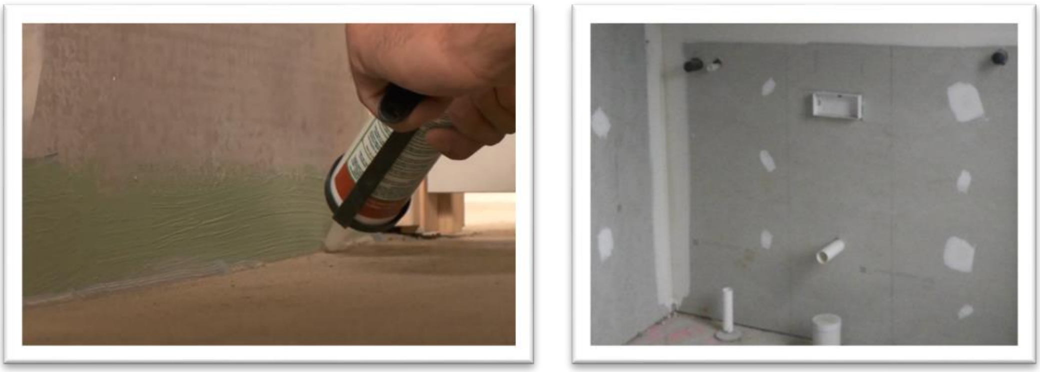


Figure 65 Sealing wet areas

6. All architraves and window reveals shall be sealed to the wall lining to prevent air flanking around window and door penetrations.

Ceilings

1. All ceiling insulation shall adequately cover and extend across the top plate of the external wall frames, where the roof space is too tight a perimeter batt may be required.
2. Ensure ceiling lining is air tight at the cornice and ceiling, minimal ceiling penetrations required, only sealed down lights (with ceiling flange gasket) are recommended.

APPENDIX C – EXTERNAL AIR BARRIER PERFORMANCE

In 2016 a leading product supplier demonstrated that simple low cost inclusions such as wall wrap can have a significant impact on the energy efficiency and thermal comfort of a home. The experiment was carried out in February 2016 at a building product Technical Research Centre located at Wetherill Park, Sydney.

The objective of the experiment was to investigate the effectiveness of external air barriers (wall wrap) in reducing air infiltration through a typical residential wall. The experiment was set up by constructing a wall onto the face of a pressure chamber. The wall comprised of a 90mm timber stud, 2 fixed windows, R2.0 90mm Bradford Gold Batts, 10mm Gyprock, timber skirting, timber architraves, 1 power point and 1 light switch. The wall wrap that was used in the experiment was Bradford Thermoseal Wall Wrap, a woven polyweave foil type membrane. Sensors monitored air pressure inside the chamber, within the stud frame and outside the wall wrap. The external pressure measured outside the wall wrap represented a pressure-equalised cavity which is typical in brick veneer and light weight cladding facades.

Figure 66 Pressure sensor tubing installed on test rig

Figure 67 Wall wrap air leakage being tested under pressure

Figure 68 Improving air barrier integrity, taping centre overlap and around windows

The results of the experiment show that Thermoseal Wall Wrap significantly reduced the air infiltration through the wall by up to 82%. Three progressive installation stages were measured and the air infiltration results for 33km/h wind speed (AS 4055 calculation assuming unity factor) or 50 Pascals (Pa) have been summarised below:

1. 20.5% reduction in air infiltration was achieved with Thermoseal Wall Wrap being installed with 150mm overlaps (no tape used).
2. 58.8% reduction in air infiltration was achieved with Thermoseal Wall Wrap being installed with overlaps and window frames taped.
3. 82.3% reduction in air infiltration was achieved with Thermoseal Wall Wrap being installed with overlaps, window frames, top plate and bottom plate taped.

The full results across the pressure range from 50Pa to 100Pa are presented in figure 69.

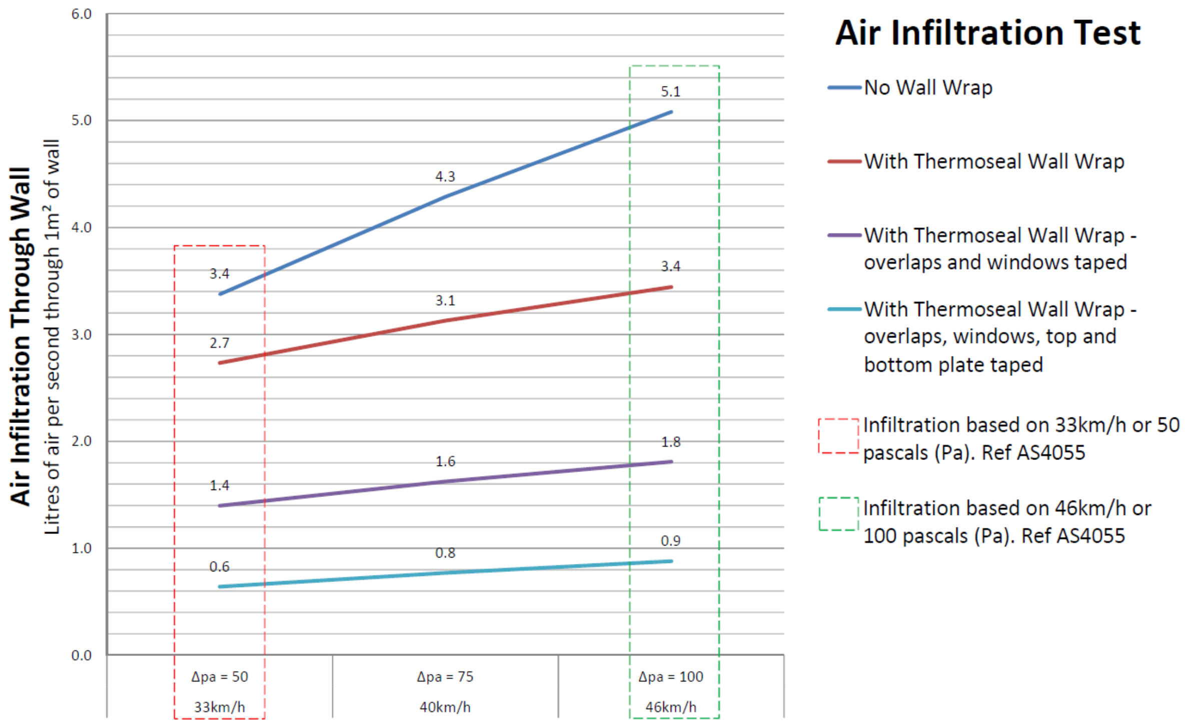


Figure 69 Effect of wall wrap and sealing on wall air infiltration

APPENDIX D - HOUSE DESIGNS

The benchmark houses used for the analysis were a simple single storey 3 bedroom design and The Housing Research Facility 3 bedroom design as shown below.

Simple 3 bedroom Single Storey Design

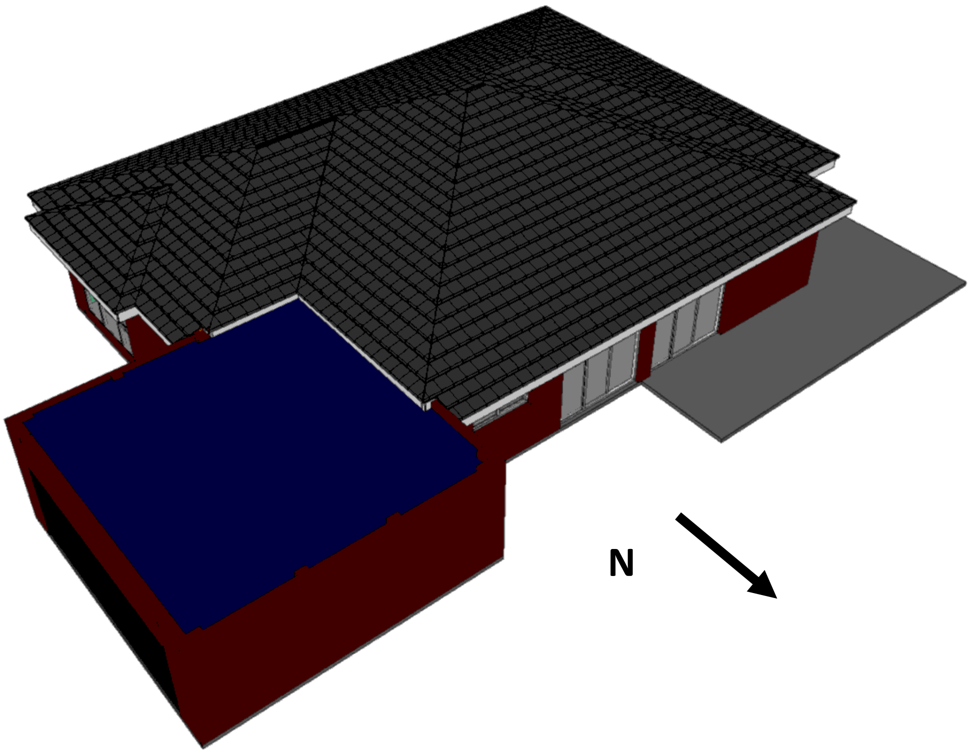


Figure 70 Simple 3 bedroom design

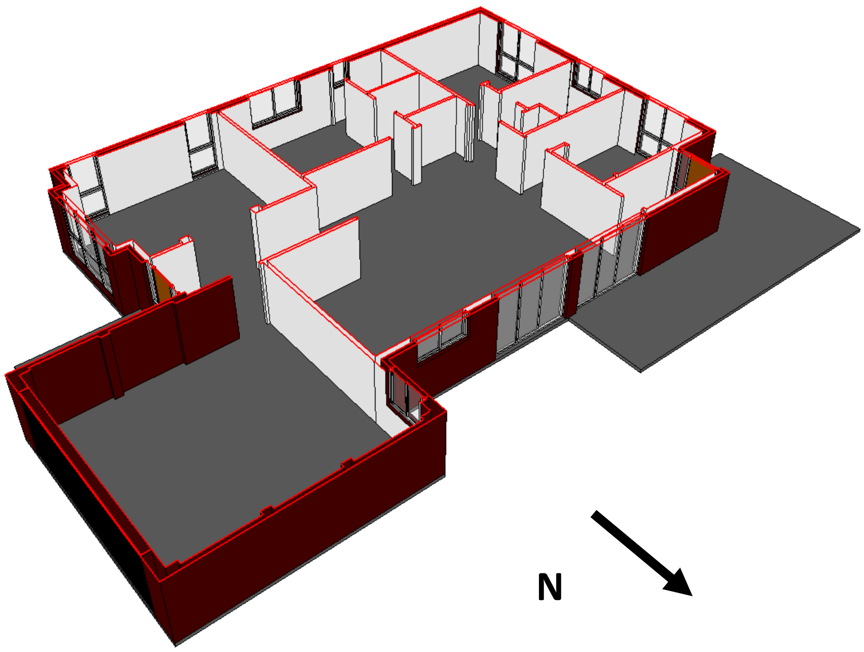


Figure 71 Simple 3 bedroom floor plan

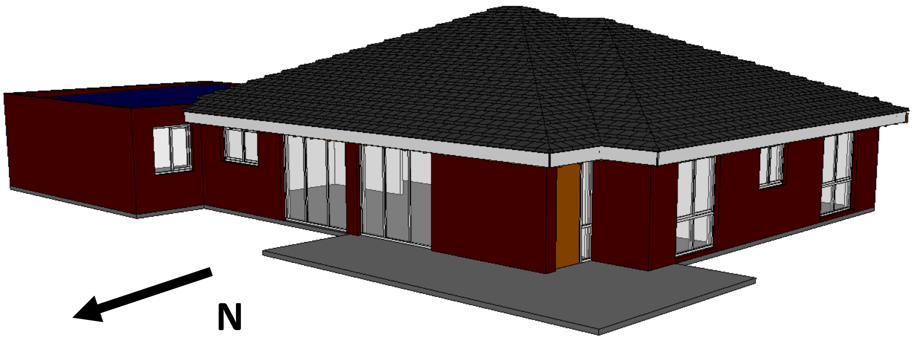


Figure 72 Simple 3 bedroom North & West facades

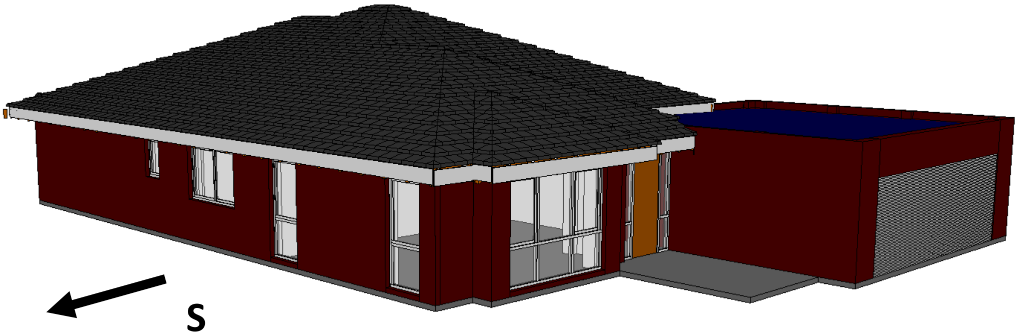


Figure 73 Simple 3 bedroom South & East facades

The Housing Research Facility

Figure 74 The Housing Research Facility

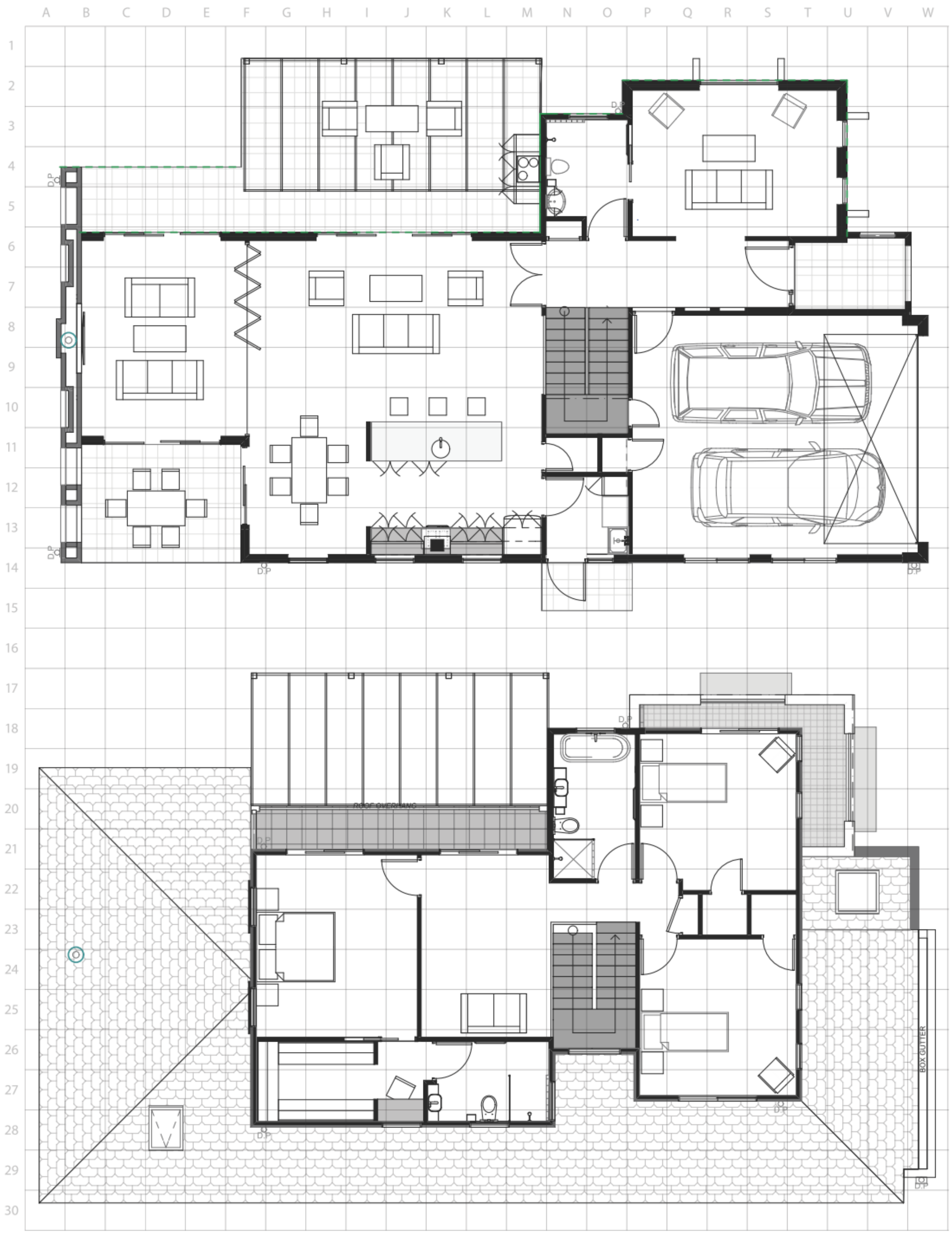


Figure 75 The Housing Research Facility Floor Plan Layout

APPENDIX E - HOUSE SPECIFICATIONS

All specifications for all simulated scenarios are detailed in this appendix.

Single Storey 3 bedroom House											
NatHERS Climate		Lower Storey	Upper Storey	Eaves	Wall Ground Floor	Wall Upper Floor	Ceiling	Garage/ Habitable Space Wall	Roof	Windows	
										U-Value	SHGC
1	Darwin	Masonry Veneer	N/A	1150	2.0	N/A	3.5	1.0	Tile + DRFL	5.6	0.4
1	Darwin	Cavity Brick	N/A	1150	0.0	N/A	3.5	0.0	Tile + DRFL	5.6	0.4
1	Darwin	Lightweight Cladding	N/A	1150	2.0	N/A	3.5	1.5	Tile + DRFL	5.6	0.4
2	Pt Hedland	Masonry Veneer	N/A	1200	2.0	N/A	3.5	1.0	Tile + DRFL	5.6	0.4
2	Pt Hedland	Cavity Brick	N/A	650	Foil	N/A	3.5	0.0	Tile + DRFL	5.6	0.4
2	Pt Hedland	Lightweight Cladding	N/A	1300	2.0	N/A	3.5	1.5	Tile + DRFL	5.6	0.4
3	Longreach	Masonry Veneer	N/A	1400	2.0	N/A	4.1	1.0	Tile + DRFL	5.6	0.4
3	Longreach	Cavity Brick	N/A	800	0.0	N/A	3.5	0.0	Tile	5.6	0.4
3	Longreach	Lightweight Cladding	N/A	1700	2.0	N/A	4.1	1.5	Tile + DRFL	5.6	0.4
4	Carnarvon	Masonry Veneer	N/A	1400	2.0	N/A	3.5	1.0	Tile + DRFL	3.7	0.4
4	Carnarvon	Cavity Brick	N/A	950	Foil	N/A	3.5	0.0	Tile + DRFL	3.7	0.4
4	Carnarvon	Lightweight Cladding	N/A	1500	2.0	N/A	3.5	1.5	Tile + DRFL	3.7	0.4
5	Townsville	Masonry Veneer	N/A	1400	2.0	N/A	3.5	1.0	Tile + DRFL	5.6	0.4
5	Townsville	Cavity Brick	N/A	1600	Foil	N/A	3.5	0.0	Tile + DRFL	5.6	0.4
5	Townsville	Lightweight Cladding	N/A	1400	2.0	N/A	3.5	1.5	Tile + DRFL	5.6	0.4
6	Alice Springs	Masonry Veneer	N/A	1300	2.0	N/A	4.1	1.0	Tile + DRFL	5.6	0.4
6	Alice Springs	Cavity Brick	N/A	400	0.0	N/A	3.5	0.0	Tile	5.6	0.4
6	Alice Springs	Lightweight Cladding	N/A	1800	2.0	N/A	4.1	1.5	Tile + DRFL	5.6	0.4
7	Rockhampton	Masonry Veneer	N/A	1150	2.0	N/A	3.5	1.0	Tile + DRFL	5.6	0.4
7	Rockhampton	Cavity Brick	N/A	500	Foil	N/A	3.5	0.0	Tile + DRFL	5.6	0.4
7	Rockhampton	Lightweight Cladding	N/A	1200	2.0	N/A	3.5	1.5	Tile + DRFL	5.6	0.4
8	Moree	Masonry Veneer	N/A	450	2.7	N/A	4.1	2.7	Tile + VP	4.6	0.4
8	Moree	Cavity Brick	N/A	450	0.0	N/A	3.0	0.0	Tile	5.6	0.4
8	Moree	Lightweight Cladding	N/A	500	2.0	N/A	3.5	0.0	Tile + DRFL	3.7	0.4

Single Storey 3 bedroom House											
NatHERS Climate		Lower Storey	Upper Storey	Eaves	Wall Ground Floor	Wall Upper Floor	Ceiling	Garage/ Habitable Space Wall	Roof	Windows	
										U-Value	SHGC
9	Amberley	Masonry Veneer	N/A	1000	2.0	N/A	3.5	1.0	Tile + DRFL	5.6	0.4
9	Amberley	Cavity Brick	N/A	600	0.0	N/A	2.5	0.0	Tile	5.6	0.4
9	Amberley	Lightweight Cladding	N/A	1200	2.0	N/A	3.5	1.5	Tile + DRFL	5.6	0.4
10	Brisbane	Masonry Veneer	N/A	1150	2.0	N/A	3.5	1.0	Tile + DRFL	5.6	0.4
10	Brisbane	Cavity Brick	N/A	450	0.0	N/A	2.5	0.0	Tile + DSRF	5.6	0.4
10	Brisbane	Lightweight Cladding	N/A	1300	2.0	N/A	3.5	1.5	Tile + DSRF	5.6	0.4
11	Coffs harbour	Masonry Veneer	N/A	600	2.0	N/A	4.1	2.0	Tile	3.7	0.4
11	Coffs harbour	Cavity Brick	N/A	450	0.0	N/A	3.5	0.0	Tile	5.6	0.4
11	Coffs harbour	Lightweight Cladding	N/A	600	2.5	N/A	5.0	2.0	Tile	3.7	0.4
12	Geraldton	Masonry Veneer	N/A	1600	2.5	N/A	3.5	1.0	Tile + DSRF	5.6	0.4
12	Geraldton	Cavity Brick	N/A	200	0.0	N/A	3.5	0.0	Tile	5.6	0.4
12	Geraldton	Lightweight Cladding	N/A	1200	2.5	N/A	3.5	2.0	Tile + DSRF	5.6	0.4
13	Perth	Masonry Veneer	N/A	1200	2.5	N/A	3.5	1.0	Tile + DSRF	5.6	0.4
13	Perth	Cavity Brick	N/A	50	0.0	N/A	3.5	0.0	Tile	5.6	0.4
13	Perth	Lightweight Cladding	N/A	950	2.5	N/A	3.5	2.0	Tile + DSRF	5.6	0.4
14	Armidale	Masonry Veneer	N/A	450	2.0	N/A	5.0	1.0	Tile	5.6	0.4
14	Armidale	Cavity Brick	N/A	450	Foil	N/A	4.1	0.0	Tile	6.7	0.7
14	Armidale	Lightweight Cladding	N/A	450	2.5	N/A	4.1	2.5	Tile	5.4	0.6
15	Williamtown	Masonry Veneer	N/A	500	2.0	N/A	5.0	2.0	Tile	5.6	0.4
15	Williamtown	Cavity Brick	N/A	450	0.0	N/A	5.0	0.0	Tile	6.7	0.7
15	Williamtown	Lightweight Cladding	N/A	450	2.7	N/A	5.0	2.7	Tile + DSRF	5.4	0.6
16	Adelaide	Masonry Veneer	N/A	600	2.0	N/A	3.5	1.0	Tile + DSRF	5.6	0.4
16	Adelaide	Cavity Brick	N/A	550	0.26+Foil	N/A	3.5	0.0	Tile + SSRF	6.7	0.7
16	Adelaide	Lightweight Cladding	N/A	600	2.0	N/A	3.5	1.5	Tile + DSRF	5.6	0.4
17	Sydney (Observatory Hill)	Masonry Veneer	N/A	600	2.0	N/A	5.0	2.0	Tile + DSRF	5.6	0.4
17	Sydney (Observatory Hill)	Cavity Brick	N/A	550	0.26+Foil	N/A	4.1	0.0	Tile + SSRF	6.7	0.7
17	Sydney (Observatory Hill)	Lightweight Cladding	N/A	600	2.7	N/A	4.1	2.7	Tile + DSRF	5.6	0.4

Single Storey 3 bedroom House											
NatHERS Climate		Lower Storey	Upper Storey	Eaves	Wall Ground Floor	Wall Upper Floor	Ceiling	Garage/ Habitable Space Wall	Roof	Windows	
										U-Value	SHGC
18	Nowra	Masonry Veneer	N/A	700	2.0	N/A	5.0	2.0	Tile	5.6	0.4
18	Nowra	Cavity Brick	N/A	600	0.0	N/A	6.0	0.0	Tile	6.7	0.7
18	Nowra	Lightweight Cladding	N/A	550	2.0	N/A	5.0	2.0	Tile + DSRF	5.4	0.6
19	Charleville	Masonry Veneer	N/A	1100	2.0	N/A	4.1	1.0	Tile + DSRF	5.6	0.4
19	Charleville	Cavity Brick	N/A	350	0.0	N/A	3.5	0.0	Tile	5.6	0.4
19	Charleville	Lightweight Cladding	N/A	1500	2.0	N/A	4.1	1.5	Tile + DSRF	5.6	0.4
20	Wagga	Masonry Veneer	N/A	450	2.0	N/A	5.0	2.0	Tile	5.6	0.4
20	Wagga	Cavity Brick	N/A	450	Foil	N/A	6.0	0.0	Tile	6.7	0.7
20	Wagga	Lightweight Cladding	N/A	450	2.5	N/A	5.0	2.5	Tile	5.4	0.6
21	Melbourne	Masonry Veneer	N/A	450	1.5	N/A	3.5	1.5	Tile	5.4	0.6
21	Melbourne	Cavity Brick	N/A	350	Foil	N/A	4.1	2.0	Tile + DSRF	5.6	0.4
21	Melbourne	Lightweight Cladding	N/A	450	2.5	N/A	3.5	1.5	Tile	5.4	0.6
22	East Sale	Masonry Veneer	N/A	700	2.0	N/A	5.0	2.0	Tile	5.6	0.4
22	East Sale	Cavity Brick	N/A	450	0.26+Foil	N/A	4.1	0.0	Tile	6.7	0.7
22	East Sale	Lightweight Cladding	N/A	550	2.0	N/A	3.5	0.8	Tile + DSRF	5.4	0.6
23	Launceston (Ti Tree Bend)	Masonry Veneer	N/A	700	2.0	N/A	4.1	2.0	Tile	5.6	0.4
23	Launceston (Ti Tree Bend)	Cavity Brick	N/A	400	0.0	N/A	5.0	0.0	Tile + DSRF	3.7	0.6
23	Launceston (Ti Tree Bend)	Lightweight Cladding	N/A	550	1.5	N/A	3.5	0.8	Tile + DSRF	5.4	0.6
24	Canberra	Masonry Veneer	N/A	450	2.0	N/A	5.0	1.0	Tile + VP	5.6	0.4
24	Canberra	Cavity Brick	N/A	450	Foil	N/A	4.1	0.0	Tile + VP	5.4	0.6
24	Canberra	Lightweight Cladding	N/A	450	2.0	N/A	5.0	1.5	Tile	5.4	0.6
25	Cabramurra	Masonry Veneer	N/A	450	2.5	N/A	6.0	2.0	Tile + VP	5.6	0.4
25	Cabramurra	Cavity Brick	N/A	450	0.51+Foil	N/A	7.0	2.7	Tile + VP	5.4	0.6
25	Cabramurra	Lightweight Cladding	N/A	650	2.0	N/A	5.0	2.5	Tile	5.4	0.6
26	Hobart	Masonry Veneer	N/A	700	2.5	N/A	4.1	2.0	Tile	5.6	0.4
26	Hobart	Cavity Brick	N/A	350	0.0	N/A	5.0	0.0	Tile + DSRF	3.7	0.6
26	Hobart	Lightweight Cladding	N/A	550	1.5	N/A	3.5	0.8	Tile + DSRF	5.4	0.6
27	Mildura	Masonry Veneer	N/A	350	2.0	N/A	3.5	1.5	Tile	4.6	0.4
27	Mildura	Cavity Brick	N/A	800	Foil	N/A	3.5	0.0	Tile	5.6	0.4
27	Mildura	Lightweight Cladding	N/A	600	2.2	N/A	3.5	0.0	Tile	3.7	0.4

Single Storey 3 bedroom House											
NatHERS Climate		Lower Storey	Upper Storey	Eaves	Wall Ground Floor	Wall Upper Floor	Ceiling	Garage/ Habitable Space Wall	Roof	Windows	
										U-Value	SHGC
28	Richmond	Masonry Veneer	N/A	700	2.0	N/A	5.0	2.0	Tile	5.6	0.4
28	Richmond	Cavity Brick	N/A	450	0.0	N/A	5.0	0.0	Tile	6.7	0.7
28	Richmond	Lightweight Cladding	N/A	550	2.7	N/A	5.0	2.7	Tile + DSRF	5.4	0.6
29	Weipa	Masonry Veneer	N/A	1100	2.0	N/A	3.5	1.0	Tile + DSRF	5.6	0.4
29	Weipa	Cavity Brick	N/A	900	0.0	N/A	3.5	0.0	Tile + DSRF	5.6	0.4
29	Weipa	Lightweight Cladding	N/A	1050	2.0	N/A	3.5	1.5	Tile + DSRF	5.6	0.4
30	Wyndham	Masonry Veneer	N/A	1300	2.0	N/A	3.5	1.0	Tile + DSRF	5.6	0.4
30	Wyndham	Cavity Brick	N/A	1300	Foil	N/A	3.5	0.0	Tile + DSRF	5.6	0.4
30	Wyndham	Lightweight Cladding	N/A	1300	2.0	N/A	3.5	1.5	Tile + DSRF	5.6	0.4
31	Willis Island	Masonry Veneer	N/A	750	2.0	N/A	3.5	1.0	Tile + DSRF	5.6	0.4
31	Willis Island	Cavity Brick	N/A	700	Foil	N/A	3.5	0.0	Tile + DSRF	5.6	0.4
31	Willis Island	Lightweight Cladding	N/A	800	2.0	N/A	3.5	1.0	Tile + DSRF	5.6	0.4
32	Cairns	Masonry Veneer	N/A	1250	2.0	N/A	3.5	1.0	Tile + DSRF	5.6	0.4
32	Cairns	Cavity Brick	N/A	1050	Foil	N/A	3.5	0.0	Tile + DSRF	5.6	0.4
32	Cairns	Lightweight Cladding	N/A	1250	2.0	N/A	3.5	1.5	Tile + DSRF	5.6	0.4
33	Broome	Masonry Veneer	N/A	850	2.0	N/A	3.5	1.0	Tile + DSRF	5.6	0.4
33	Broome	Cavity Brick	N/A	650	Foil	N/A	3.5	0.0	Tile + DSRF	5.6	0.4
33	Broome	Lightweight Cladding	N/A	900	2.0	N/A	3.5	1.5	Tile + DSRF	5.6	0.4
34	Learmonth	Masonry Veneer	N/A	950	2.0	N/A	3.5	1	Tile + DSRF	3.7	0.4
34	Learmonth	Cavity Brick	N/A	300	Foil	N/A	3.5	0.0	Tile + DSRF	5.6	0.4
34	Learmonth	Lightweight Cladding	N/A	1000	2.5	N/A	4.1	1.5	Tile + DSRF	3.7	0.4
35	Mackay	Masonry Veneer	N/A	1450	2.0	N/A	3.5	1.0	Tile + DSRF	5.6	0.4
35	Mackay	Cavity Brick	N/A	1100	Foil	N/A	3.5	0.0	Tile + DSRF	5.6	0.4
35	Mackay	Lightweight Cladding	N/A	1500	2.0	N/A	3.5	1.5	Tile + DSRF	5.6	0.4
36	Gladstone	Masonry Veneer	N/A	1450	2.0	N/A	3.5	1.0	Tile + DSRF	5.6	0.4
36	Gladstone	Cavity Brick	N/A	550	Foil	N/A	3.5	0.0	Tile + DSRF	5.6	0.4
36	Gladstone	Lightweight Cladding	N/A	1300	2.0	N/A	3.5	1.5	Tile + DSRF	5.6	0.4

Single Storey 3 bedroom House											
NatHERS Climate		Lower Storey	Upper Storey	Eaves	Wall Ground Floor	Wall Upper Floor	Ceiling	Garage/ Habitable Space Wall	Roof	Windows	
										U-Value	SHGC
37	Halls Creek	Masonry Veneer	N/A	1400	2.0	N/A	3.5	1.0	Tile + DSRF	5.6	0.4
37	Halls Creek	Cavity Brick	N/A	800	Foil	N/A	3.5	0.0	Tile + DSRF	5.6	0.4
37	Halls Creek	Lightweight Cladding	N/A	750	2.5	N/A	4.1	1.5	Tile + DSRF	3.7	0.4
38	Tennant Creek	Masonry Veneer	N/A	1400	2.0	N/A	4.1	2.0	Tile + DSRF	5.6	0.4
38	Tennant Creek	Cavity Brick	N/A	900	0.26+Foil	N/A	3.5	0.0	Tile	5.6	0.4
38	Tennant Creek	Lightweight Cladding	N/A	1600	2.0	N/A	4.1	1.5	Tile + DSRF	5.6	0.4
39	Mt Isa	Masonry Veneer	N/A	1300	2.0	N/A	4.1	2.0	Tile + DSRF	5.6	0.4
39	Mt Isa	Cavity Brick	N/A	850	0.26+Foil	N/A	3.5	0.0	Tile	5.6	0.4
39	Mt Isa	Lightweight Cladding	N/A	1500	2.0	N/A	4.1	1.5	Tile + DSRF	5.6	0.4
40	Newman	Masonry Veneer	N/A	1400	2.0	N/A	3.5	1.0	Tile + DSRF	5.6	0.4
40	Newman	Cavity Brick	N/A	450	Foil	N/A	3.5	0.0	Tile + DSRF	5.6	0.4
40	Newman	Lightweight Cladding	N/A	750	2.5	N/A	4.1	1.5	Tile + DSRF	3.7	0.4
41	Giles	Masonry Veneer	N/A	900	2.0	N/A	3.5	1.0	Tile + DSRF	5.6	0.4
41	Giles	Cavity Brick	N/A	50	0.0	N/A	2.5	0.0	Tile + DSRF	5.6	0.4
41	Giles	Lightweight Cladding	N/A	450	1.5	N/A	3.5	1.5	Tile + DSRF	3.7	0.4
42	Meekatharra	Masonry Veneer	N/A	1000	2.0	N/A	3.5	1.0	Tile + DSRF	5.6	0.4
42	Meekatharra	Cavity Brick	N/A	50	0.0	N/A	2.5	0.0	Tile + SSRF	5.6	0.4
42	Meekatharra	Lightweight Cladding	N/A	550	1.5	N/A	3.5	1.5	Tile + DSRF	3.7	0.4
43	Oodnadatta	Masonry Veneer	N/A	1800	2.0	N/A	4.1	2.0	Tile + DSRF	5.6	0.4
43	Oodnadatta	Cavity Brick	N/A	1200	0.26+Foil	N/A	3.5	0.0	Tile + SSRF	6.7	0.7
43	Oodnadatta	Lightweight Cladding	N/A	2000	2.0	N/A	4.1	1.5	Tile + DSRF	5.6	0.4
44	Kalgoorlie	Masonry Veneer	N/A	600	1.5	N/A	3.5	1.0	Tile + DSRF	5.6	0.4
44	Kalgoorlie	Cavity Brick	N/A	200	0.0	N/A	2.0	0.0	Tile	5.6	0.4
44	Kalgoorlie	Lightweight Cladding	N/A	550	1.0	N/A	3.5	1.0	Tile + DSRF	3.7	0.4
45	Woomera	Masonry Veneer	N/A	650	2.0	N/A	4.1	2.0	Tile + DSRF	5.6	0.4
45	Woomera	Cavity Brick	N/A	500	0.0	N/A	3.5	0.0	Tile + SSRF	6.7	0.7
45	Woomera	Lightweight Cladding	N/A	750	2.0	N/A	4.1	1.5	Tile + DSRF	5.6	0.4

Single Storey 3 bedroom House											
NatHERS Climate		Lower Storey	Upper Storey	Eaves	Wall Ground Floor	Wall Upper Floor	Ceiling	Garage/ Habitable Space Wall	Roof	Windows	
										U-Value	SHGC
46	Cobar	Masonry Veneer	N/A	450	2.7	N/A	4.1	1.5	Tile	4.6	0.4
46	Cobar	Cavity Brick	N/A	350	0.0	N/A	3.5	0.0	Tile	5.6	0.4
46	Cobar	Lightweight Cladding	N/A	600	2.5	N/A	4.1	0.0	Tile	3.7	0.4
47	Bickley	Masonry Veneer	N/A	600	1.5	N/A	3.5	0.5	Tile + DSRF	5.6	0.4
47	Bickley	Cavity Brick	N/A	650	0.0	N/A	3.5	0.0	Tile	5.6	0.4
47	Bickley	Lightweight Cladding	N/A	450	1.5	N/A	3.5	0.0	Tile + DSRF	3.7	0.4
48	Dubbo	Masonry Veneer	N/A	450	2.0	N/A	4.1	0.0	Tile + VP	4.6	0.4
48	Dubbo	Cavity Brick	N/A	450	0.0	N/A	4.1	0.0	Tile	5.6	0.4
48	Dubbo	Lightweight Cladding	N/A	450	2.0	N/A	4.1	0.0	Tile	3.7	0.4
49	Katanning	Masonry Veneer	N/A	600	1.5	N/A	3.5	0.5	Tile + DSRF	5.6	0.4
49	Katanning	Cavity Brick	N/A	550	0.0	N/A	3.5	0.0	Tile	5.6	0.4
49	Katanning	Lightweight Cladding	N/A	650	1.5	N/A	3.5	0.0	Tile + DSRF	3.7	0.4
50	Oakey	Masonry Veneer	N/A	800	2.5	N/A	3.5	0.0	Tile + DSRF	5.6	0.4
50	Oakey	Cavity Brick	N/A	0	0.0	N/A	2.0	0.0	Tile	5.6	0.4
50	Oakey	Lightweight Cladding	N/A	700	2.0	N/A	3.5	1.5	Tile + DSRF	5.6	0.4
51	Forrest	Masonry Veneer	N/A	600	2.0	N/A	3.5	0.5	Tile + DSRF	5.6	0.4
51	Forrest	Cavity Brick	N/A	850	0.0	N/A	2.0	0.0	Tile	5.6	0.4
51	Forrest	Lightweight Cladding	N/A	450	1.5	N/A	3.5	0.0	Tile + DSRF	3.7	0.4
52	Swanbourne	Masonry Veneer	N/A	600	2.0	N/A	3.5	0.5	Tile + DSRF	5.6	0.4
52	Swanbourne	Cavity Brick	N/A	500	0.0	N/A	2.0	0.0	Tile	5.6	0.4
52	Swanbourne	Lightweight Cladding	N/A	450	1.5	N/A	3.5	0.0	Tile + DSRF	3.7	0.4
53	Ceduna	Masonry Veneer	N/A	350	2.0	N/A	4.1	2.0	Tile + DSRF	5.6	0.4
53	Ceduna	Cavity Brick	N/A	150	0.0	N/A	2.5	0.0	Tile + SSRF	6.7	0.7
53	Ceduna	Lightweight Cladding	N/A	650	2.0	N/A	4.1	1.5	Tile + DSRF	5.6	0.4
54	Mandurah	Masonry Veneer	N/A	550	2.0	N/A	3.5	0.5	Tile + DSRF	5.6	0.4
54	Mandurah	Cavity Brick	N/A	1000	0.0	N/A	2.5	0.0	Tile	5.6	0.4
54	Mandurah	Lightweight Cladding	N/A	450	1.5	N/A	3.5	0.0	Tile + DSRF	3.7	0.4
55	Esperance	Masonry Veneer	N/A	750	2.0	N/A	3.5	0.5	Tile + DSRF	5.6	0.4
55	Esperance	Cavity Brick	N/A	700	0.0	N/A	3.5	0.0	Tile	4.6	0.5
55	Esperance	Lightweight Cladding	N/A	450	1.0	N/A	4.1	0.0	Tile + DSRF	3.7	0.4

Single Storey 3 bedroom House												
NatHERS Climate		Lower Storey	Upper Storey	Eaves	Wall Ground Floor	Wall Upper Floor	Ceiling	Garage/ Habitable Space Wall	Roof	Windows	
										U-Value	SHGC
56	Mascot (Sydney Airport)	Masonry Veneer	N/A	500	2.0	N/A	4.1	2.0	Tile + DSRF	5.6	0.4
56	Mascot (Sydney Airport)	Cavity Brick	N/A	400	Foil	N/A	3.5	0.0	Tile + SSRF	6.7	0.7
56	Mascot (Sydney Airport)	Lightweight Cladding	N/A	550	2.0	N/A	4.1	2.0	Tile + DSRF	5.6	0.4
57	Manjimup	Masonry Veneer	N/A	700	2.0	N/A	3.5	1.0	Tile + DSRF	5.6	0.4
57	Manjimup	Cavity Brick	N/A	500	0.0	N/A	5.0	0.0	Tile + DSRF	4.6	0.5
57	Manjimup	Lightweight Cladding	N/A	700	1.5	N/A	4.1	0.0	Tile + DSRF	3.7	0.4
58	Albany	Masonry Veneer	N/A	600	1.5	N/A	3.5	1.0	Tile + DSRF	5.6	0.4
58	Albany	Cavity Brick	N/A	400	0.0	N/A	5.0	0.0	Tile + DSRF	4.6	0.5
58	Albany	Lightweight Cladding	N/A	900	1.5	N/A	4.1	0.0	Tile + DSRF	3.7	0.4
59	Mt Lofty	Masonry Veneer	N/A	350	2.5	N/A	4.1	2.0	Tile + DSRF	5.6	0.4
59	Mt Lofty	Cavity Brick	N/A	150	0.26+Foil	N/A	5.0	1.0	Tile + SSRF	6.7	0.7
59	Mt Lofty	Lightweight Cladding	N/A	250	2.5	N/A	4.1	1.5	Tile + DSRF	5.6	0.4
60	Tullamarine (Melbourne Airport)	Masonry Veneer	N/A	350	2.5	N/A	3.5	0.0	Tile	4.6	0.4
60	Tullamarine (Melbourne Airport)	Cavity Brick	N/A	600	0.26+Foil	N/A	4.1	0.0	Tile	5.4	0.6
60	Tullamarine (Melbourne Airport)	Lightweight Cladding	N/A	450	1.7	N/A	3.5	1.0	Tile	4.3	0.5
61	Mt Gambier	Masonry Veneer	N/A	450	1.5	N/A	4.1	1.5	Tile + DSRF	5.6	0.4
61	Mt Gambier	Cavity Brick	N/A	350	Foil	N/A	5.0	0.0	Tile + SSRF	6.7	0.7
61	Mt Gambier	Lightweight Cladding	N/A	450	2.0	N/A	4.1	1.5	Tile + DSRF	5.6	0.4
62	Moorabbin	Masonry Veneer	N/A	350	2.0	N/A	3.5	0.0	Tile	4.6	0.4
62	Moorabbin	Cavity Brick	N/A	600	0.26+Foil	N/A	5.0	1.0	Tile	5.4	0.6
62	Moorabbin	Lightweight Cladding	N/A	450	1.5	N/A	4.1	0.0	Tile	4.3	0.5
63	Warrnambool	Masonry Veneer	N/A	700	1.7	N/A	5.0	2.0	Tile	5.6	0.4
63	Warrnambool	Cavity Brick	N/A	450	0.26+Foil	N/A	6.0	0.0	Tile	6.7	0.7
63	Warrnambool	Lightweight Cladding	N/A	550	1.5	N/A	3.5	0.8	Tile + DSRF	5.4	0.6

Single Storey 3 bedroom House											
NatHERS Climate		Lower Storey	Upper Storey	Eaves	Wall Ground Floor	Wall Upper Floor	Ceiling	Garage/ Habitable Space Wall	Roof	Windows	
										U-Value	SHGC
64	Cape Otway	Masonry Veneer	N/A	700	2.7	N/A	5.0	2.0	Tile	5.6	0.4
64	Cape Otway	Cavity Brick	N/A	350	0.0	N/A	4.1	0.0	Tile + DSRF	3.7	0.6
64	Cape Otway	Lightweight Cladding	N/A	550	1.5	N/A	3.5	0.8	Tile + DSRF	5.4	0.6
65	Orange	Masonry Veneer	N/A	450	2.0	N/A	4.1	0.0	Tile	5.4	0.6
65	Orange	Cavity Brick	N/A	350	0.26+Foil	N/A	6.0	2.0	Tile + DSRF	5.6	0.4
65	Orange	Lightweight Cladding	N/A	450	2.5	N/A	5.0	0.0	Tile	5.4	0.6
66	Ballarat	Masonry Veneer	N/A	700	2.7	N/A	6.0	2.0	Tile	5.6	0.4
66	Ballarat	Cavity Brick	N/A	600	0.26+Foil	N/A	3.0	0.0	Tile + DSRF	3.7	0.6
66	Ballarat	Lightweight Cladding	N/A	550	1.5	N/A	4.1	2.0	Tile + DSRF	5.4	0.6
67	Low Head	Masonry Veneer	N/A	700	2.7	N/A	4.1	2.0	Tile	5.6	0.4
67	Low Head	Cavity Brick	N/A	450	0.0	N/A	3.5	0.0	Tile + DSRF	3.7	0.6
67	Low Head	Lightweight Cladding	N/A	450	1.5	N/A	3.5	0.8	Tile	5.4	0.6
68	Launceston Airport	Masonry Veneer	N/A	700	2.0	N/A	5.0	2.0	Tile	5.6	0.4
68	Launceston Airport	Cavity Brick	N/A	300	0.0	N/A	5.0	0.0	Tile + DSRF	3.7	0.6
68	Launceston Airport	Lightweight Cladding	N/A	550	1.5	N/A	3.5	0.8	Tile + DSRF	5.4	0.6
69	Thredbo	Masonry Veneer	N/A	450	2.0	N/A	6.0	2.0	Tile + VP	5.6	0.4
69	Thredbo	Cavity Brick	N/A	450	0.26+Foil	N/A	6.0	2.7	Tile + VP	5.4	0.6
69	Thredbo	Lightweight Cladding	N/A	450	2.0	N/A	5.0	2.0	Tile	5.4	0.6

The Housing Research Facility											
NatHERS Climate		Lower Storey	Upper Storey	Eaves	Wall Ground Floor	Wall Upper Floor	Ceiling	Garage/ Habitable Space Wall	Roof	Windows	
										U-Value	SHGC
1	Darwin	Masonry Veneer	Lightweight Cladding	650	2.0	2.0	3.5	0.0	Tile + DSRF	5.6	0.41
1	Darwin	Cavity Brick	Lightweight Cladding	800	Foil	1.5	2.5	0.0	Tile + DSRF	4.8	0.59
1	Darwin	Lightweight Cladding	Lightweight Cladding	750	1.5	1.5	2.0	1.0	Tile + DSRF	4.8	0.59
2	Pt Hedland	Masonry Veneer	Lightweight Cladding	1100	2.0	2.0	3.5	0.0	Tile + DSRF	5.6	0.41
2	Pt Hedland	Cavity Brick	Lightweight Cladding	700	Foil	1.5	2.5	0.0	Tile + DSRF	4.8	0.59
2	Pt Hedland	Lightweight Cladding	Lightweight Cladding	1000	2.0	2.0	2.0	1.0	Tile + DSRF	5.6	0.41
3	Longreach	Masonry Veneer	Lightweight Cladding	1000	2.5	2.5	3.5	0.0	Tile + DSRF	5.6	0.36
3	Longreach	Cavity Brick	Lightweight Cladding	250	0.0	1.0	2.0	0.0	Tile + DSRF	5.6	0.41
3	Longreach	Lightweight Cladding	Lightweight Cladding	1200	2.0	2.0	2.5	2.0	Tile + DSRF	5.6	0.36
4	Carnarvon	Masonry Veneer	Lightweight Cladding	350	1.5	1.5	3.5	0.0	Tile + DSRF	5.6	0.41
4	Carnarvon	Cavity Brick	Lightweight Cladding	450	0.0	1.5	2.0	0.0	Tile + DSRF	6.7	0.7
4	Carnarvon	Lightweight Cladding	Lightweight Cladding	1200	2.0	2.0	4.1	2.5	Tile + DSRF	6.7	0.57
5	Townsville	Masonry Veneer	Lightweight Cladding	450	2.0	2.0	3.5	0.0	Tile + DSRF	5.4	0.58
5	Townsville	Cavity Brick	Lightweight Cladding	250	Foil	1.5	2.5	0.0	Tile + DSRF	4.8	0.59
5	Townsville	Lightweight Cladding	Lightweight Cladding	1200	1.5	1.5	2.0	1.0	Tile + DSRF	6.7	0.7
6	Alice Springs	Masonry Veneer	Lightweight Cladding	900	2.7	2.7	5.0	2.7	Tile + DSRF	4.8	0.59
6	Alice Springs	Cavity Brick	Lightweight Cladding	800	0.0	1.5	2.5	0.0	Tile + DSRF	4.8	0.59
6	Alice Springs	Lightweight Cladding	Lightweight Cladding	1200	2.0	2.0	3.5	2.0	Tile + DSRF	4.3	0.47
7	Rockhampton	Masonry Veneer	Lightweight Cladding	650	2.0	2.0	3.5	0.0	Tile + DSRF	5.4	0.58
7	Rockhampton	Cavity Brick	Lightweight Cladding	550	0.0	1.5	2.0	0.0	Tile + DSRF	6.7	0.7
7	Rockhampton	Lightweight Cladding	Lightweight Cladding	1200	2.7	2.7	4.1	2.7	Tile + DSRF	6.7	0.7
8	Moree	Masonry Veneer	Lightweight Cladding	450	1.5	1.5	3.5	1.0	Tile + DSRF	4.8	0.59
8	Moree	Cavity Brick	Lightweight Cladding	700	0.0	1.5	3.5	0.0	Tile + DSRF	6.7	0.7
8	Moree	Lightweight Cladding	Lightweight Cladding	450	2.0	2.0	4.1	2.0	Tile + DSRF	4.8	0.59
9	Amberley	Masonry Veneer	Lightweight Cladding	450	1.5	1.5	3.5	1.0	Tile + DSRF	4.8	0.59
9	Amberley	Cavity Brick	Lightweight Cladding	50	0.0	1.0	2.0	0.0	Tile + SRFL	6.7	0.7
9	Amberley	Lightweight Cladding	Lightweight Cladding	1000	2.0	2.0	3.5	1.0	Tile + DRFL	5.6	0.41

The Housing Research Facility

NatHERS Climate		Lower Storey	Upper Storey	Eaves	Wall Ground Floor	Wall Upper Floor	Ceiling	Garage/ Habitable Space Wall	Roof	Windows	
										U-Value	SHGC
10	Brisbane	Masonry Veneer	Lightweight Cladding	450	1.5	1.5	3.5	1.0	Tile + DRFL	6.7	0.7
10	Brisbane	Cavity Brick	Lightweight Cladding	450	0.0	0.5	1.5	0.0	Tile	6.7	0.7
10	Brisbane	Lightweight Cladding	Lightweight Cladding	700	1.5	1.5	3.5	0.0	Tile + DSRF	5.6	0.41
11	Coffs harbour	Masonry Veneer	Lightweight Cladding	450	1.5	2.0	3.5	2.0	Tile + DSRF	6.7	0.7
11	Coffs harbour	Cavity Brick	Lightweight Cladding	450	0.0	DSRF	2.0	0.0	Tile	6.7	0.7
11	Coffs harbour	Lightweight Cladding	Lightweight Cladding	450	2.0	2.0	3.5	1.0	Tile + DSRF	5.6	0.41
12	Geraldton	Masonry Veneer	Lightweight Cladding	200	1.0	1.0	3.5	1.0	Tile + DSRF	4.9	0.33
12	Geraldton	Cavity Brick	Lightweight Cladding	350	0.0	DSRF	2.0	0.0	Tile + DSRF	6.7	0.7
12	Geraldton	Lightweight Cladding	Lightweight Cladding	1000	2.5	2.5	3.5	2.0	Tile + DSRF	5.6	0.36
13	Perth	Masonry Veneer	Lightweight Cladding	450	1.0	1.0	3.5	1.0	Tile + DSRF	3.4	0.4
13	Perth	Cavity Brick	Lightweight Cladding	350	0.0	DSRF	5.0	0.0	Tile + DSRF	5.2	0.39
13	Perth	Lightweight Cladding	Lightweight Cladding	750	2.7	2.7	4.1	2.0	Tile + DSRF	5.2	0.35
14	Armidale	Masonry Veneer	Lightweight Cladding	450	2.5	2.5	4.1	2.0	Tile + DSRF	6.7	0.7
14	Armidale	Cavity Brick	Lightweight Cladding	600	Foil	1.5	3.5	1.0	Tile	4.8	0.59
14	Armidale	Lightweight Cladding	Lightweight Cladding	450	2.5	2.5	3.5	1.0	Tile + DSRF	4.8	0.59
15	Williamtown	Masonry Veneer	Lightweight Cladding	450	2.7	2.7	6.0	0.0	Tile + DSRF	4.8	0.59
15	Williamtown	Cavity Brick	Lightweight Cladding	450	0.0	1.5	3.5	0.0	Tile	4.8	0.59
15	Williamtown	Lightweight Cladding	Lightweight Cladding	450	2.0	2.0	4.1	1.0	Tile + DSRF	4.8	0.59
16	Adelaide	Masonry Veneer	Lightweight Cladding	450	2.0	1.5	3.5	0.0	Tile + DSRF	2.9	0.51
16	Adelaide	Cavity Brick	Lightweight Cladding	600	0.0	2.7	4.1	0.0	Tile + DSRF	4.1	0.52
16	Adelaide	Lightweight Cladding	Lightweight Cladding	900	2.0	2.0	3.5	2.0	Tile + DSRF	4.3	0.53
17	Sydney (Observatory Hill)	Masonry Veneer	Lightweight Cladding	400	1.5	2.0	3.5	0.0	Tile + DSRF	4.8	0.59
17	Sydney (Observatory Hill)	Cavity Brick	Lightweight Cladding	450	0.0	1.0	2.0	0.0	Tile	4.8	0.59
17	Sydney (Observatory Hill)	Lightweight Cladding	Lightweight Cladding	550	1.5	1.5	4.1	0.0	Tile + DSRF	4.8	0.59
18	Nowra	Masonry Veneer	Lightweight Cladding	450	1.5	1.5	3.5	0.0	Tile	2.9	0.51
18	Nowra	Cavity Brick	Lightweight Cladding	800	0.0	1.5	2.0	0.0	Tile + DSRF	4.1	0.52
18	Nowra	Lightweight Cladding	Lightweight Cladding	450	1.5	1.5	3.5	1.0	Tile + DSRF	4.3	0.53

The Housing Research Facility											
NatHERS Climate		Lower Storey	Upper Storey	Eaves	Wall Ground Floor	Wall Upper Floor	Ceiling	Garage/ Habitable Space Wall	Roof	Windows	
										U-Value	SHGC
19	Charleville	Masonry Veneer	Lightweight Cladding	600	2.5	2.5	3.5	0.0	Tile + DSRF	4.8	0.34
19	Charleville	Cavity Brick	Lightweight Cladding	600	0.0	1.5	2.0	0.0	Tile + DSRF	5.6	0.41
19	Charleville	Lightweight Cladding	Lightweight Cladding	450	2.5	2.5	3.5	0.5	Tile + DSRF	4.9	0.33
20	Wagga	Masonry Veneer	Lightweight Cladding	450	2.0	2.0	3.5	0.0	Tile	2.9	0.51
20	Wagga	Cavity Brick	Lightweight Cladding	450	0.0	2.5	6.0	0.0	Tile + DSRF	4.1	0.52
20	Wagga	Lightweight Cladding	Lightweight Cladding	450	1.5	1.5	6.0	1.5	Tile + DSRF	4.3	0.53
21	Melbourne	Masonry Veneer	Lightweight Cladding	450	2.0	2.5	3.5	0.0	Tile +VPM	2.9	0.51
21	Melbourne	Cavity Brick	Lightweight Cladding	450	Foil + 0.38	2.0	3.5	0.0	Tile +VPM	4.1	0.52
21	Melbourne	Lightweight Cladding	Lightweight Cladding	450	2.5	2.5	4.1	2.0	Tile +VPM	4.3	0.53
22	East Sale	Masonry Veneer	Lightweight Cladding	450	1.5	1.5	4.1	0.0	Tile +VPM	2.9	0.51
22	East Sale	Cavity Brick	Lightweight Cladding	450	Foil	2.0	5.0	1.0	Tile +VPM	4.1	0.47
22	East Sale	Lightweight Cladding	Lightweight Cladding	450	2.0	2.0	4.1	1.0	Tile +VPM	4.3	0.53
23	Launceston (Ti Tree Bend)	Masonry Veneer	Lightweight Cladding	450	1.5	1.5	4.1	0.0	Tile +VPM	2.9	0.51
23	Launceston (Ti Tree Bend)	Cavity Brick	Lightweight Cladding	450	Foil	2.0	5.0	1.0	Tile +VPM	4.1	0.47
23	Launceston (Ti Tree Bend)	Lightweight Cladding	Lightweight Cladding	450	2.0	2.0	4.1	1.0	Tile +VPM	4.3	0.53
24	Canberra	Masonry Veneer	Lightweight Cladding	450	1.5	1.5	4.1	0.0	Tile +VPM	2.9	0.51
24	Canberra	Cavity Brick	Lightweight Cladding	450	Foil	2.0	3.5	1.0	Tile +VPM	4.1	0.47
24	Canberra	Lightweight Cladding	Lightweight Cladding	450	2.0	2.0	4.1	1.0	Tile +VPM	4.3	0.53
25	Cabramurra	Masonry Veneer	Lightweight Cladding	450	2.0	2.0	4.1	0.5	Tile +VPM	2.9	0.51
25	Cabramurra	Cavity Brick	Lightweight Cladding	450	Foil + 0.26	2.0	5.0	1.0	Tile +VPM	2.9	0.51
25	Cabramurra	Lightweight Cladding	Lightweight Cladding	450	2.0	2.0	4.1	0.5	Tile +VPM	2.9	0.51
26	Hobart	Masonry Veneer	Lightweight Cladding	450	2.0	2.0	3.5	1.5	Tile +VPM	3.6	0.54
26	Hobart	Cavity Brick	Lightweight Cladding	450	Foil	2.0	3.5	1.0	Tile +VPM	3.6	0.54
26	Hobart	Lightweight Cladding	Lightweight Cladding	450	2.0	2.0	4.1	0.5	Tile +VPM	3.6	0.54
27	Mildura	Masonry Veneer	Lightweight Cladding	450	2.7	2.7	5.0	2.7	Tile +VPM	3.6	0.54
27	Mildura	Cavity Brick	Lightweight Cladding	450	0.0	2.0	4.1	0.5	Tile +VPM	3.6	0.54
27	Mildura	Lightweight Cladding	Lightweight Cladding	450	2.7	2.7	4.1	1.0	Tile +VPM	3.6	0.54

The Housing Research Facility											
NatHERS Climate		Lower Storey	Upper Storey	Eaves	Wall Ground Floor	Wall Upper Floor	Ceiling	Garage/ Habitable Space Wall	Roof	Windows	
										U-Value	SHGC
28	Richmond	Masonry Veneer	Lightweight Cladding	450	2.7	2.7	6.0	0.0	Tile + DSRF	4.8	0.59
28	Richmond	Cavity Brick	Lightweight Cladding	450	0.0	1.0	3.5	0.0	Tile + DSRF	4.8	0.59
28	Richmond	Lightweight Cladding	Lightweight Cladding	450	2.0	2.0	4.1	1.0	Tile + DSRF	4.8	0.59
29	Weipa	Masonry Veneer	Lightweight Cladding	300	2.0	2.0	3.5	0.0	Tile + DSRF	5.6	0.41
29	Weipa	Cavity Brick	Lightweight Cladding	300	0.0	1.0	2.5	0.0	Tile + DSRF	4.8	0.59
29	Weipa	Lightweight Cladding	Lightweight Cladding	300	1.5	1.5	2.0	1.0	Tile + DSRF	4.8	0.59
30	Wyndham	Masonry Veneer	Lightweight Cladding	600	1.0	1.0	3.5	1.0	Tile + DSRF	4.8	0.34
30	Wyndham	Cavity Brick	Lightweight Cladding	600	Foil	1.0	2.5	1.0	Tile + DSRF	4.8	0.34
30	Wyndham	Lightweight Cladding	Lightweight Cladding	600	1.5	1.5	2.0	1.0	Tile + DSRF	4.8	0.34
31	Willis Island	Masonry Veneer	Lightweight Cladding	450	1.0	1.0	3.5	1.0	Tile + DSRF	6.7	0.7
31	Willis Island	Cavity Brick	Lightweight Cladding	600	0.0	1.0	2.5	1.0	Tile + DSRF	6.7	0.7
31	Willis Island	Lightweight Cladding	Lightweight Cladding	600	1.5	1.5	2.0	1.0	Tile + DSRF	6.7	0.7
32	Cairns	Masonry Veneer	Lightweight Cladding	450	2.0	2.0	3.5	0.0	Tile + DSRF	6.7	0.7
32	Cairns	Cavity Brick	Lightweight Cladding	450	Foil	2.0	3.5	0.0	Tile + DSRF	6.7	0.7
32	Cairns	Lightweight Cladding	Lightweight Cladding	450	1.5	1.5	2.0	1.0	Tile + DSRF	6.7	0.7
33	Broome	Masonry Veneer	Lightweight Cladding	700	2.0	2.0	3.5	0.0	Tile + DSRF	5.6	0.41
33	Broome	Cavity Brick	Lightweight Cladding	800	Foil	2.0	3.5	0.0	Tile + DSRF	5.6	0.41
33	Broome	Lightweight Cladding	Lightweight Cladding	900	1.5	1.5	2.0	1.0	Tile + DSRF	5.6	0.41
34	Learmonth	Masonry Veneer	Lightweight Cladding	900	2.0	2.0	3.5	0.0	Tile + DSRF	5.6	0.41
34	Learmonth	Cavity Brick	Lightweight Cladding	800	0.0	2.0	2.5	0.0	Tile + DSRF	6.7	0.7
34	Learmonth	Lightweight Cladding	Lightweight Cladding	1200	1.5	1.5	2.0	1.0	Tile + DSRF	5.6	0.41
35	Mackay	Masonry Veneer	Lightweight Cladding	450	1.0	1.0	2.0	0.0	Tile	6.7	0.7
35	Mackay	Cavity Brick	Lightweight Cladding	450	0.0	0.0	0.0	0.0	Tile + SSRF	6.7	0.7
35	Mackay	Lightweight Cladding	Lightweight Cladding	450	DSRF	DSRF	2.0	0.0	Tile + SSRF	6.7	0.7
36	Gladstone	Masonry Veneer	Lightweight Cladding	450	1.0	1.5	2.0	0.0	Tile	6.7	0.7
36	Gladstone	Cavity Brick	Lightweight Cladding	300	0.0	0.0	0.5	0.0	Tile	6.7	0.7
36	Gladstone	Lightweight Cladding	Lightweight Cladding	550	DSRF	DSRF	2.0	0.0	Tile + SSRF	6.7	0.7

The Housing Research Facility

NatHERS Climate		Lower Storey	Upper Storey	Eaves	Wall Ground Floor	Wall Upper Floor	Ceiling	Garage/ Habitable Space Wall	Roof	Windows	
										U-Value	SHGC
37	Halls Creek	Masonry Veneer	Lightweight Cladding	1300	2.0	2.0	3.5	0.0	Tile + DSRF	5.6	0.41
37	Halls Creek	Cavity Brick	Lightweight Cladding	1200	0.0	1.0	2.0	1.0	Tile + DSRF	5.6	0.41
37	Halls Creek	Lightweight Cladding	Lightweight Cladding	1200	2.0	2.0	3.5	1.0	Tile + SSRF	5.6	0.41
38	Tennant Creek	Masonry Veneer	Lightweight Cladding	1500	2.0	2.0	3.5	0.0	Tile + DSRF	5.6	0.36
38	Tennant Creek	Cavity Brick	Lightweight Cladding	700	0.0	1.0	2.0	1.0	Tile + DSRF	5.6	0.41
38	Tennant Creek	Lightweight Cladding	Lightweight Cladding	1300	2.0	2.0	3.5	1.0	Tile + SSRF	5.6	0.41
39	Mt Isa	Masonry Veneer	Lightweight Cladding	800	2.0	2.0	3.5	0.0	Tile + DSRF	5.6	0.36
39	Mt Isa	Cavity Brick	Lightweight Cladding	700	0.0	0.5	1.5	0.0	Tile + DSRF	5.6	0.41
39	Mt Isa	Lightweight Cladding	Lightweight Cladding	800	2.0	2.0	3.5	1.0	Tile + SSRF	5.6	0.41
40	Newman	Masonry Veneer	Lightweight Cladding	1400	2.0	2.0	3.5	0.0	Tile + DSRF	5.2	0.39
40	Newman	Cavity Brick	Lightweight Cladding	1400	0.0	1.0	2.0	1.0	Tile + DSRF	5.6	0.41
40	Newman	Lightweight Cladding	Lightweight Cladding	1600	2.0	2.0	3.5	1.0	Tile + SSRF	5.2	0.39
41	Giles	Masonry Veneer	Lightweight Cladding	1200	2.5	2.5	3.5	0.0	Tile + DSRF	4.9	0.33
41	Giles	Cavity Brick	Lightweight Cladding	700	0.0	2.0	3.5	1.0	Tile + DSRF	5.6	0.41
41	Giles	Lightweight Cladding	Lightweight Cladding	450	2.7	2.7	4.1	2.7	Tile + DSRF	4.9	0.33
42	Meekatharra	Masonry Veneer	Lightweight Cladding	1200	2.5	2.5	4.1	0.0	Tile + DSRF	4.9	0.33
42	Meekatharra	Cavity Brick	Lightweight Cladding	600	0.0	1.5	3.5	1.0	Tile + DSRF	5.6	0.41
42	Meekatharra	Lightweight Cladding	Lightweight Cladding	450	2.5	2.5	4.1	1.0	Tile + DSRF	4.9	0.33
43	Oodnadatta	Masonry Veneer	Lightweight Cladding	1300	2.7	2.7	4.1	1.0	Tile + DSRF	4.9	0.33
43	Oodnadatta	Cavity Brick	Lightweight Cladding	1200	Foil	1.5	4.1	1.0	Tile + DSRF	5.6	0.41
43	Oodnadatta	Lightweight Cladding	Lightweight Cladding	1300	2.7	2.7	4.1	1.0	Tile + DSRF	4.9	0.33
44	Kalgoorlie	Masonry Veneer	Lightweight Cladding	800	2.7	2.7	5.0	1.0	Tile + DSRF	4.9	0.33
44	Kalgoorlie	Cavity Brick	Lightweight Cladding	1200	0.0	1.5	4.1	1.0	Tile + DSRF	5.6	0.41
44	Kalgoorlie	Lightweight Cladding	Lightweight Cladding	1300	2.7	2.7	4.1	1.0	Tile + DSRF	4.9	0.33
45	Woomera	Masonry Veneer	Lightweight Cladding	800	2.7	2.7	4.1	1.0	Tile + DSRF	4.9	0.33
45	Woomera	Cavity Brick	Lightweight Cladding	450	Foil	1.5	4.1	0.0	Tile + DSRF	5.6	0.41
45	Woomera	Lightweight Cladding	Lightweight Cladding	1300	2.5	2.5	3.5	1.0	Tile + DSRF	4.9	0.33

The Housing Research Facility											
NatHERS Climate		Lower Storey	Upper Storey	Eaves	Wall Ground Floor	Wall Upper Floor	Ceiling	Garage/ Habitable Space Wall	Roof	Windows	
										U-Value	SHGC
46	Cobar	Masonry Veneer	Lightweight Cladding	600	2.0	2.0	3.5	1	Tile + DSRF	4.9	0.33
46	Cobar	Cavity Brick	Lightweight Cladding	450	0.0	1.5	4.1	0.0	Tile + DSRF	5.6	0.41
46	Cobar	Lightweight Cladding	Lightweight Cladding	450	2.0	2.0	3.5	1	Tile + DSRF	4.9	0.33
47	Bickley	Masonry Veneer	Lightweight Cladding	450	2.7	2.7	5.0	2.7	Tile + DSRF	4.9	0.33
47	Bickley	Cavity Brick	Lightweight Cladding	450	Foil	1.5	4.1	2.0	Tile + DSRF	5.6	0.41
47	Bickley	Lightweight Cladding	Lightweight Cladding	450	2.7	2.7	4.1	2.7	Tile + DSRF	4.9	0.33
48	Dubbo	Masonry Veneer	Lightweight Cladding	450	2.7	2.7	6.0	2.7	Tile + DSRF	4.9	0.33
48	Dubbo	Cavity Brick	Lightweight Cladding	450	Foil	2.5	4.1	2.0	Tile + DSRF	5.6	0.41
48	Dubbo	Lightweight Cladding	Lightweight Cladding	450	2.7	2.7	4.1	2.7	Tile + DSRF	4.9	0.33
49	Katanning	Masonry Veneer	Lightweight Cladding	450	2.0	2.5	4.1	2.0	Tile + DSRF	4.8	0.59
49	Katanning	Cavity Brick	Lightweight Cladding	450	0.0	1.0	3.5	1.0	Tile + SSRF	4.8	0.59
49	Katanning	Lightweight Cladding	Lightweight Cladding	450	2.5	2.5	3.5	1.0	Tile + SSRF	4.8	0.59
50	Oakey	Masonry Veneer	Lightweight Cladding	450	2.0	2.0	4.1	2.0	Tile + DSRF	4.8	0.59
50	Oakey	Cavity Brick	Lightweight Cladding	450	0.0	1.0	2.5	0.0	Tile + SSRF	6.7	0.7
50	Oakey	Lightweight Cladding	Lightweight Cladding	450	2.0	2.0	4.1	1.0	Tile + SSRF	4.8	0.59
51	Forrest	Masonry Veneer	Lightweight Cladding	600	2.5	2.5	6.0	1.5	Tile + DSRF	4.5	0.61
51	Forrest	Cavity Brick	Lightweight Cladding	450	Foil	1.0	2.5	0.0	Tile + SSRF	6.7	0.7
51	Forrest	Lightweight Cladding	Lightweight Cladding	450	2.5	2.5	6.0	1.5	Tile + SSRF	4.5	0.61
52	Swanbourne	Masonry Veneer	Lightweight Cladding	450	2.5	2.5	4.1	2.0	Tile + DSRF	4.8	0.59
52	Swanbourne	Cavity Brick	Lightweight Cladding	450	0.0	2.5	2.5	0.0	Tile + DSRF	6.7	0.7
52	Swanbourne	Lightweight Cladding	Lightweight Cladding	450	2.0	2.0	4.1	2.0	Tile + SSRF	4.8	0.59
53	Ceduna	Masonry Veneer	Lightweight Cladding	450	2.5	2.5	5.0	2.0	Tile + DSRF	4.3	0.47
53	Ceduna	Cavity Brick	Lightweight Cladding	450	Foil + 0.38	2.5	3.5	0.0	Tile + DSRF	6.7	0.7
53	Ceduna	Lightweight Cladding	Lightweight Cladding	450	2.5	2.5	4.1	2.0	Tile + SSRF	4.3	0.47
54	Mandurah	Masonry Veneer	Lightweight Cladding	450	2.0	2.0	3.5	1.0	Tile + DSRF	4.8	0.59
54	Mandurah	Cavity Brick	Lightweight Cladding	450	0.0	2.5	2.5	0.0	Tile + DSRF	6.7	0.7
54	Mandurah	Lightweight Cladding	Lightweight Cladding	450	2.0	2.0	4.1	2.0	Tile	4.8	0.59

The Housing Research Facility											
NatHERS Climate		Lower Storey	Upper Storey	Eaves	Wall Ground Floor	Wall Upper Floor	Ceiling	Garage/ Habitable Space Wall	Roof	Windows	
										U-Value	SHGC
55	Esperance	Masonry Veneer	Lightweight Cladding	450	2.7	2.7	5.0	2.7	Tile + DSRF	4.8	0.59
55	Esperance	Cavity Brick	Lightweight Cladding	450	Foil	2.0	3.5	2.0	Tile + DSRF	6.7	0.7
55	Esperance	Lightweight Cladding	Lightweight Cladding	450	2.7	2.7	4.1	2.0	Tile + VPM	4.8	0.59
56	Mascot (Sydney Airport)	Masonry Veneer	Lightweight Cladding	450	2.5	2.5	3.5	0.0	Tile + VPM	4.8	0.59
56	Mascot (Sydney Airport)	Cavity Brick	Lightweight Cladding	450	0.0	2.5	5.0	0.0	Tile + VPM	6.7	0.7
56	Mascot (Sydney Airport)	Lightweight Cladding	Lightweight Cladding	450	2.0	2.0	4.1	0.0	Tile + VPM	4.8	0.59
57	Manjimup	Masonry Veneer	Lightweight Cladding	450	2.7	2.7	4.1	2.7	Tile + VPM	4.3	0.47
57	Manjimup	Cavity Brick	Lightweight Cladding	450	Foil	2.7	6.0	0.0	Tile + VPM	4.3	0.47
57	Manjimup	Lightweight Cladding	Lightweight Cladding	450	2.5	2.5	4.1	2.5	Tile + VPM	4.3	0.47
58	Albany	Masonry Veneer	Lightweight Cladding	450	2.0	2.0	4.1	2.0	Tile + VPM	4.3	0.47
58	Albany	Cavity Brick	Lightweight Cladding	450	Foil	2.7	6.0	0.0	Tile + VPM	4.3	0.47
58	Albany	Lightweight Cladding	Lightweight Cladding	450	2.0	2.0	4.1	1.5	Tile + VPM	4.3	0.47
59	Mt Lofty	Masonry Veneer	Lightweight Cladding	300	2.7	2.7	5.0	2.7	Tile + VPM	4.1	0.52
59	Mt Lofty	Cavity Brick	Lightweight Cladding	50	Foil + 0.38	2.7	6.0	2.7	Tile + VPM	4.1	0.52
59	Mt Lofty	Lightweight Cladding	Lightweight Cladding	450	2.7	2.7	5.0	2.7	Tile + VPM	4.1	0.52
60	Tullamarine (Melbourne Airport)	Masonry Veneer	Lightweight Cladding	450	2.5	2.5	5.0	2.5	Tile + VPM	4.3	0.47
60	Tullamarine (Melbourne Airport)	Cavity Brick	Lightweight Cladding	450	Foil + 0.38	2.0	4.1	1.0	Tile + VPM	4.3	0.47
60	Tullamarine (Melbourne Airport)	Lightweight Cladding	Lightweight Cladding	450	2.5	2.5	5.0	2.0	Tile + VPM	4.3	0.47
61	Mt Gambier	Masonry Veneer	Lightweight Cladding	450	2.5	2.5	5.0	1.5	Tile + VPM	4.3	0.47
61	Mt Gambier	Cavity Brick	Lightweight Cladding	450	Foil + 0.38	2.0	3.5	1.0	Tile + VPM	4.3	0.47
61	Mt Gambier	Lightweight Cladding	Lightweight Cladding	450	2.5	2.5	4.1	0.0	Tile + VPM	4.3	0.47
62	Moorabbin	Masonry Veneer	Lightweight Cladding	450	2.7	2.7	6.0	2.7	Tile + VPM	4.3	0.47
62	Moorabbin	Cavity Brick	Lightweight Cladding	450	Foil + 0.38	2.7	6.0	1.5	Tile + VPM	4.3	0.47
62	Moorabbin	Lightweight Cladding	Lightweight Cladding	450	2.7	2.7	6.0	2.7	Tile + VPM	4.3	0.47

The Housing Research Facility											
NatHERS Climate		Lower Storey	Upper Storey	Eaves	Wall Ground Floor	Wall Upper Floor	Ceiling	Garage/ Habitable Space Wall	Roof	Windows	
										U-Value	SHGC
63	Warrnambool	Masonry Veneer	Lightweight Cladding	450	2.7	2.7	5.0	1.5	Tile + VPM	4.3	0.47
63	Warrnambool	Cavity Brick	Lightweight Cladding	450	Foil + 0.38	2.7	4.1	1.0	Tile + VPM	4.3	0.47
63	Warrnambool	Lightweight Cladding	Lightweight Cladding	450	2.7	2.7	5.0	1.0	Tile + VPM	4.3	0.47
64	Cape Otway	Masonry Veneer	Lightweight Cladding	450	2.7	2.7	6.0	2.7	Tile + VPM	3.6	0.47
64	Cape Otway	Cavity Brick	Lightweight Cladding	450	Foil + 0.38	2.5	5.0	1.5	Tile + VPM	3.6	0.54
64	Cape Otway	Lightweight Cladding	Lightweight Cladding	450	2.7	2.7	5.0	1.0	Tile + VPM	3.6	0.54
65	Orange	Masonry Veneer	Lightweight Cladding	450	2.7	2.7	4.1	2.7	Tile + VPM	3.6	0.47
65	Orange	Cavity Brick	Lightweight Cladding	450	Foil + 0.38	2.5	3.5	1.5	Tile + VPM	3.6	0.54
65	Orange	Lightweight Cladding	Lightweight Cladding	450	2.7	2.7	3.5	1.0	Tile + VPM	3.6	0.54
66	Ballarat	Masonry Veneer	Lightweight Cladding	450	2.7	2.7	5.0	2.7	Tile + VPM	3.6	0.54
66	Ballarat	Cavity Brick	Lightweight Cladding	450	Foil + 0.38	2.5	5.0	1.5	Tile + VPM	3.6	0.54
66	Ballarat	Lightweight Cladding	Lightweight Cladding	450	2.7	2.7	5.0	1.5	Tile + VPM	3.6	0.54
67	Low Head	Masonry Veneer	Lightweight Cladding	450	2.0	2.0	4.1	1.0	Tile + VPM	3.6	0.47
67	Low Head	Cavity Brick	Lightweight Cladding	450	Foil	2.5	6.0	0.0	Tile + VPM	3.6	0.54
67	Low Head	Lightweight Cladding	Lightweight Cladding	450	2.0	2.0	3.5	1.0	Tile + VPM	3.6	0.47
68	Launceston Airport	Masonry Veneer	Lightweight Cladding	450	2.5	2.5	5.0	1.0	Tile + VPM	3.6	0.47
68	Launceston Airport	Cavity Brick	Lightweight Cladding	450	Foil	2.5	5.0	1.0	Tile + VPM	3.6	0.54
68	Launceston Airport	Lightweight Cladding	Lightweight Cladding	450	2.5	2.5	4.1	1.0	Tile + VPM	3.6	0.47
69	Thredbo	Masonry Veneer	Lightweight Cladding	450	2.7	2.7	6.0	2.7	Tile + VPM	3.6	0.54
69	Thredbo	Cavity Brick	Lightweight Cladding	450	Foil + 0.38	2.7	5.0	2.7	Tile + VPM	3.5	0.64
69	Thredbo	Lightweight Cladding	Lightweight Cladding	450	2.7	2.7	5.0	2.7	Tile + VPM	3.6	0.54

APPENDIX F – ASHRAE VENTILATION EFFECTIVENESS

The study by ASHRAE (Rudd, Lstiburek, & Townsend, 2009) utilised a reference exposure level based on the ASHRAE Standard 62.2-2007 ventilation rate using a fully-ducted balanced ventilation system as the reference system and a moderately airtight building enclosure (3.5 ACH_{50}). A ventilation airflow coefficient was then determined for each ventilation system such that the occupant exposure using the subject ventilation system was equal to the occupant exposure using the reference system at the baseline ventilation rate. These coefficients can be used to compare the effectiveness of different ventilation systems.

A single house plan was used in this study. The house modelled is a two-story, approximately 2600 sf (240 m2) house with four bedrooms and three bathrooms.

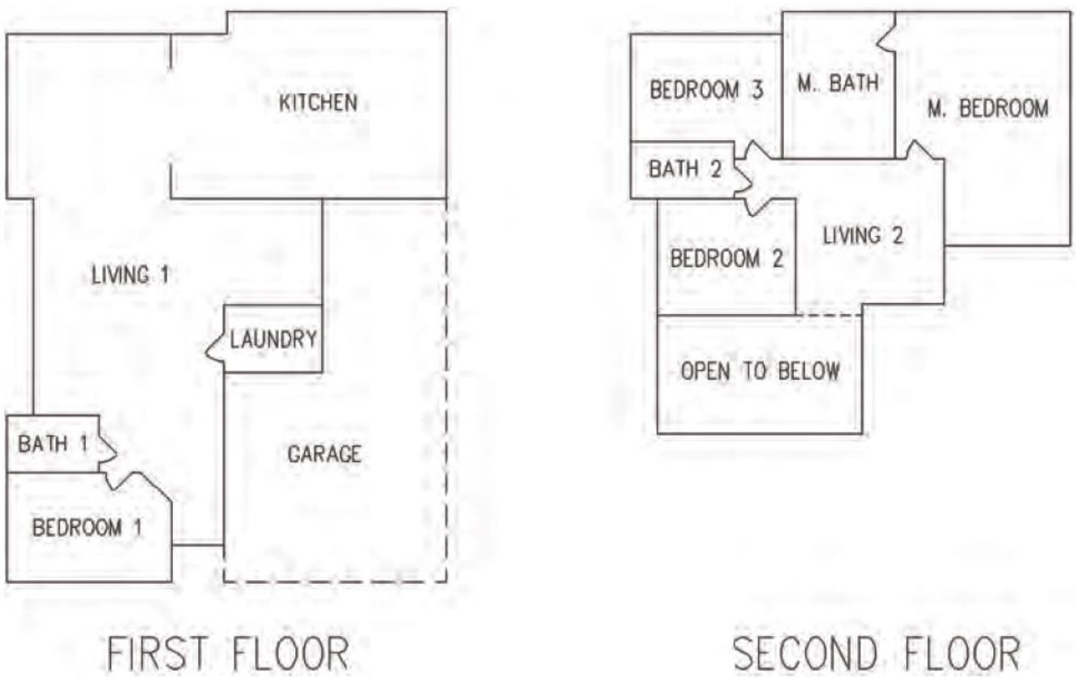


Figure 76 ASHRAE house used for ventilation effectiveness simulations

APPENDIX G – PEAK COOLING LOAD BY NATHERS CLIMATE

Using hourly load analysis the peak load spikes for the summer cooling and winter heating are able to be calculated for all climate zones.

The graphs below show an example in Canberra for how the peak heating and cooling requirements vary based on approximately 1.75ACH^{-1} (35ACH$_{50}$) and 0.5ACH^{-1} (10 ACH$_{50}$) and using Typical Meteorological Year (TMY) data for load analysis. Figure 77 -80 show the hourly loads for the double storey 6 Star Housing Research Facility in Canberra. It can be seen that the estimated cooling and heating peaks are significantly reduced with an infiltration reduction from 1.75 to 0.5ACH^{-1} by 16% and 25% respectively.

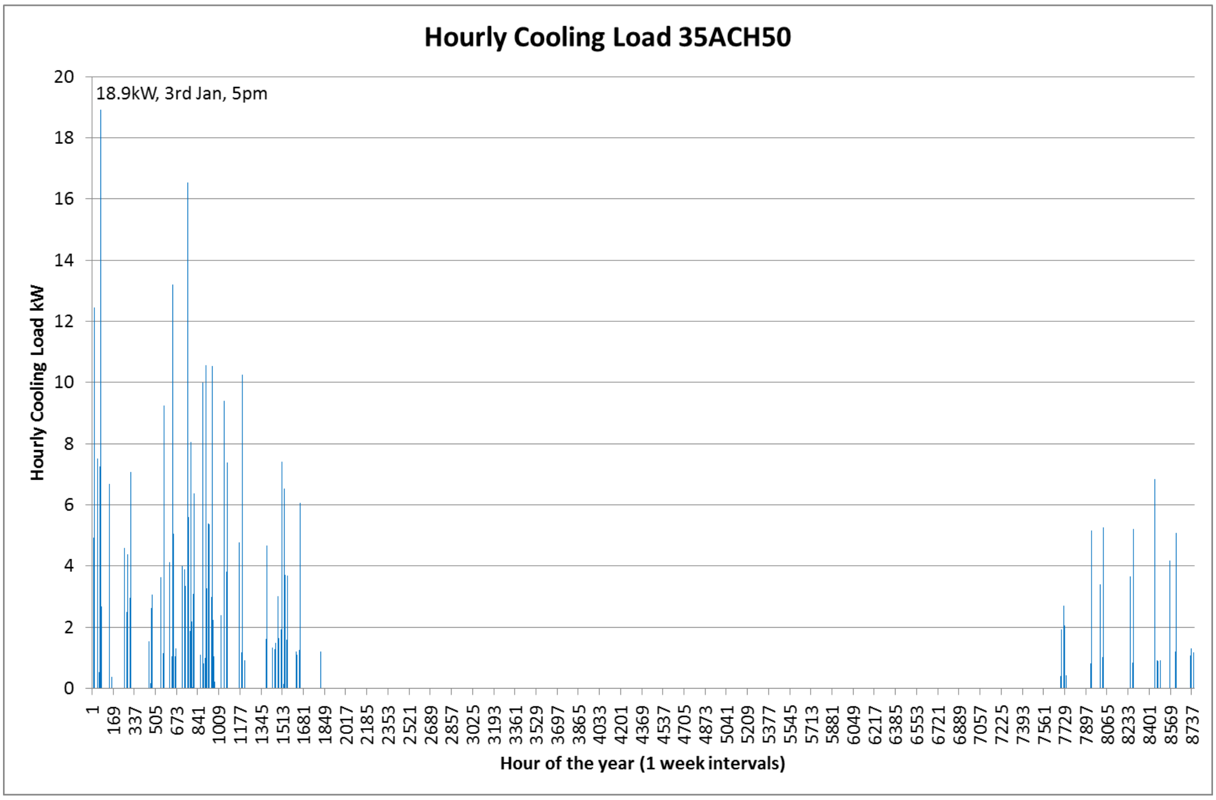


Figure 77 Hourly peak cooling load, Housing Research Facility, Canberra, 35 ACH$_{50}$ (Leaky)

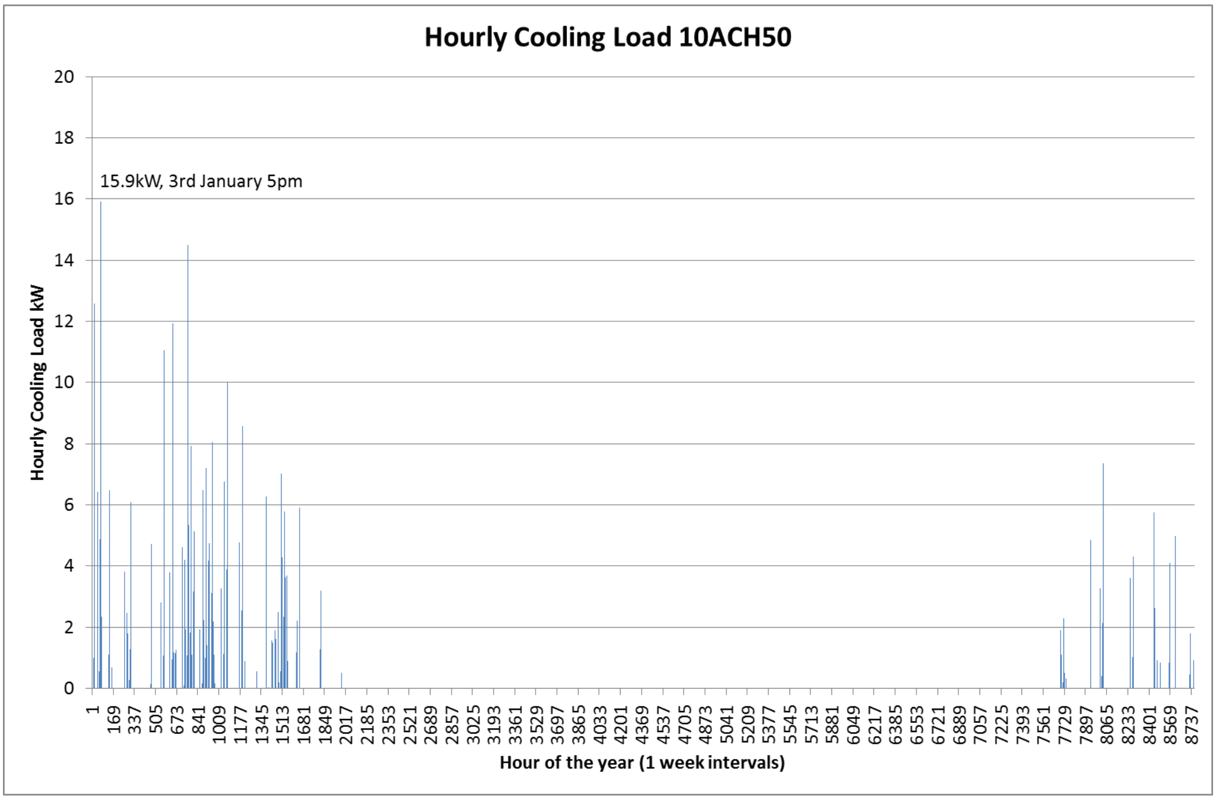


Figure 78 Hourly peak cooling load, Housing Research Facility, Canberra, 10 ACH_{50} (Sealed)

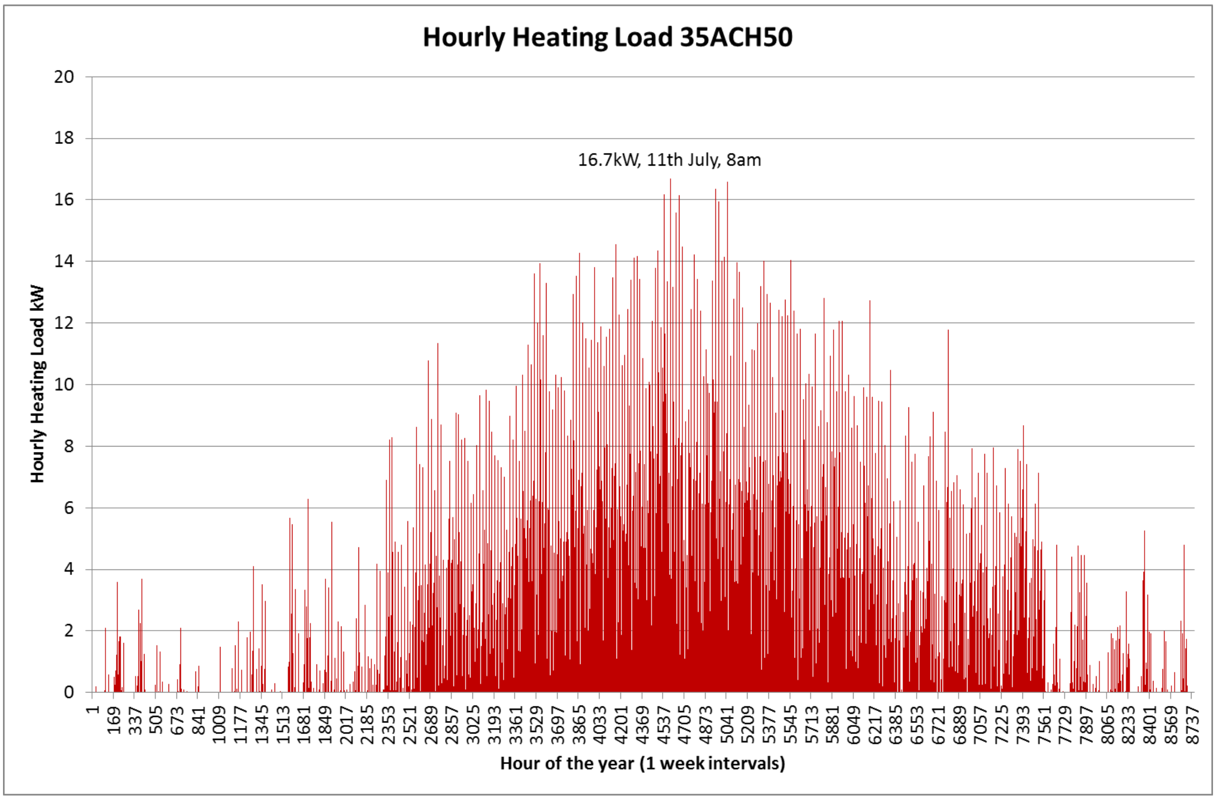


Figure 79 Hourly peak heating load, Housing Research Facility, Canberra, 35 ACH_{50} (Leaky)

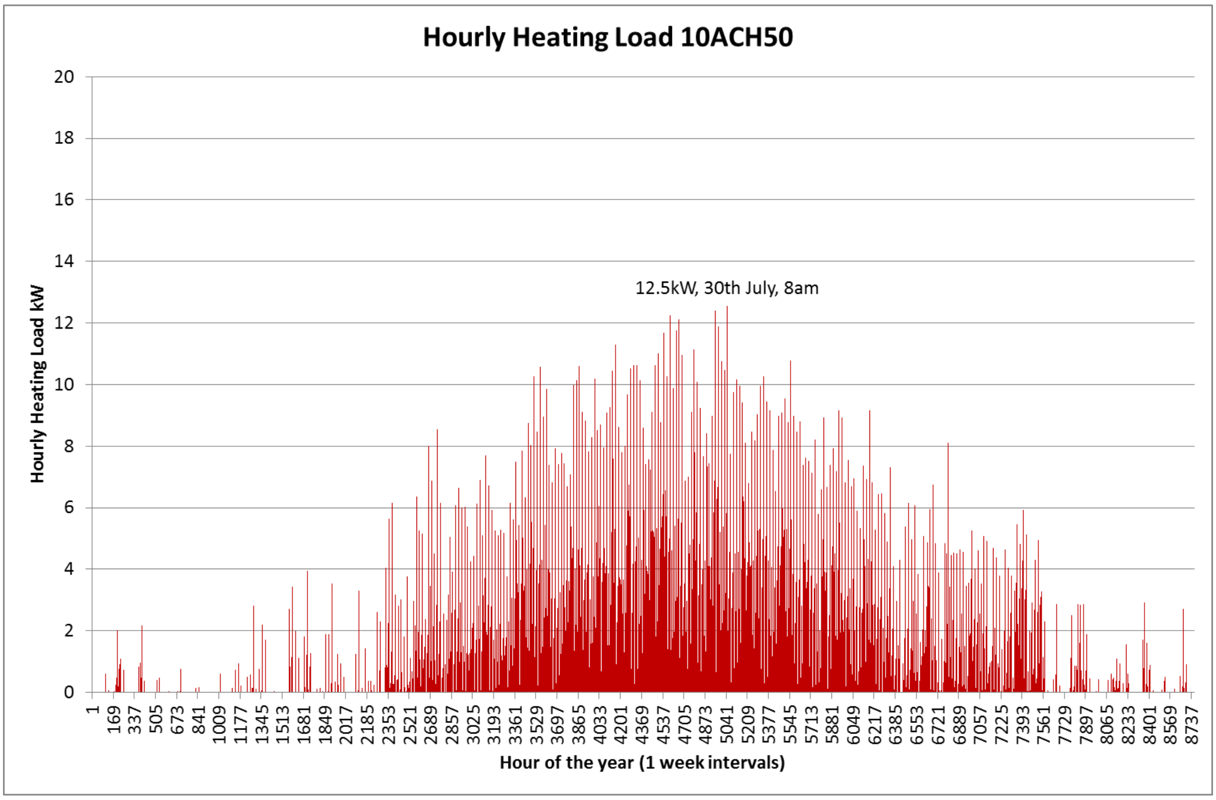


Figure 80 Hourly peak heating load, Housing Research Facility, Canberra, 5 ACH_{50} (Sealed)

End of report