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# FINAL REPORT

## APY Lands Energy Efficiency Retrofit Pilot

## Final report

RACE for Homes

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**Research Theme H2:** Enhancing Thermal Efficiency
APY Lands Energy Efficiency Retrofit Pilot

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### Aboriginal health & housing

Aboriginal Affairs & Reconciliation, SA Attorney-General's Department, Healthabitat, Nganampa Health Council

### Home assessment & monitoring

Powertech Energy, Air Tightness Testing & Measurement Association

### Retrofit solutions

Insulation Council of Australia & New Zealand, Kingspan, Sika Australia

### Trades training

Deep Space, Efficiency Matrix, Pointsbuild, TAFE SA

## Acknowledgement of Country

The authors of this report would like to respectfully acknowledge the Traditional Owners of the ancestral lands throughout Australia and their connection to land, sea and community. We recognise their continuing connection to the land, waters, and culture and pay our respects to them, their cultures and to their Elders past and present. We acknowledge that everything we do in this project impacts on Aboriginal country and Aboriginal people. We are ready to walk, learn and work together.

## What is RACE for 2030?

Reliable, Affordable Clean Energy for 2030 (RACE for 2030) is an innovative cooperative research centre for energy and carbon transition. We were funded with $68.5 million of Commonwealth funds and commitments of $280 million of cash and in-kind contributions from our partners. Our aim is to deliver $3.8 billion of cumulative energy productivity benefits and 20 megatons of cumulative carbon emission savings by 2030. https://www.racefor2030.com.au/

## Disclaimer

# Executive Summary

The RACE for 2030 APY Lands Energy Efficiency Retrofit Pilot took place in the Indulkana (Iwantja) community between 2023 and 2025. The Pilot was born out of a drive by the University of South Australia (UniSA; now part of Adelaide University – AU), the South Australian Housing Trust (SAHT) and the Department for Energy and Mining (DEM) to address the high energy demand and poor thermal comfort of housing stock in the APY Lands. Through improving the houses' energy efficiency, our aim was enabling community members to live well on Country now and in the future.

Building assessments at the commencement of the Pilot revealed uncontrolled air leakage and thermal bridging throughout the thermal envelope as key areas of concern in APY Lands community housing. To understand the lived experience within the homes, community engagement and interviews were undertaken with the assistance of local energy education workers.

A wide range of industry partners supported the project by cash and in-kind contributions, and it was through the expertise of the technical partners that retrofit solutions were developed.

Modelling using DesignBuilder software allowed us to test a range of potential solutions, with test rooms subsequently constructed in Adelaide to trial and understand their practical application. With monitoring devices installed in the Pilot homes, we recorded temperature, humidity and electricity consumption before and after the retrofits.

Six community homes had retrofit solutions applied, while six reference houses of comparable construction and age were monitored during the study period. We implemented three levels of retrofit: **Level** 1, gap sealing; **Level** 2, gap sealing and additional ceiling insulation; and **Level** 3, gap sealing, additional ceiling insulation and a continuous layer of rigid insulation applied to the façade of the house.

Our simulations suggested that the retrofits would save energy primarily through reducing heating demand by up to 59%. Airtightness improvements contributed the greatest individual savings, with the addition of continuous insulation layers most impactful where existing insulation was compromised.

Interviews from before and after highlight that households felt warmer in their homes after the retrofit, even when a heating source was not being used, and when heating was used it was needed for less time. In summer, cooling was more often used for only a few hours each day, rather than all day as was the case prior to the retrofit.

Monitoring data revealed significant reductions in electricity consumption on cold days, particularly following the Level 3 retrofits. While limited summer data was available, one Level 3 retrofit house showed a significant reduction in evaporative cooler use after the retrofit.

The positive results from the retrofits have been supported by home energy education materials, including posters, booklets, and an animated video, created with the Indulkana community and the project's Industry Reference Group. These materials were used during the Pilot and will continue to be shared during home energy education visits across the APY Lands.

Trade training materials include instructional videos curated by industry partners for the project, and an animated video summarising the key problems discovered with housing during the Pilot and the solutions developed to fix them. SAHT will continue use these materials in their wider retrofit program.

All energy education and trade training materials can be found on the Net Zero Energy Builder learning hub.[1]

The project demonstrated that reduced air leakage and thermal bridging, along with insulation improvements, can deliver greater thermal comfort as well as energy savings for residents. Modelling predicts that households receiving at least a Level 1 retrofit can save approximately $400 per year (on the heavily subsidised $0.10/kWh tariff). The cost for government to supply electricity to households (at a rate $0.68/kWh) is predicted to be reduced by at least $2600 per household per year. For the 411 SAHT-managed houses across the APY region, this equates to around $1 million per year in energy savings.

Implementation of the findings from the Pilot is already underway, with SAHT applying gap sealing and insulation treatments to homes across the APY Lands. Plans are in place to repeat this remediation work in other remote communities across South Australia. The findings from the Pilot have also influenced SAHT design updates, and our hope is that this project will continue to influence government housing policy across Australia.

## Key Retrofit Outcomes

- Households report feeling warmer in winter and cooler in summer, using heating and cooling less than previously.
- Air leakage in houses was reduced by an average of 53% and thermal bridging mitigation appears effective.
- Each retrofitted household saved an estimated 20 kWh/day of electricity on cold days.
- The energy education program is expected to deliver further energy reductions.

Modelling indicates:

- The minimum annual savings per home are estimated at $400 in household energy costs and $2600 in State Government electricity supply costs.
- Demand reduction equates to ~$1 million per year in energy savings for the 411 SAHT-managed houses across the APY region.
- A reduction of over 10 tonnes carbon dioxide equivalent per household per year.

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[1] https://netzeroenergybuilder.com.au/netzero/welcome

# Contents

# 1 Project initiation and baseline

## 1.1 Project background

While Aboriginal people have lived in Australia's Western Desert for tens of thousands of years, temperature extremes and associated severe thermal stresses have become more pronounced, compounded by complex social and logistical challenges. With broader climate extremes and overall hotter summers predicted for the future, how people are living and maintaining healthy communities on Country is of growing concern.

This project investigated and provided solutions to challenges for energy performance and thermal comfort faced by Aboriginal people living in remote housing, specifically in the extremely harsh and variable climate of the Aṉangu Pitjantjatjara Yankunytjatjara (APY) Lands (Figure 1). We conducted a retrofitting Pilot in the community of Indulkana (Iwantja). The aim was to test the effectiveness and financial viability of various energy efficiency solutions for houses of different ages and constructions, towards the goal of replicating successful measures throughout the region. Data and experience captured in this Pilot are also relevant to future upgrades in other remote locations with similar challenges, and in existing homes across Australia.

**Figure 1. Map showing the location of the Aṉangu Pitjantjatjara Yankunytjatjara (APY) Lands (red border).**[2]

### 1.1.1 Community engagement

The South Australian Housing Trust (SAHT) and the Department for Energy and Mining (DEM) had formed relationships with community members in their previous work, which assisted in engagement with the community throughout the Pilot. The Future Sustainability Energy Education Program, delivered by

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[2] Map created using Digital Atlas of Australia (digital.atlas.gov.au).

MoneyMob Talkabout on behalf of DEM, provided a best practice model for engagement and education in APY Land communities, and was the catalyst for this Pilot. The work undertaken by the two departments and community members during the Future Sustainability Program highlighted the need for energy efficient homes for households to better control their energy consumption—hence the Pilot was born.

Energy Education Workers (EEWs), employed through the Future Sustainability Program, were recruited for the Pilot to ensure clear two-way communication was possible between the project team and participating households. The Indulkana community council was engaged throughout the Pilot, for initial permission to conduct the research, contributing feedback on education materials, and updates on Pilot progress. At each meeting the council members were supportive of the work being conducted and happy to share Indulkana's experience in the Pilot with a wider audience.

### 1.1.2 The houses

The SAHT-managed houses in the APY Lands are of lightweight steel-framed, slab-on-ground construction, with steel cladding and flat ceilings under pitched rooves. They typically have impact board wall linings and profiled steel ceiling linings.[3] The construction is durable for the harsh environment while minimising transport and construction costs. Insulation includes glasswool batts in ceilings and walls (R4.1 and R2.5 respectively). AIRCELL Insulbreak, a proprietary 3-in-1 insulation, vapour barrier and thermal break (R0.2) material for steel-framed construction, is installed between the roof cladding and steel trusses and between the wall cladding and steel frame. The windows are aluminium-framed with durable polycarbonate panes. The low window-to-floor ratio, along with 3.4m deep verandas, limits solar heat gains. The newer APY houses in our Pilot were rated above eight stars in the Nationwide House Energy Rating Scheme (NatHERS), significantly exceeding the 6-star requirement of the National Construction Code at the time of construction.

Each house is fitted with a ducted evaporative cooling system and a wood combustion heater/stove. While the wood stoves are liked by some residents, access to wood is limited across the arid region, so most households rely on electric radiant heaters. The coolers are up to nine times the efficiency of the heaters, which is apparent in electricity consumption records (see 1.2.3). A<u>n</u>angu[4] also display a tendency to prefer warmer temperatures and at times have limited access to warm clothing.

## 1.2 Baseline assessment

To target the housing retrofits, we first assessed the current thermal performance and energy use of houses in Indulkana. A brief summary is presented here, with further details provided in the Pilot's Year 1 Impact Report.[5] The measured thermal performance and reported comfort of residents seemed inconsistent with the high NatHERS rating of the houses and their energy-efficient design features.

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[3] Construction details such as interior linings and thermal breaks vary with era of construction and specific designs.

[4] A<u>n</u>angu, meaning "people", is used to refer to Aboriginal peoples of the Western Desert region.

[5] Wilson, C., Curtis, L., Douglas-Hill, S., Hespe, P., Huang, B., Reeves, C., and Xing, K. (2025). APY Lands Energy Efficiency Retrofit Pilot—Annual Impact Report. Prepared for RACE for 2030. https://online.fliphtml5.com/jczqfe/fmyv/

### 1.2.1 Building assessment

**Figure 2. Key thermal performance issues identified in building assessments. (*a*) The temperature differences shown by infrared imaging highlight the impact of thermal bridging via wall framing. (*b*) The roof trusses introduce gaps that allow heat to bypass the ceiling insulation; this photograph also shows age-related compaction of the insulating batts. (*c*) Gaps at cornices allowed air leakage through the building fabric. (*d*) Blower door testing revealed air leakage via an unsealed door.**

Thermal performance assessments of 20 houses, in winter 2023, highlighted uncontrolled air leakage and thermal bridging as prominent issues (Figure 2).[6] Additionally, some sections of bulk insulation were missing, damaged or degraded. In the walls and ceilings, infrared imaging showed evidence of heat bypassing the insulation batts via the heat-conducting steel framing. This *thermal bridging* was apparent even where thermal break material was present between the cladding and frame. It is possible that the effectiveness of the thermal break was diminished by compression and dust accumulation. Air leakage allows hotter or colder outside air to replace conditioned indoor air. The houses tested in the APY Lands averaged a leakage (permeability) of 24.3 $m^3/(h \cdot m^2)$ at 50 Pascals of pressurisation—more than double the limit specified in the National Construction Code (NCC) since 2019.[7] While air leakage was widespread, the evaporative cooling system contributed around one third of all leakage measured.

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[6] Testing was conducted by Sean Maxwell, Air Tightness Testing and Measurement Association of Australia (Maxwell, S. (2023) APY Retrofit Pilot Study—Building Envelope Performance Testing—Final Report, ATTMA Australia).

[7] **H6V3 – Verification of building envelope sealing, NCC 2022 Volume Two – Building Code of Australia Class 1 and 10 buildings. https://ncc.abcb.gov.au/editions/ncc-2022/adopted/volume-two/h-class-1-and-10-buildings/part-h6-energy-efficiency**

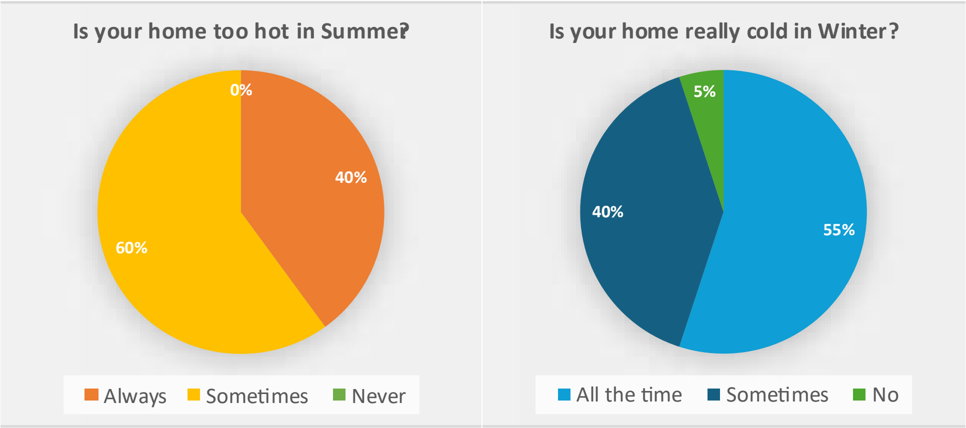

**Figure 3. Households reported that their homes were too hot in summer and too cold in winter, at least some of the time. Over half told us their houses were always cold in winter.**

### 1.2.2 Household interviews

In household interviews conducted in October 2023, the most prominent issue was that residents felt cold in their homes in winter (Figure 3). With scarce fuel for the houses' combustion heaters, all households used electric heaters to stay warm, with electric stoves also sometimes used for heating. Following the Future Sustainability Program, Aṉangu were conscious of energy costs for heaters and attempted to limit the use of ovens for heating; however, the high levels of discomfort and reliance on radiant heating were consistent with the high winter electricity usage recorded (see 1.2.3). Over summer, about two thirds of households used evaporative cooling all day and night, or at least when home. Feeling too hot generally related to problems with the coolers. Because fresh air is valued, windows are frequently opened in winter as well as summer. The difficulty in maintaining comfortable conditions is exacerbated in large households, which are common in the APY Lands.

As Pitjantjatjara/Yankunytjatjara are first languages in the APY Lands, EEWs accompanied the project team when conducting interviews, to interpret and to seek clarification when necessary, allowing a more nuanced understanding than purely delivering questions to a formula. To account for cultural and language differences, the team engaged Iwiri Aboriginal Corporation to ensure interview questions were culturally appropriate and could be readily understood.

### 1.2.3 In-home monitoring

We recorded indoor and outdoor temperature and humidity in 12 houses, from May 2024 through August 2025, along with electricity use for the evaporative coolers, stoves, and electric boost for solar water heaters. Electricity supply records from DEM confirmed that cold weather dominates energy consumption. The mean daily electricity use for winter in 2024 was 57 kWh, with the maximum daily usage averaging 121 kWh over the 12 households.[8] In contrast, the mean electricity usage over summer in 2024-25 was 21 kWh/day, with the maximum averaging 42 kWh/day, across the six non-retrofit houses. For the same houses, the winter quarter of 2024 comprised over 40% of the annual electricity consumption (June 2024 through May 2025).

Although monitoring of heater usage at the power outlet was limited to a brief period for two houses, it showed daily electricity usage up to 49 kWh—consistent with a 2000W heater running all day. Over winter

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[8] Daily electricity usage for a single household was as high as 170 kWh during winter.

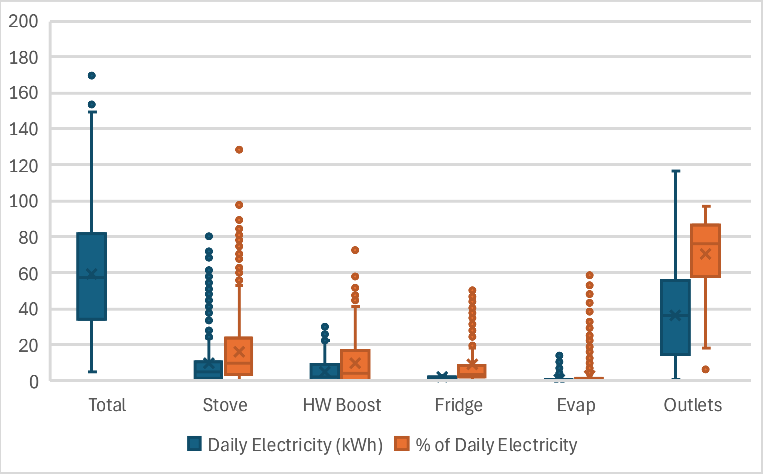

**Figure 4. Breakdown of electricity consumption by appliance/circuit, for the 12 study houses (pooled data), Winter 2024. The high upper ranges of stove usage are consistent with its use for heating in some homes. The electric boost for solar hot water (HW Boost) also shows high usage in winter. Because the time period is heating dominated, the "Outlets" consumption (inferred by subtracting monitored appliances from totals) may be largely attributed to bar heaters. Evaporative coolers (Evap) were occasionally used. In the box plot, the boxes indicate the 25th to 75th percentile ranges, the horizontal lines within each box the medians, crosses the means, and circles are outliers.**

2024, approximately two thirds of the average daily electricity could be attributed to power outlets, suggesting over 30 kWh/day used by heaters (Figure 4). Stove and hot water booster usage also increase in winter (10 kWh/day for stoves vs 4.0 kWh over the remaining nine months; 5.7 kWh vs 2.6 kWh for hot water), although the figures were highly variable.

Evaporative cooler usage in summer 2024-25 averaged 11 kWh/day, corresponding to about 11 hours of running at maximum power. Temperature monitoring showed that, even on days when outdoor temperatures exceeded 50°C, the coolers could maintain indoor temperatures below 30°C.

### 1.2.4 Modelling baseline house performance

We developed a computer model of a recent three-bedroom APY house using DesignBuilder, to evaluate the thermal and energy performance of the houses in their "as lived in" state. For the baseline model, air leakage was set to 25 $m^3/(h{\cdot}m^2)$ at 50 Pa (mean for the three-bedroom houses in our study; equivalent to 29 air changes per hour [ach]).[9] Using the calculation methods of NZS 4214: 2006[10], thermal bridging reduced wall and ceiling insulation performance by about half. As a worst-case scenario for the condition of the bulk insulation, we developed a separate model with no bulk insulation.

The performance of the building envelope was quantified in terms of heating and cooling demand—the amount of heat (kWh) that needs to be added and removed from the house, respectively, to maintain indoor temperatures in a comfortable 24–26°C range. We used NatHERS weather data for climate zone 6 for current

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[9] This maximum infiltration rate was applied May through September, when the unused evaporative cooler is a major air leakage path (see 1.2.1). Assuming the cooler would be in use for the remainder of the year, a reduced infiltration of 17 $m^3/(m^2h)$ at 50Pa was applied, based on an average 8 $m^3/(m^2h)$ attributable to the cooling system.[6] Because the combustion heaters are rarely used (see 1.1.2), we did not include them in our modelling, either in terms of heating or venting of indoor air via the combustion chamber.

[10] NZS 4214: 2006 – Methods of Determining the Total Thermal Resistance of Parts of Buildings. This is the method prescribed in the 2022 National Construction Code. However, we calculated bridged areas according to the actual frame layout rather than using nominal stud spacing as prescribed.

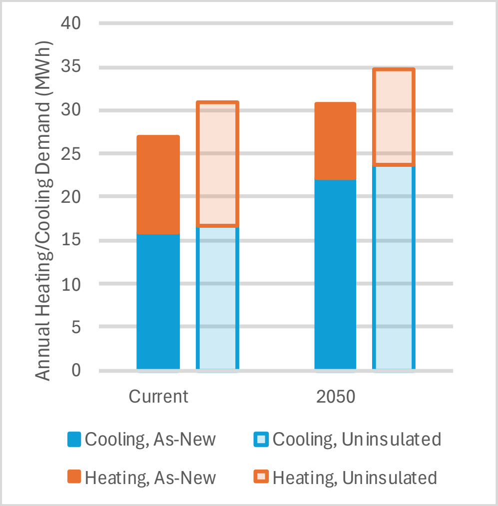

**Figure 5 shows annual heating and cooling demand for "intact" and "missing" insulation cases, for current and 2050 RCP 8.5 climate scenarios. These figures represent the amount of heat that must be moved to maintain temperatures between 24 and 26°C, while the electricity consumption will depend on the appliances used.**

climate, and the CSIRO-developed projection of these data[11] to 2050 under the high-emissions scenario, RCP 8.5,[12] to examine the likely impacts of climate change.

In the baseline scenario (insulation intact), heating demand comprises 45% of the annual total (Figure 5). However, the nominal efficiency of the evaporative coolers is almost nine times that of the heaters, making heating up to 88% of annual electricity usage for heating and cooling. The worst-case insulation scenario results in a 28% increase in heating demand, and a 6% increase in cooling demand. Under RCP 8.5 projections, annual cooling demand increases by 42% by 2050, while heating demand decreases by 23%, with similar changes for the uninsulated scenario.

The prominence of cold discomfort reported in resident interviews, and of heating energy in both monitoring and simulation data, highlight cold-weather performance as a clear target for reducing electricity demand. However, the warming expected by 2050 indicates that any upgrades will need to also deliver energy efficiency in hot weather for lasting impacts.

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[11] Ren, Z., Tang, Z. and James, M. (2021) Predictive weather files for building energy modelling. User Guide. CSIRO, Australia.

[12] Representative Concentration Pathway 8.5: regarded as a "business as usual" emissions scenario, it corresponds to radiative forcing of 8.5 W/m$^2$ above the 2005 level by 2100. The RCPs are climate change scenarios developed for the 5th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC).

# 2 Retrofit strategy development

Our priority in this Pilot was to improve the thermal envelope of the houses, to reduce the energy needed for heating and cooling, and to improve protection from extreme temperatures for residents now and in the future. In developing the retrofit strategy, we formed specific working groups with our industry partners: one to target air leakage and the other targeting insulation and thermal bridging issues.[5]

## 2.1 Exploring solutions

DesignBuilder simulations of 14 candidate solutions for insulation and thermal bridging showed a greater impact on heating demand than cooling. Both simulations and the working group's ranking against weighted criteria placed a continuous layer of 50mm rigid foam insulation as the preferred solution for ceilings and exterior walls, with installation over the existing exterior wall cladding judged less complex and disruptive than other options. The second-ranked option for ceiling upgrades was to install a continuous layer of semi-rigid glasswool insulation through the roof trusses, after restoring any compromised bulk insulation. The same material delivered the next best wall improvements in the simulations, and was favoured over foam thermal break strips in installation trials (see 2.2), where the latter showed excessive compression. Wall upgrades were generally considered more complex than ceiling retrofits, but showed slightly greater benefits in most simulations.

The airtightness working group proposed a range of potential solutions for specific leakage points, with product selection for gap sealing ultimately relying on trials on site, and in two purpose-built test rooms (see 2.2). For all retrofit simulations, we assumed airtightness upgrades could achieve an air infiltration rate of 10 ach (~9m$^3$/(m$^2$h) permeability) at 50 Pa, as the best result from our initial testing in Indulkana and just below the upper limit specified in the National Construction Code.[7] Of the individual upgrades modelled, airtightness had the largest impact on heating and cooling demands.

## 2.2 Pre-installation testing

The project team built two test rooms in Adelaide, mimicking the construction of contemporary SAHT houses in the APY Lands (Figure 6). These allowed us to test sealing methods and refine insulation fixing details before attempting installation in the remote Pilot location where resources are limited. We assessed the efficacy of

**Figure 6. Two 3 m × 3 m test rooms were built in Adelaide, mimicking the construction of houses in the APY Lands. They were made possible through the support of industry partners and donors of materials: ICANZ, Fletcher Insulation, ATTMA, OptiSeal, Kingspan, Steeline Roofing Mt Gambier, Lysaght, Weathertex, Neata Glass, and Efficiency Matrix.**

solutions by blower door testing and infrared imaging. We also used the test rooms to demonstrate the final retrofit installation techniques to supervisors and trainers of the tradespeople performing the work within the Pilot and in future.

## 2.3 Finalisation of strategy

The technical working groups agreed on three levels of retrofit of increasing complexity and predicted benefit, to maximise insights from the six study houses. A further six reference houses would remain unmodified. We allocated houses such that each retrofit would be tested on one older (constructed up to 2002) and one newer (constructed from 2009 on) house, with three older and three newer houses in the control group. The three levels of retrofit comprised:

1. Airtightness upgrades, including gap sealing, replacing extraction fans, and fitting dampers to evaporative coolers;
2. Airtightness upgrades, replacement of bulk ceiling insulation, and addition of continuous insulation at the ceiling as thermal bridge mitigation;
3. Airtightness upgrades, top-up of bulk ceiling insulation, and continuous insulation applied to both ceiling and outer surface of exterior walls.

For Level 2 and 3 retrofits, we elected to test both a semi-rigid glasswool blanket and a rigid phenolic foam as the continuous insulation layer. The semi-rigid blanket would be installed through the roof trusses, above the bulk insulation and bottom chords, while the foam boards would be attached between existing and new layers of ceiling lining.

## 2.4 Retrofit simulation

Simulations showed that each level of retrofit could deliver substantial reductions in heating demand in particular (Figure 7). Airtightness upgrades (Level 1) again delivered the largest individual reduction in energy demand for maintaining comfortable temperatures. Although adding continuous insulation approximately halved heat flows through ceilings and walls, the impacts on energy demand were relatively small. The continuous ceiling insulation of the Level 2 retrofit had minimal impact in the simulations. Each higher level of retrofit was of greater benefit when the existing bulk insulation was compromised. Both products for Level 2 and 3 retrofits performed similarly, due to comparable thermal resistances. Climate projections for 2050 shift the energy demand towards cooling-dominant. While the retrofits show greater effectiveness in reducing annual cooling demand in this scenario than under current conditions, their primary impact is still on heating demand, whose attenuation under the hotter climate reduces the overall energy savings.

In addition to reducing annual heating demand, the retrofits also reduced the associated peak loads. Peak heating demand decreased by 34% and 44% for Level 1 and 3 retrofits respectively, while peak cooling demand decreased by 8% and 13% respectively. While the high efficiency and fixed power draw of evaporative coolers means the peak electricity draw for cooling is unlikely to change substantially according to these simulations,[13] the current reliance on radiant heaters means that any reductions in peak heating demand translate directly into reduced electricity loads, important for remote off-grid networks.

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[13] A reduction of ~140 W for Level 3, if the evaporative coolers operate at their rated 8.85 energy efficiency ratio at all times (which is highly optimistic).

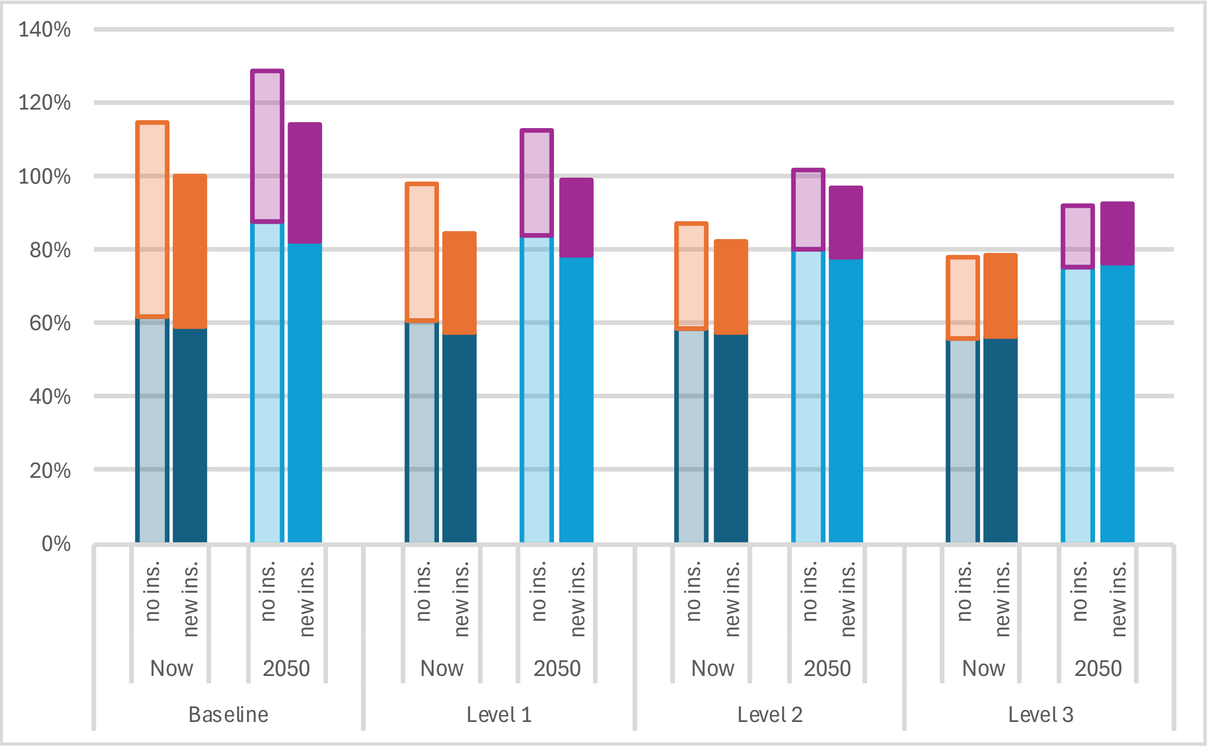

**Figure 7. Changes in annual heating (orange and purple) and cooling (blue) demand relative to present-day baseline, for each level of retrofit. The solid bars show results for houses beginning with "as new" bulk insulation, while the translucent bars show the case where bulk insulation is eliminated from the pre-retrofit baseline. Simulation results are shown for current climate and the projected climate for 2050 under RCP 8.5. The Level 2 and 3 variants shown here use the semi-rigid insulation in the ceilings and the rigid foam insulation on the walls, with other variants producing similar results.**

## Limitations

Our DesignBuilder model was refined over time, and the final version checked by consultants from LBS Consult. However, limitations in the software and data available for configuration meant that our estimates of cooling demand reduction in particular are likely extremely conservative. Our conservative modelling assumptions and their impacts on simulation outcomes are summarised in Table 1.

**Table 1. Key modelling assumptions and their impact on simulation results.**

| Assumption | Impact on Simulations |
|---|---|
| Effective thermal break layer in existing external walls. | Less thermal bridging impact than in reality, for most or all baseline houses. |
| Retrofits had no impact on "linear" thermal bridging at junctions. | Diminished impact of Level 3 retrofits. |
| No natural ventilation (including windows, doors). | Internal heat gains must be removed by cooling system, and increasingly for improved thermal envelope. |
| Internal heat gains follow National Construction Code,[14] but with seven adult occupants. | Approximately 40% of peak cooling demand is made up of fixed components: internal heat gains and solar gains through windows, restricting the scope for reductions. |

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[14] H6V2 Verification using a reference building. NCC 2022 Volume Two – Building Code of Australia Class 1 and 10 buildings.

# 3 Retrofit implementation

The maintenance contractor for SAHT housing in the APY Lands, Furnell Plumbing, installed building envelope upgrades between September and December 2024 (Figure 8; see Year 1 Impact Report[5] for further details). We scheduled the installation to prioritise roof work in the cooler weather and to ensure completion of all exterior work before the extreme heat of summer. SAHT and DEM project members attended during each of the four rostered periods, to deliver training prior to commencement of works, verify correct application of materials, and assist with problem-solving.

**Figure 8. Examples of airtightness upgrades and thermal bridging mitigation measures: (a) damper installed in evaporative cooling system; (b) door seal; (c) new cornice detail, applied to linings with caulking; (d) semi-rigid glasswool covering roof truss bottom chords; (e) rigid foam board added to external walls.**

During the installation process, the project team worked with the contractors to adapt the strategy when needed. For example, strips of ceiling insulation were used to cover the roof truss bottom chords, after the semi-rigid material caused excessive compression of the softer ceiling batts in one home.

Some works could not be satisfactorily completed during the installation period. One type of door seal needed replacing within weeks of installation, and sealing of cooling system diffusers to ceilings was completed later. The combustion heater manufacturer has not approved any products to safely seal the flange of the flue to the ceiling, and the flue remains a substantial leakage route (see 7.2.1).

Installation during the Pilot was labour intensive, but the time required for each component decreased with experience. As methods are optimised, the time required for trouble-shooting in future retrofit programs is also expected to decrease. Additional training and/or supervision could further reduce the costs of both labour and materials. Removing the roof cladding greatly improved accessibility for ceiling insulation upgrades, and the difficult access towards the pitching points would have been more limited without this approach.

The retrofit crews were eager to learn, and to see the impacts of their work. The Indulkana community has also shown interest in the principles guiding the retrofits, and the project team has endeavoured to communicate clearly to satisfy and nurture this interest.

# 4 Retrofit outcomes

## 4.1 Follow-up interviews

Follow-up interviews for the winter period occurred in June 2025, and again in early November 2025, as only two households were available for interview in June. For the retrofitted houses, six pre-retrofit interviews were completed and five post-retrofit. The results highlight that residents felt warmer in the houses after the retrofit, even when a heating source was not being used (Table 2; corresponding data from all 20 pre-retrofit households is presented in Appendix A). Households said they felt warmer when the heater was used post retrofit, and when heating was used it was for less time. These improvements were perceived despite windows being opened for fresh air. Also worth noting is that reports of using ovens/stove-tops for heating reduced from 4/6 households prior to retrofit to 1/5 after. This may be a reflection of the *Be Power Smart* energy education program (see 5.2) in combination with the homes feeling less cold after the retrofits.

**Table 2. Interview responses from retrofit households regarding winter comfort and heating, before and after the retrofit.**

| Question | Pre-retrofit | Post-retrofit |
|---|---|---|
| Is your home too cold in winter? | 83% all the time<br>0% never | 20% all the time<br>40% never |
| Do you use oven as heater? | 67% yes | 20% yes |
| Comfort without using heater? | 67% cold<br>17% little bit warm | 0% cold<br>60% little bit warm |
| If heating is used how warm are you? | 83% warm<br>17% very warm | 40% warm<br>60% very warm |
| How long do you keep the heater on? | 17% all day and night<br>67% few hours a day / until warm | 0% all day and night<br>100% few hours a day / none |

We conducted summer post-retrofit interviews with five out of six households in March 2025 (all six pre-retrofit interviews were completed). The results for summer were not as profound as for winter, which is consistent with the monitoring data (see 4.3). However, the interviews showed that people did feel a positive effect after the retrofit (Table 3).[15] No household felt that their house was always too hot in summer post-retrofit, compared to half the households pre-retrofit. A greater proportion of households reported using evaporative coolers for only a few hours a day. How cool people felt with the coolers on increased slightly. Meanwhile, people felt less hot when the coolers were off. While not related to the retrofit, multiple residents reported problems with evaporative cooling when the weather was humid; the frequency of days with higher humidity appears to be increasing in the region.

When householders were asked how they felt in the home after the retrofit, responses were positive for both winter and summer, with the overarching theme that they felt warmer in winter and cooler in summer and needed to use heating and cooling appliances less. There were also some comments on noticeable reduction in draughts and light seen coming in through gaps.

One resident (Level 3 retrofit house) said that the house now became too cold when running the evaporative cooler. Although data were too limited for high confidence, monitoring (see 4.3 below) showed a significant reduction in evaporative cooler usage in this house on days with outdoor mean temperatures above 30°C (Figure 9). The same household reported rarely using a heater since the retrofit.

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[15] In many cases, multiple answers were selected, indicating a dependency on weather conditions and potentially occupancy at any given time. We consider that using coolers for only a few hours a day, and also all day and night, likely represents “typical” and “when needed” cases.

**Table 3. Interview responses from retrofit households concerning summer comfort and cooling, pre- and post-retrofit. EC = evaporative cooler.**

| Question | Pre-retrofit | Post-retrofit |
|---|---|---|
| Is your home too hot in summer? | 50% always<br>50% sometimes | 100% sometimes |
| How long to you keep EC on?[15] | 50% few hours a day<br>67% when home / all/most of day | 80% few hours a day<br>100% all day & night |
| How cool are you in summer when cooling is used?[15] | 33% cool<br>67% very cool | 60% cool<br>80% very cool |
| Are you too hot in summer with no EC? | 83% hot<br>17% little bit hot | 60% hot<br>40% little bit hot |

Key challenges in the interview process were:

- The same residents were not always present in each house both before and after the retrofits, to report on observed changes.
- While the structured interview format helped to collate and quantify responses, it did not readily foster elaboration or suit the story-based speech patterns of Aṉangu.
- Translation of the questions into Pitjantjatjara, with review for clarity, helped facilitate interviews in a region where English is not widely spoken, but language was a barrier in seeking clarification during the interviews if interpreters were not present.
- The level of detail contributed by residents varied between households. Some gave detailed explanations while other responses were very limited. Residents generally (but not always) spoke more when EEWs were present.

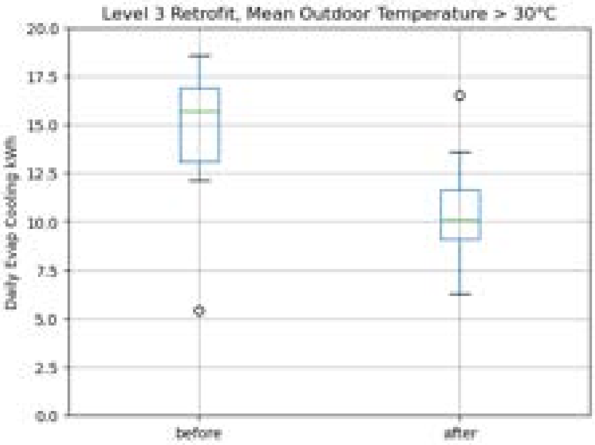

**Figure 9. Daily evaporative cooler use in an older house, for days with a mean outdoor temperature above 30°C, shows a significant reduction in electricity consumption after the level 3 retrofit.**

Further issues are discussed in 10.1.

In addition to the Pilot, the South Australian Housing Trust (SAHT) commenced a broader program of retrofits in the APY Lands in May 2025 (see 11.5.3), beginning with ceiling insulation upgrades. Residents commented that they felt an immediate difference once the insulation was improved, with houses being cooler in summer and warmer in winter. Informal reports have indicated noticeable improvements in comfort when continuous wall insulation was installed.

## 4.2 Building performance improvements

Improvements in airtightness averaged 53% (42 to 65%) across the six retrofit houses (Figure 10). Blower door testing showed infiltration rates ranging from 8.6 to 16 $m^3/(m^2h)$ at 50 Pa pressure (9.6 to 19 ach). Installation of dampers on evaporative coolers and new cornice details drastically reduced air leakage via ducting and wall-ceiling connections respectively. Because sealing work was incomplete at the time of testing, we anticipate

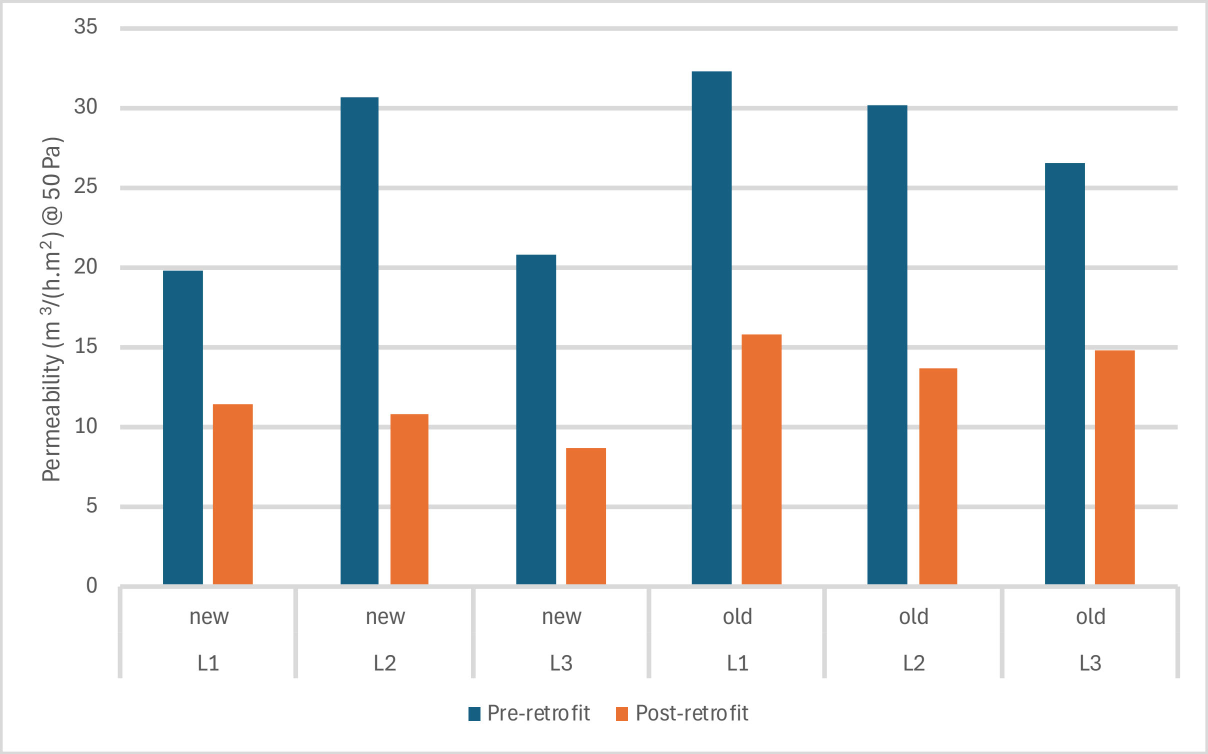

**Figure 10. Airtightness improvements following the retrofits averaged 53%. The higher post-retrofit permeability figures are all for older houses.**

further improvements following flue and door seal replacements and sealing of air conditioning registers to the ceiling.

There appears to be some relation between the age of the houses and the post-retrofit permeability reduction: although permeability was about halved in each case, houses built from 2013 on measured between 8 and 12 m³/(m²h) at 50 Pa after the retrofit, while those constructed 2002 and earlier reduced to between 12 and 18 m³/(m²h) at 50 Pa. In addition to increased wear and tear (and therefore gaps), older houses contained a greater range of materials, presenting increased difficulties in sealing.

Thermal imaging qualitatively showed a reduced degree of thermal bridging after upgrading walls and ceilings with continuous insulation (Figure 11). In some parts of the ceiling, the roof space was too narrow to allow

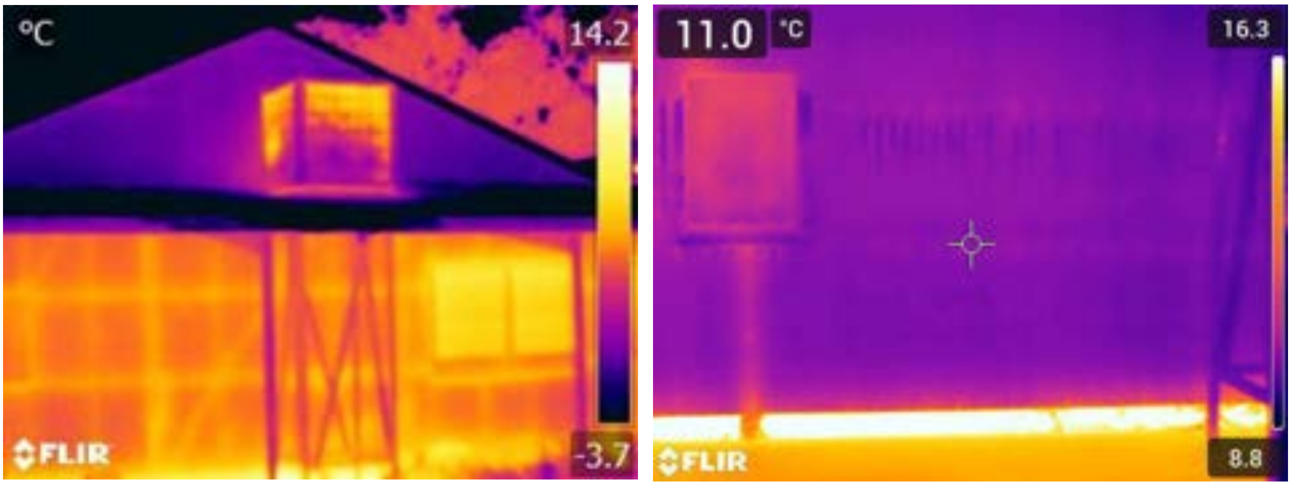

**Figure 11. Infrared imaging of one exterior wall before (left) and after Level 3 retrofit (right), showing a distinct reduction in visible thermal bridging. White arrow indicates the same location in each photograph. Note the different temperature colour scale between the two images. The visible bridging at screws in the post-retrofit image may be a result of the higher-resolution camera, as well as a reduction in visible bridging via the frame.**

upgrades—a limitation that would not be present for a new-build. There was some evidence of air infiltrating the bulk insulation layer from the top of external and partition walls under depressurisation conditions. This highlights the importance of sealing at top- and bottom-plates of walls whenever they are accessible[6] (see also 7.2.2).

Qualitative observations from the infrared survey suggested that the Level 3 retrofit houses were better able to retain heat than houses before the retrofit. This was indicated by internal surfaces reaching higher temperatures than were achieved in baseline testing. However, the different weather conditions preclude direct comparison. The initial infrared survey was not designed as a quantitative assessment of thermal bridging for comparison to a post-retrofit result, aiming rather to locate problems in the thermal envelope. This further limits direct quantitative comparison.

## 4.3 Energy impacts

To test for changes in electricity consumption for heating and cooling, we grouped monitoring and electricity supply data from February 2024 through August 2025 according to daily mean outdoor temperatures. This allowed us to compare energy use between retrofit and non-retrofit houses, for equivalent weather conditions, regardless of dates and discontinuities in the data.

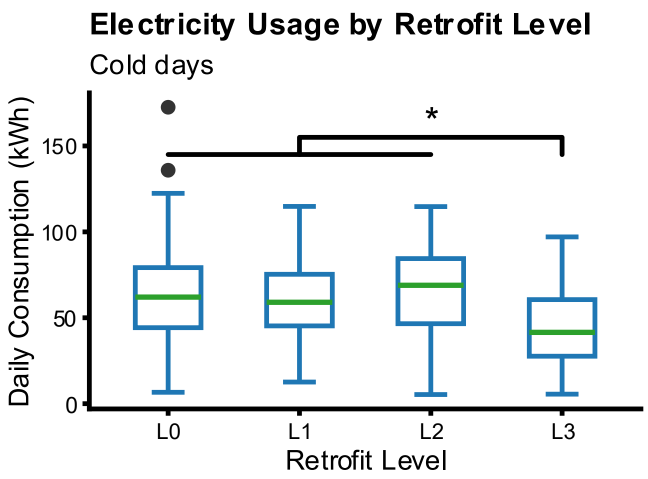

**Figure 12. Total daily household electricity consumption on days below 17°C, showing a significant reduction ($p < 0.00001$) in Level 3 retrofit houses (star) relative to each other category. Note that the higher median consumption in Level 2 houses is not statistically significant, and that one Level 2 house showed high energy consumption both before and after the retrofit but nonetheless showed a reduction (see also Figure 13).**

The Level 3 retrofit delivered a significant reduction in cold-weather[16] electricity use, relative to reference houses and other levels of retrofit (Figure 12). Pooling data for all six retrofit houses likewise showed significantly lower electricity consumption on cold days than for reference houses. Pre- and post-retrofit comparisons for each level of retrofit showed a clear trend towards lower total electricity consumption on days below 17°C after the upgrades, with reductions in the order of 20 kWh/day (Figure 13).[17] No significant differences were detected in cold-weather stove and hot water boost usage, but data were limited.

Comparing household electricity use on cold days with days between 22 and 28°C, we estimated a mean heating demand of 40 kWh (equivalent to running a 2500 W heater for 16 hours). This is comparable to the average of 35 kWh for living room heating at similar temperatures in the detailed heating and cooling simulation of a baseline house. While the simulations' high average household heating demand (over 100 kWh/day) is based on a constant indoor temperature of 24°C, daily electricity consumption above 120 kWh was not uncommon on days below 17°C, particularly in non-retrofit houses. The significant decrease

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[16] Based on plots of energy consumption against temperature, we defined "cold days" as those with mean daily outdoor temperatures no higher than 17°C.

[17] The one exception was the newer of the Level 3 retrofit houses: although it showed increased electricity use on cold days after the retrofit, the usage was still similar to the other five post-retrofit houses, and indoor temperatures were substantially lower in similar weather prior to the retrofit. The household seldom used an electric heater during the previous winter, and there were some changes in occupancy.

in household electricity use on cold days, following the Level 3 retrofit, corresponds to a reduction of 24 kWh/day in mean electricity consumption. Relative to the baseline 40 kWh/day for heating, we can thus speculate that the level 3 retrofit could reduce heating demand by about 60%.

For the one house with pre- and post-retrofit data available, evaporative cooler electricity consumption was significantly lower after the Level 3 retrofit on hot days (Figure 9).[18] While we have low confidence in this result, due to the limited data available, it is consistent with the resident's interview responses (see 4.1). Across the broader dataset, we could not detect significant differences in evaporative cooler use between retrofit levels,[19] or between retrofit and reference houses, with daily usage averaging 10–13 kWh. Total household electricity use, for hot days on which evaporative coolers were used, does not obviously match the results for cooler usage, with Level 1 and 2 retrofits showing significantly greater total daily consumption relative to both reference houses and Level 3 houses.

Indoor temperature trends were inconsistent, as data were limited and highly variable. The only statistically significant result was that mean daily living room temperatures were lower for Level 3 retrofit houses than for Level 2 on hot days when evaporative coolers were used. Nonetheless, plotting living room temperatures for days on which evaporative cooler use was recorded indicates that the coolers maintained average daily temperatures below 26°C on most days across all houses.

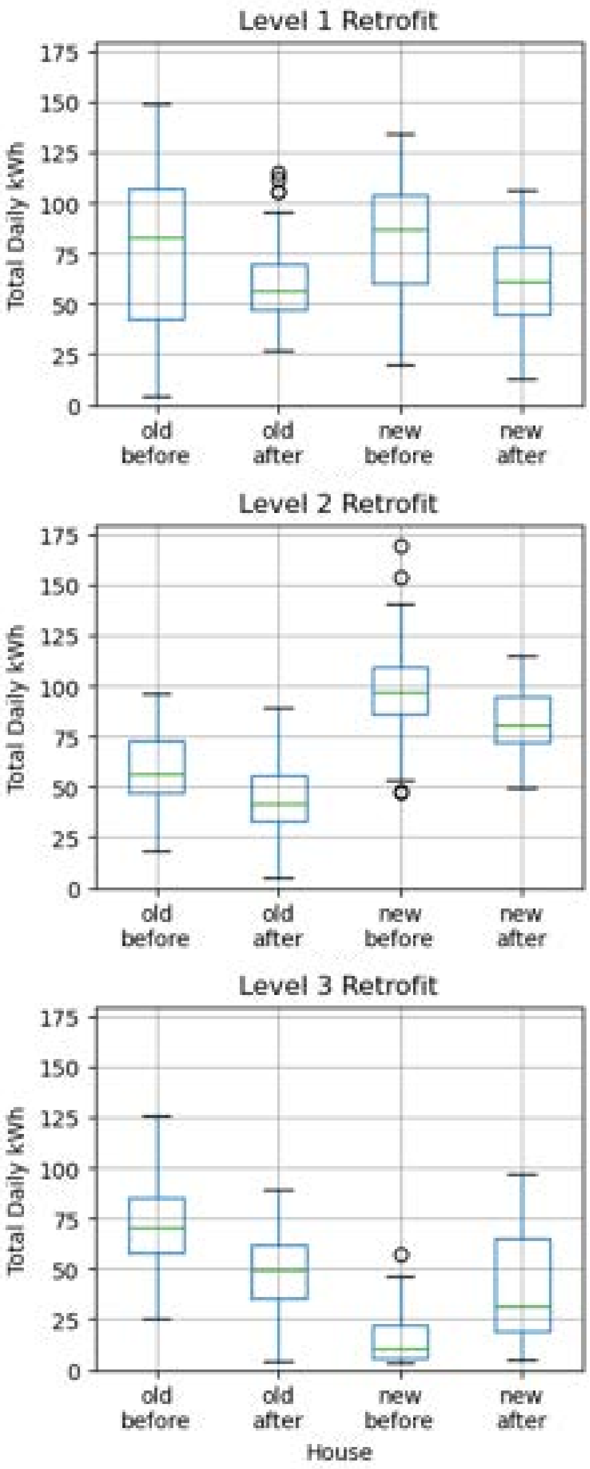

**Figure 13. Box plots showing total daily household electricity, before and after upgrades, for each retrofit house. For each level, "old" denotes houses built before 2003, while "new" denotes houses built from 2009 onwards.**

## 4.4 Learnings

Reports of improved comfort and decreased dependence on heating and cooling are a positive indication, both in terms of outcomes and residents' awareness of thermal comfort and energy use. Local workers involved in the broader retrofit program based on our work (11.5.3) have reported that their families felt distinct differences from one day to the next, upon installation of the insulation upgrades.

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[18] Defined here as days with a mean outdoor temperature above 30°C.

[19] Level 3 retrofit houses did show significantly lower evaporative cooler electricity usage than Level 2 houses, for hot days, but of the two Level 2 houses, the one with high cooler usage contributed 21 of 23 data points.

The halving of air permeability as a result of the upgrades was broadly in line with expectations, with further improvements anticipated from the additional work completed after testing. Thermography indicated that continuous insulation likely reduced thermal bridging overall, but a quantitative comparison would need a more controlled protocol.

The apparent building age disparity in post-retrofit permeability may reflect the increased difficulty in implementing sealing measures effectively in older houses. The older houses had more varied materials, including metal wall linings, different ceiling lining profiles, and leakier windows and door frames. Movement over time also tends to open additional gaps, e.g. in lap joints of ceiling lining.

Because most residents reported leaving windows open for fresh air at least sometimes, year round, the degree to which airtightness retrofits will save energy during winter remains uncertain at this time.[20] If the community education materials successfully promote more energy-efficient use of fresh air, the energy savings may be stronger and more consistent for all three retrofit levels. Likewise, because evaporative coolers require houses to be open when operating, this is expected to largely negate the effect of airtightness improvements in summer when coolers are on. Nonetheless, improved sealing will potentially keep houses cooler for longer before and after coolers are used, thus reducing the overall energy demand for cooling. In summer, even the air entering through windows is likely cooler than day-time infiltration from the roof cavity prior to sealing improvements.[21]

The strongest evidence in support of the retrofit program is from the significantly lower cold-weather energy use in retrofit houses as a group, and in Level 3 houses specifically. Although it will take time for our household energy education messaging to guide the behavioural changes needed to derive maximal benefits, with cold weather dominating annual energy use, this is already a substantial positive impact. We anticipate that the current roll-out of ceiling fans across the APY Lands (see 8.6) will reduce the need for evaporative cooler use on moderately warm days.

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[20] Clearly scale is critical: a single window opened for a short period will have minimal impact compared to the whole house opened for most of each day.

[21] Because the simulations relied on schedules for building permeability, they were unable to capture these subtle distinctions and, therefore, may have under-estimated the impacts of air leakage in the baseline houses over the hotter months. The airtightness improvements may therefore have produced greater impacts than predicated by the models.

# 5 Community energy education

The key objective of the Pilot is to find cost effective, replicable, energy efficiency retrofit solutions for community housing in the APY Lands. Whilst the retrofit solutions themselves provide residents with the *opportunity* for increased comfort, reduced energy costs, and protection against increasing temperatures, no solution is guaranteed. Residents need to understand how to best utilise their home and modify their behaviours to truly realise the full benefit of the housing retrofits. Therefore, an education package focusing on household knowledge of home energy efficiency concepts was developed for use during and post-retrofits.

## 5.1 Consultation and engagement

Community participation in all aspects of the Pilot was of high importance, and this was especially the case in the development of the education program. Community members participated in sessions to guide what messages were needed and how best to communicate ideas. The Community Council was also engaged throughout the process, as well as local service providers, such as TAFE and Community Development Program staff.

The project's Industry Reference Group (IRG) comprised individuals with ties to or experience working with First Nations communities in the APY Lands and other states and territories. The IRG met on several occasions to discuss the development and refinement of the materials, which included native speakers and teachers of the Pitjantjatjara/Yankunytjatjara language.

Working with the community and IRG, the project team developed key message themes for community education. These included information about the retrofits, keeping cool in summer and warm in winter, and appliance use. To ensure the materials had the best chance of reaching the audience, representatives from Monash University's Behaviour Works—part of the Energy Upgrades for Australian Homes project within RACE for 2030—were engaged to review the messaging with a behavioural science lens. This greatly helped refine the messages and ensure they were as effective as possible.

## 5.2 *Nintingku Pawa Yuutjumilala – Be Power Smart*

We Create Print Deliver (WE)[22] worked closely with the project team to create educational posters, booklets, and an animated video under the *Nintingku Pawa Yuutjumilala – Be Power Smart* campaign. Iwiri's language team worked hard to ensure messages in English were carefully translated into Pitjantjatjara, with printed materials presented in two versions (Figure 14), and the animated video spoken in Pitjantjatjara with English subtitles.

We have used the materials in meetings in the Indulkana community and with some households as part of the Pilot work. The materials will continue to be disseminated through an Energy Support Officer, who conducts house visits to all APY Lands communities through DEM's contract with MoneyMob Talkabout. Promotion of these materials to a wider audience will also continue digitally, with all content being hosted on the Net Zero Energy Builder website.[1]

A social media campaign has been scoped by WE to develop tiles for the various social media platforms conveying key messages. The intention is for these materials to be shared on the APY Lands Facebook page,

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[22] https://www.wecreateprintdeliver.com.au/

and potentially other community social media pages, subject to interest. This work is yet to be completed, pending the availability of the APY administration team to progress. This will be investigated in early 2026.

**Figure 14. Examples of household energy education posters (in English on the left, and in Pitjantjatjara on the right) developed within the Pilot and produced by We Create Print Deliver.**

## 5.3 Learnings

Because materials were introduced to the community in late 2025, any major impact is not expected to be seen for some time. Retrofits have provided the opportunity for energy savings and increased thermal comfort. Education materials will help to realise these benefits.

DEM energy metering data shows an early indication of positive impact from the Indulkana community education. It was noted when comparing self-disconnection data[23] for 2023/24 and 2024/25, between Indulkana and a community with the same number of meters, that Indulkana experienced 19% fewer disconnections than the comparable community. In fact, Indulkana had the lowest rates of self-disconnection across all of the prepayment meter communities in the APY Lands.

Some of this reduction could be attributed to the physical retrofits, but given only six houses had been retrofitted, it is more likely due to behavioural changes in the community. Through the community education materials and general awareness of the Pilot work over the 2024/25 period, the community has a higher level of understanding of energy efficiency concepts. DEM will closely monitor both self-disconnections and consumption as the retrofit work is extended across remaining communities.

A key learning, as with all community-based activity, is around time. Some community videos were planned as part of the education series, with several attempts to record. However, the availability of community members during the time periods the project team were present in community proved challenging. The capacity of such

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[23] Self-disconnections are a result of household pre-payment meters running out of credit.

a small project team also played into this, as the workload of physical retrofit work, alongside trade training and community education proved to be very high.

The behaviour change component of this Pilot warrants a larger program of work, which is being investigated for a future project.

# 6 Trade skills training

The replicability of these retrofits is highly important, and how well they are executed depends on the skill level and motivation of the workforce implementing them. Understanding the "why" is a critical part of ensuring those undertaking the work are committed to achieving the desired results. In addition, it is critical that any program of works undertaken in the APY Lands, and other Aboriginal communities, has a strong commitment to prioritising the employment of local workforce. Effective strategies for upskilling the local trade workforce in Aboriginal communities have potential in many remote and rural communities Australia-wide, where similar comfort and affordability issues are present in both older and new housing stock, often as a result of distance, freight costs and skilled labour shortages.

## 6.1 Content development

Partners Pointsbuild, CodeSafe/Deep Space, ICANZ, Efficiency Matrix, and ATTMA have all contributed to the development of trade training materials. TAFE SA, which will be instrumental in content delivery, has also provided feedback and direction as to how to best deliver messages to the target audience. Staff of Furnell Plumbing—the APY Lands maintenance contractor responsible for delivery of the retrofits—have provided invaluable on-the-job learnings that have fed back into both the education materials and strategies for effective delivery.

## 6.2 Online platform

Pointsbuild has developed a dedicated landing page for the APY Retrofit Pilot (also linking to the RACE for 2030 website) on the Net Zero Energy Builder (NZEB) learning hub.[1] It includes training content in Net Zero Home design and construction from the Commonwealth Government, builder training modules from Pointsbuild, Efficiency Matrix and ATTMA, and ICANZ insulation instructional videos and handbook, which are

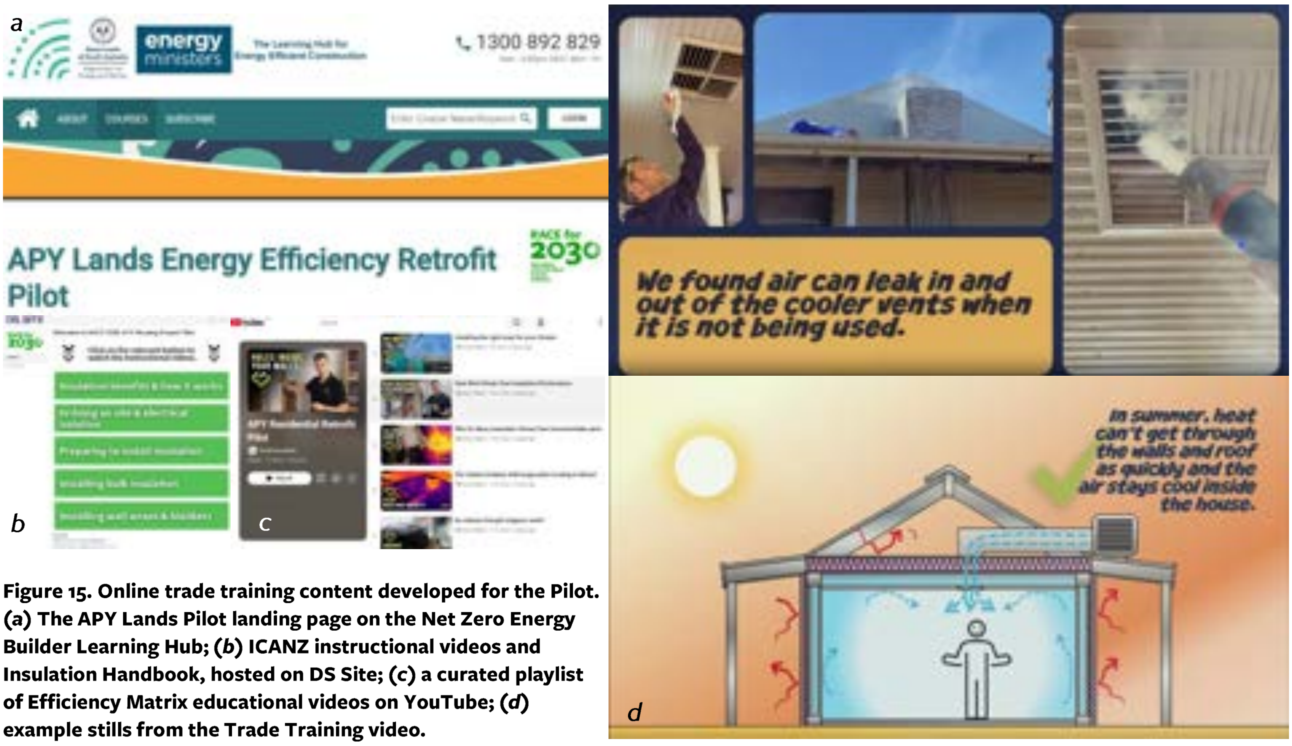

**Figure 15. Online trade training content developed for the Pilot. (*a*) The APY Lands Pilot landing page on the Net Zero Energy Builder Learning Hub; (*b*) ICANZ instructional videos and Insulation Handbook, hosted on DS Site; (*c*) a curated playlist of Efficiency Matrix educational videos on YouTube; (*d*) example stills from the Trade Training video.**

also available on the Deep Space platform[24] (Figure 15). The Pointsbuild Net Zero Energy Builder Scholarship was launched in July 2024, providing recipients with 20–30 hours of accredited training from the NZEB Learning Hub and Pointsbuild. The first ten scholarships were awarded to trainers attending APY retrofit training in Adelaide, including staff of TAFE SA (Umuwa, Gilles Plains and Tonsley campuses), SAHT, the Master Builders Association, and Renewal SA. Another 80 scholarships will be available to APY residents over 2026.

We Create Print Deliver produced an APY-specific trade training video, using bespoke animations developed by ATTMA and a compilation of photographs and video taken on site, with a Pitjantjatjara voice-over by Iwiri.[25] The video will be used in training locals to deliver retrofit works, and to help community members understand the work and reasons for doing it before consenting to retrofits in their homes.

## 6.3 Training the trainers

The project team hosted a "Train the Trainers" program in July 2024. The first day, delivered by the Australian Passivhaus Association, detailed the principles of designing and constructing for optimal thermal efficiency and building health. The second day, led by Sean Maxwell from ATTMA, directly addressed the issues and retrofit solutions in the context of the APY Pilot, demonstrating retrofit installation and diagnostic techniques using the purpose-built test rooms. For more information refer to the NetZero Energy Builder website.[1]

## 6.4 Learnings

In addition to providing training, the project team's being on the ground during the retrofit supported the installation workers in new techniques and trouble-shooting. Whereas inadequate compliance checking is a critical problem across the building industry, the presence of the project team on site helped ensure correct application of materials. We found the contractors highly responsive to learning the reasons why each component of work was being done. Their interest and engagement in preliminary testing provoked them to speculate on further potential improvements.

Educational videos proved useful in simply explaining quite complex thermal management and air flow concepts while also demonstrating the desired outcomes of retrofitting. It is critical to provide practical, hands-on instruction, preferably on-site, in conjunction with abstract skills training such as provided by videos, posters or written materials.

As with all elements of the project, allowing time for community involvement is key; however, there were times where this did not go to plan. We had hoped to gain more footage of community members performing the work, but availability of willing participants during visits to community proved challenging. While some video was captured after multiple attempts, with more time better instructional quality and variety could be achieved.

## 6.5 Spreading the impact

Training materials will be used to train the local workforce to deliver retrofits across the APY Lands as part of the SA Housing Trust's delivery under the Housing Australia Future Fund (see 11.5.3). TAFE SA will use the collection of video and other training materials provided on the Net Zero Energy Builder (NZEB) Learning Hub

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[24] app.qin.world/race2030apyhousingproject/pages/142

[25] English captions and subtitles allow the video to be used across all regions.

towards its Certificate II in Construction Pathways,[26] as well as within an active recruitment program to prepare participants to deliver the retrofits in each community.

With some adaptation, the retrofit solutions and training materials developed for the Pilot are highly relevant to the remaining public housing stock in SA, and Australia-wide, particularly in regional, rural and remote communities. The materials have been disseminated to government agencies in other jurisdictions through the IRG, and all trade training resources will be available indefinitely on the NZEB Learning Hub.[1]

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[26] https://www.tafesa.edu.au/xml/course/aw/aw_TP01277.aspx

# 7 Products and supply chains

## 7.1 Supply chain considerations

The Pilot encountered no substantial issues with the availability or supply of insulation materials. This was an advantage of designing the retrofit strategy in collaboration with the manufacturers. Because airtightness retrofits relied on off-the-shelf materials, product selection was more an iterative process, but availability was no issue.

Transportation timing and logistics were simplified by the installation contractor, Furnell, using their depot at Marla to store materials until required on site. This shortened the final, immediate leg of transport to just over 50km, instead of over 1000km from Adelaide.

## 7.2 Review of building products

### 7.2.1 Ventilation

Air volume control dampers (Bullock Model 6700) for the evaporative coolers were inexpensive, and quick and simple to install. The mounting allows fitting to a range of coolers. The dampers are now being fitted to all new constructions. The only problem encountered was that high winds could force open the damper, allowing air infiltration through the ducting. A motor-actuated damper would overcome this problem, but at an increased cost for both the damper and maintenance (due to likely dust-related motor failures).

Replacement of older Clipsal CE series exhaust fans (bathroom and kitchen areas) with Clipsal 6220 self-closing fans was similarly a simple job. They were already standard in new constructions across the region. Blower door testing confirmed they worked correctly, although the initial survey noted that one had been jammed with grease from cooking. Exhaust fans may be a routine maintenance item in the long run.

The flues fitted as standard to the Nectre combustion heaters are vented by design,[27] and we could not source a fire-rated caulking to seal them to ceilings. A single-jacketed flue (Pivot Stove & Heating 6" Fully Room Sealed Flue, RSF6 FKFULLYINSULATED) was sourced by SAHT, but has not yet been installed to assess its effectiveness in reducing air leakage and safe removal of smoke.[28]

### 7.2.2 Gap sealing

To address the challenging gaps at the intersection of walls with the Lysaght Mini Orb® or Panelrib® ceiling linings,[29] folded Colorbond® flashings were screwed to the existing cornices, after applying high-flex sealant (Sikaflex® PRO) at the interfaces with the wall and ceiling linings. We used low-expansion spray-foam to seal wide gaps in joints between steel lining sheets, but opted for Sikaflex PRO for the cornice flashings, to achieve tidy, consistent results. Imperfectly flat surfaces and difficulty in cleaning narrow spaces for sealant bonding resulted in some minor imperfections, evident in thermography with the houses at negative pressure. When bonding of the filler was problematic, Hannoband®-600 tape was used. Due to the relative thermal expansion caused by the temperature extremes of the location, the cornices may need intermittent re-sealing.

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[27] While Nectre does offer a heater with an external air intake, SAHT considers this unsuitable for conditions in the APY Lands. Moreover, the level of airtightness achieved in the retrofits still allows adequate ventilation for combustion.

[28] The manufacturer also claims that the flue can reduce fuel consumption.

[29] We noted a contrast in the initial airtightness results between houses with plywood ceilings and those with metal ceilings.

Hannoband®-600 is an expanding polyurethane foam sealing tape. It was effective for sealing air diffusers (multi-directional outlets) to the ceiling, although a complete seal was challenging for the sharper and deeper of the steel ceiling lining profiles. Although costly, the Hannoband tape is able to fill relatively large gaps without the mess and inconsistent results of expanding spray-foam. In recent SAHT constructions, in which Kooltherm boards were included in the ceiling assembly, sealing of cooling system diffusers at the duct connection was more effective than at the ceiling, as advocated in the initial ATTMA report.[6]

Our Pilot retrofits did not include sealing at wall top plates (see 4.2). Where continuous insulation is installed over existing wall cladding, there is no access to seal the cladding to the top plate. While spray-foam could be delivered to seal partition wall linings to top plates from above and close the service holes in the top plate itself, the tight junction at the pitching point would preclude this approach for external walls. Where cladding or linings are removed, sealing them to top and bottom plates with a thick bead of sealant would be a reasonable solution.

For window frames the best solution was to apply clear silicone sealant (Parfix Window and Glass) around the pane, and Polyfilla F20 around the outside of the frame. In several houses, gaps around windows were wide, requiring a large volume of filler; this was minimised by inserting foam backing rod. Where gaps around e.g. door frames were too narrow to permit sealant penetration, sealing tape was effective. For new-build houses, TESCON® VANA (from Pro Clima) tape is being used to seal window and door frames, which was faster to install and delivered cleaner, more consistent sealing than expanding spray-foam.

The Tight V-Seal Window and Door Seal we trialled for external doors proved unsuitable for the conditions, failing within weeks of installation. In some cases, the gaps were too wide for the seals to close. Commercial Raven door seals (RP84Si) have since been installed.[30] They are more robust and working satisfactorily, and the size is better suited to the doors in our Pilot, but they will need to be monitored long-term.

The sash windows remain a problem area for air leakage between fixed and moving panes, but modification would add customisation costs to what is already a non-commercial window. Polycarbonate remains the preferred glazing option, for durability. The cost currently places double-glazing out of consideration.

### 7.2.3 Insulation & thermal bridge mitigation

Installing 50mm thick (R2.3), rigid phenolic foam boards (Kingspan Kooltherm) over the existing wall cladding, then re-cladding, proved the most efficient process for creating a continuous wall insulation layer. An experienced crew can now complete this retrofit on a house within one day. It is expected that the boards should be durable enough to not be replaced over the lifespan of the houses. Expert advice from ATTMA was that positioning continuous insulation outside the frames would be the lower-risk option with respect to condensation in cold weather, by moving the dewpoint towards the exterior. Careful taping of the board joins is essential maintaining adequate barrier functions.[31]

While the material cost of the 50mm semi-rigid glasswool insulation (Fletcher FI32, R1.5) was comparable to that of the Kooltherm, the Rondo Key-Lock® Direct Fix System used to minimise compression of the glasswool at attachment points was costly and almost doubled the labour hours for installation (although also included the additional step of removing the existing cladding). Because the semi-rigid insulation is more dense than the

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[30] Model RP87HSi seals, with an integrated doorstop, are being used in new-builds.

[31] Further advice from ATTMA was that, in the climate of the APY Lands, the risk of condensation was relatively low overall, and more likely to arise from air leakage than the position of the new insulation within the wall construction.

bulk insulation batts, it was speculated that it may be less susceptible to rodent damage. Follow-up thermal imaging could help to monitor its condition non-invasively.

The semi-rigid blanket was effective in covering the exposed roof truss bottom chords and localised gaps in the ceiling insulation. However, its weight caused excessive compression in one of the two brands of ceiling batt in use. Although not creating a truly continuous insulation layer, a more universal solution was to place extra strips of ceiling batts (R4.1) either side of each truss, to cover the bottom chords. This approach also simplifies placement, as each segment to be handled is smaller.

With roof cladding removed, replacing or filling in bulk ceiling insulation was an efficient process, becoming faster with experience. Covering truss bottom chords in the same operation adds to this efficiency.

Using the rigid foam at the ceiling simplifies gap sealing as well as reducing thermal bridging, but is difficult and time-consuming to install overhead, with the work also highly disruptive to residents. It may be expected that thermal bridging is more completely eliminated by the boards, due to their being entirely outside the truss, but ceiling bridging had a minimal impact on energy demand in the simulations.

Insulation upgrades could not be applied to ceilings with narrow roof spaces, including skillion rooves. The rigid foam board would overcome this restriction, but in general, thermal break strategies suitable for walls should be effective for skillion rooves.

# 8 Cost–benefit analysis

We quantified the benefits of each retrofit variant in terms of energy cost savings and reductions in greenhouse gas emissions and evaluated these relative to the costs of carrying out the upgrades. We also present potential net benefits at a national scale, based on two adoption rate scenarios. Because monitoring data were incomplete, we used energy demand outputs from the simulations, with models updated to match the retrofits as implemented in the Pilot (Table 4).

**Table 4. Summary of models used for cost-benefit analyses, based on the retrofits installed in the Pilot.**

| Retrofit Variant | Airtightness | Ceiling Upgrades | Wall Upgrades |
|---|---|---|---|
| Baseline | 29ach winter, 19ach summer | R4.1 batts bridged by bottom truss chords | Bridged R2.5 batts with R0.2 break |
| Level 1 | Improvement to 10ach at 50Pa. | — | — |
| Level 2-S | | Semi-rigid insulation over bulk and bottom chords | — |
| Level 2-K | | Rigid foam insulation to ceiling + lining. | — |
| Level 2-B | | Strips of R4 batt covering bottom chords | — |
| Level 3-S | | Strips of R4 batt covering bottom chords | Semi-rigid insulation under wall cladding |
| Level 3-K | | Strips of R4 batt covering bottom chords | Rigid foam insulation to walls + cladding |

## 8.1 Retrofit costings

Figure 16 shows the costs of each retrofit variant. For all scenarios labour costs exceed material costs; the scale of each labour component reflects both the relative timescale and complexity of the retrofit option (see 7.1 above) and the high unit cost for very remote locations ($162.11/person-hour). We assumed identical labour costs for each of the above-batts ceiling insulation upgrades, with additional batts being the more economical material. The higher labour cost for the semi-rigid Level 3 option (3-S) reflects the complexity of its installation and the additional step of removing wall cladding.

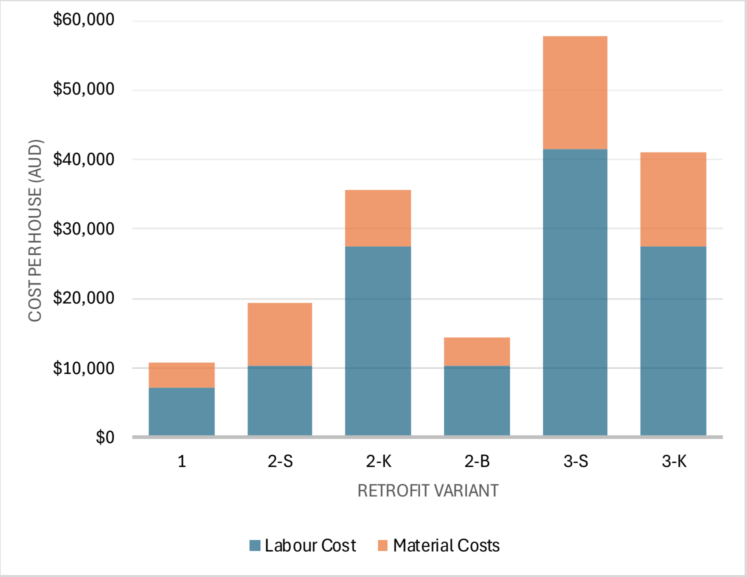

**Figure 16. Cost breakdown vs retrofit variant. For explanation of retrofit codes, refer to Table 4.**

Because the generous support of our industry partners covered most of the material costs in the Pilot, and the labour costs of installation included the considerable learning curve and problem-solving inherent in performing work for the first time, we have based cost estimates for each level of retrofit (where possible) on a larger-scale remote housing retrofit program currently being conducted by SAHT (see 11.5.3 below). Gap-sealing has not yet commenced in that program, so the estimates used here are based on the

Pilot, and are therefore likely conservative. We have excluded transport costs for retrofit materials, which we consider too specific to the Pilot region and the scale of the work at any particular location.

Comparing the labour costs from the wider retrofit program to Pilot installations allows us to estimate the savings in using dedicated crews, and the impact of learning curves. Installation of Kooltherm to walls averaged about 100 person-hours in the roll-out but took over 200 in the Pilot—a cost saving of almost $19,000 per house.[32] Likewise, the cost of installing ceiling insulation upgrades has approximately halved, from the Pilot to the large-scale rollout (~$3000 saving). We anticipate further cost savings in airtightness upgrades when the work begins in summer, although these will likely be less substantial, due to the larger number of separate tasks involved.

## 8.2 Benefits

Annual energy savings range from 3.8MWh (Level 1) to 5.2MWh (Level 3), according to our conservative household energy modelling under current climate conditions. At the government electricity supply cost to the Pilot location of $0.68/kWh, these correspond to cost savings from $2600 to $3600 per annum (Figure 17). For households, the associated annual savings range from $384 to $524 at the subsidised cost of $0.1/kWh. Within each retrofit level, there is little variation between energy savings. We have excluded potential maintenance savings, which will take some years to assess.

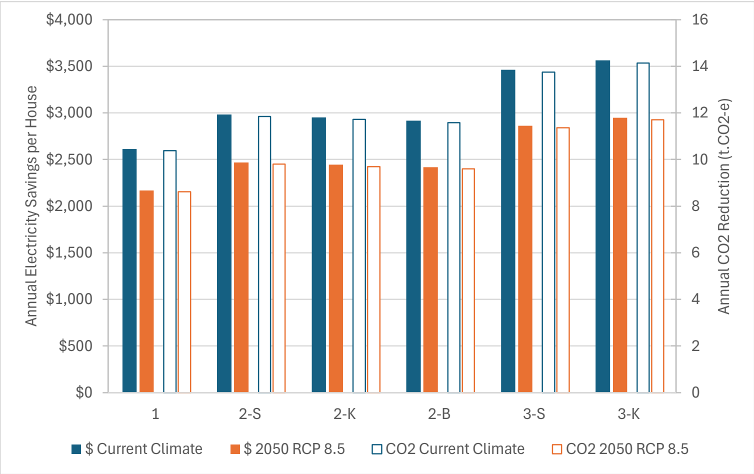

**Figure 17. Reductions in annual energy costs and greenhouse gas emissions per household vs retrofit scenario. Blue bars show reductions based on energy savings under current typical weather conditions, while orange bars are based on energy demand for the projected 2050 climate under the RCP 8.5 scenario.**

The closed electricity grid supplying the Indulkana community from Umuwa in the APY Lands averages 77% diesel generation and 23% photovoltaic (solar farm). To estimate reductions in greenhouse gas emissions, we assumed solar PV supply remains constant, with only diesel generation responding to any demand reductions. At a diesel emission factor of 2.7 kg $CO_2e$/kWh, the energy savings equate to emissions reductions from 10–14 tonnes $CO_2e$ per year for each household. This is equivalent to removing around 2.3~3.1 petrol-powered vehicles from the road each year (based on 4.6 t $CO_2e$ per vehicle per year), or growing 470~640 mature trees (assuming an annual sequestration rate of 22 kg $CO_2$ per tree).

The shift in demand from heating towards cooling by 2050, under RCP 8.5, reduces the energy savings, due to the minimal impact of the retrofits on cooling demand (see 2.4), but the annual cost savings (based on current costs) and emissions reductions remain substantial: $2200–$2900 per house in electricity supply costs ($320–$430 reduction in cost to the household), and emissions reductions of 8.6–12 t $CO_2e$/house.

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[32] Two-bedroom houses have recently been completed in as little as 50 person-hours.

If the bulk insulation in a house is initially compromised (or missing), the value of the Level 2 and 3 retrofits can be substantially greater (see Figure 7). Similarly, any mitigation of thermal bridging at junctions in the structure will increase the energy savings for the Level 3 retrofit (see 10.55).

## 8.3 Payback duration

Balancing the annual energy cost savings against capital costs, all three levels of retrofit could pay for themselves within 12 years (Figure 18).[33] Both Levels 1 and 2 represent excellent value in this respect, with payback periods from 4–5 years. However, the diminishing incremental energy savings for increasing levels of retrofit and the high costs for Level 3 substantially increase the payback period from Level 2 to Level 3. This trend is amplified by climate change, as the scale of savings reduce with heating demand. However, when the bulk insulation is missing or severely compromised, the payback period for the Level 3 retrofit (Kooltherm variant) reduces from 12 to seven years. Figure 18 gives a clear picture of which variant of each retrofit level represents the best value in this context. Although the incremental benefits of the Level 2 retrofit are small, the low cost of the "batts" variant results in only a slightly longer payback period than Level 1. The payback calculation is based on the $0.68/kWh electricity supply cost. A lower energy cost will proportionally increase the payback periods.

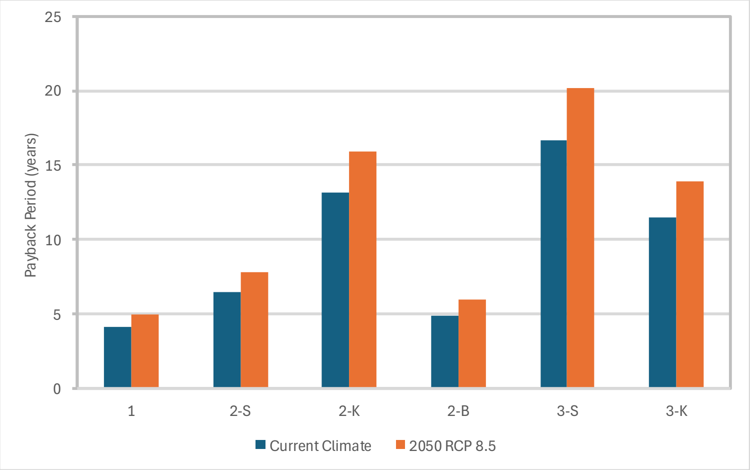

**Figure 18. Payback periods per house for each retrofit variant, based on energy savings under current and 2050 climate scenarios. We assumed current value of costs and electricity remain constant, and that all bulk insulation is in as-new condition.**

## 8.4 Impact scaling

Here we project the financial and emissions reduction impacts of retrofits out to 2050 for remote Aboriginal housing across Australia, considering only the most cost-effective variant of each retrofit level (see 8.3 above). We assumed energy savings and implementation and electricity costs are similar across all regions. Starting from the most recent Census data,[34] if we assume national growth rate projections (1% in the Northern Territory, 1.2% elsewhere[35]) apply uniformly and continue into the future, we can estimate an increase in remote Aboriginal housing stock from about 34,400 in 2025 to approximately 45,800 households in 2050. We modelled two retrofit adoption pathways,[36] representing modest (community and not-for-profit driven) and accelerated (strong policy and funding support) uptake.

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[33] This analysis was based on energy supply costs rather than costs to households, due to the government-subsidised electricity cost and government-funded retrofit works. For privately owned housing, the retail electricity rates would be closer to the supply costs than the subsidised household rates in the APY Lands.

[34] Australian Bureau of Statistics *Search Census data*, https://www.abs.gov.au/census/find-census-data/search-by-area (2021 data, last accessed 18 December 2025).

[35] Based on 2011–2021 ABS trends.

[36] Fisher-Pru diffusion model of technology adoption.

Figure 19 shows the projected impacts for the modest uptake scenario; the accelerated uptake scenario simply doubles the figures for any given year. The initial period of negative returns is due to the cost of accelerating implementation outpacing the annual savings. Under both adoption scenarios, the Level 1 retrofit delivers a net economic benefit after 10 years, Level 2 after 13 years, and Level 3 after 23 years. Each increasing level of retrofit delivers additional greenhouse gas emissions reductions. The cumulative 2.6 Mt $CO_2e$ saved by 2050 (Level 3, modest adoption) is equivalent to removing over 22,000 petrol-powered vehicles from the road, or growing over 4.5 million mature trees, for the 25-year timespan.

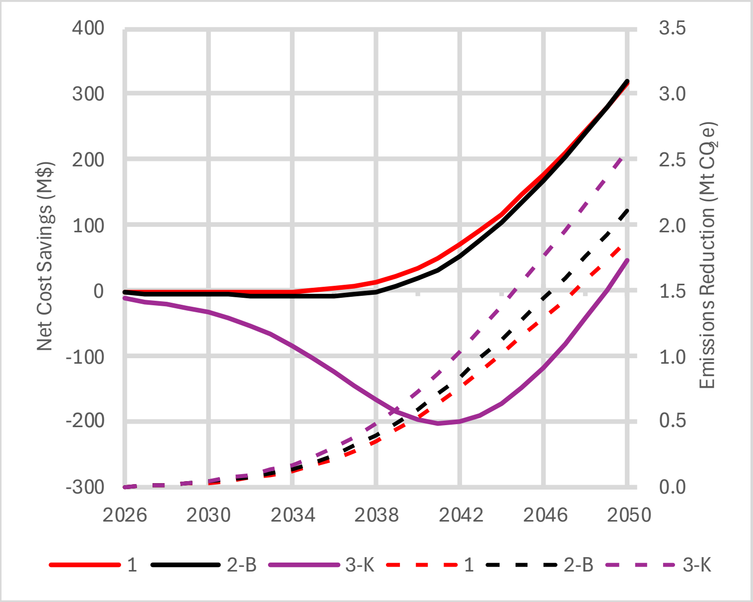

**Figure 19. Net cost savings and greenhouse gas emissions from present to 2050, under the modest uptake scenario. In legend, numbers indicate retrofit level, B represents the "batts" variant of continuous ceiling insulation, and K represents the Kooltherm variant of continuous wall insulation.**

## 8.5 Learnings

The airtightness upgrades of the Level 1 retrofit represent excellent value, delivering net cost reductions in under five years, or around 10 years when implemented in remote Aboriginal communities nationally with a moderate uptake rate.[37] Under this scenario, they save over 1.8 Mt $CO_2e$ by 2050. For the same timespan and adoption rate, adding ceiling insulation upgrades (Level 2) delivers similar financial benefits with an additional 8% reduction in greenhouse gas emissions. It ensures bulk ceiling insulation is performing to specifications and is particularly economical if ceiling batts are used for thermal bridge mitigation. Further energy savings would be derived from a Level 2 or 3 retrofit if the initial condition of the bulk insulation were compromised (see 2.4 above). The complexity and additional material costs of affixing the semi-rigid insulation to external walls, and the time-consuming difficulty of attaching the rigid foam boards to the ceiling, rule out these Level 2 and 3 variants as cost-effective retrofits. Although our modelling indicated that the Level 3 retrofit had a payback period of almost 12 years, and reach cost neutrality only by 2049 in national roll-out projections, its estimated energy savings are highly conservative (see section 10). With labour the largest component of costs, the use of a dedicated workforce, along with training and refinement of methods and tooling, offers the best prospects for further savings.

## 8.6 Preliminary appraisal: heating and cooling upgrades

While the building envelope upgrades trialled in this Pilot help to stabilise indoor temperatures, outdoor conditions ranging from below freezing to over 50°C require active heating and cooling to maintain comfort. With heating a key challenge in both energy consumption and capacity, we investigated the potential of reverse-cycle air conditioning to deliver improved efficiency and comfort.

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[37] The scale of savings will depend on the specific rates of retrofitting and construction. However, even if there were no change in housing numbers from 2021 to 2050, the national savings would still be ~70% of those indicated in 8.4, with payback periods unchanged.

While the house designs effectively exclude extreme heat in summer, they also block passive heating on mild winter days, increasing the reliance on heaters. Monitoring suggested that heaters used in Indulkana are of 2–3kW capacity. Both our modelling and indoor temperature monitoring indicate this is insufficient to maintain a comfortable 24°C, despite consuming a large amount of electricity. In models of baseline houses, a 2.5 kW heater in each bedroom and the living area consumed an average 104 kWh of electricity on cold days (mean outdoor temperature below 17°C) but failed to reach the 24°C target 45% of the time.

While highly efficient in dry climates and delivering ample fresh air, evaporative coolers consume large volumes of water. As well as being a precious resource, the bore water used in the APY Lands has a high mineral content, which requires more frequent maintenance of the coolers. Changing weather patterns have brought an increasing number of humid days over recent years, when evaporative cooling is ineffective; households have reported that walls and floors are wet with no cooling benefit delivered. There is also concern about the existing coolers continuing to meet demand as the climate warms further.

Neither the radiant heaters nor the evaporative coolers are thermostat controlled, so over-heating and over-cooling also contribute to excessive energy use. Each relies on human intervention to turn the systems on or off as comfort dictates.

SAHT previously trialled reverse-cycle split system air conditioners in the APY Lands; these typically use 2–5 times less electricity for a given heating demand than radiant heaters, depending on air temperature and moisture levels. The indoor "head" units failed in less than a year, due to the ingress of small, warmth-seeking cockroaches, which shorted the control circuitry. With no local refrigeration mechanics, maintenance costs are also a critical issue for systems involving refrigerant pipe connections.

After consultation with IRG members and industry, we concluded that packaged reverse-cycle air conditioning units appeared to offer a robust solution for both heating and cooling. Although ducted systems are generally considered more expensive than split systems to operate (and to install), the packaged units offer two clear advantages: low risk of vermin ingress, lacking indoor electronics and with sealed external electronics; and the whole unit can be exchanged for maintenance to be done off-site, without needing local refrigeration mechanics. Appendix B gives an overview of other options explored. A dedicated pilot study is currently in development, to investigate heating and cooling retrofits in detail (see 10.6).

### Modelling

To compare thermal performance and energy consumption, we modelled a 12 kW packaged reverse-cycle system (based on an ActronAir Vertical Packaged Unit), and a combination of four 2500 W electric radiant heaters[38] and an evaporative cooler (based on Braemar EA120S).

Reverse-cycle air conditioning delivered over 80% reductions in annual electricity demand for heating (Figure 20) in our DesignBuilder simulations, along with drastic reductions in peak heating loads.[39] While this was partially offset by lower cooling efficiency, overall energy demand was approximately halved for each retrofit scenario examined (Level 1 and Level 3). Moreover, reverse-cycle air conditioning offers the real-world advantages of cooling to a specific set-point[40] and maintaining cooling capacity at increased humidity levels.

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[38] Although households typically have only one heater, we modelled one in each conditioned room, to quantify the energy required to maintain comfortable temperatures throughout. The heater capacities of 2500W were based on monitoring in mid-2024.

[39] Reducing from 9.2kW to 3.3kW, and from 8.2kW to 3.1kW, for level 1 and 3 retrofits respectively.

[40] Evaporative coolers are available with thermostat control, but it cannot be retrofitted to the existing systems in the APY Lands.

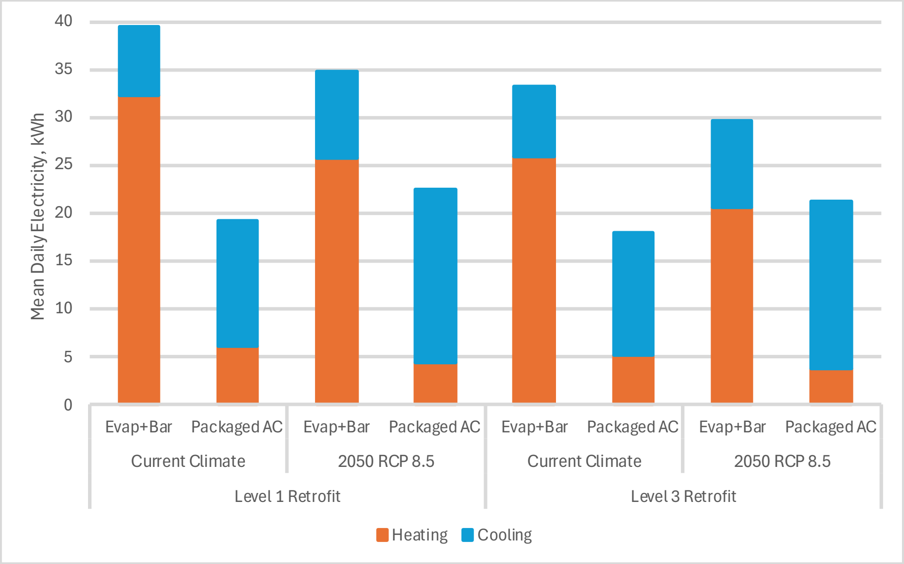

**Figure 20. Electricity consumption for heating and cooling in houses after Level 1 and Level 3 retrofits, based on the two heating and cooling scenarios and comparing current to projected 2050 climate. Figures are for daily usage, averaged over a full year.**

The evaporative cooler's peak power consumption is approximately 1kW, while the cooling load peaked around 3kW for the reverse-cycle system. It is important to note that the evaporative cooler draws the same power constantly (for a given fan speed), while the energy use for reverse-cycle systems responds to the total heat losses or gains at a given time. Averaged over time, therefore, this difference is much diminished (see Figure 20).

The simulations showed that 2.5kW bar heaters could not reach the 24°C setpoint in the living room on cold days for 33–45% of the time, depending on the level of retrofit. In contrast, the reverse-cycle system never failed to maintain the setpoint in retrofitted houses.

Due to its dramatic impact on heating energy consumption, the simulations show that switching to reverse-cycle air conditioning could deliver improved winter comfort without substantially affecting the payback period for a Level 1 retrofit (Figure 21). The increased energy savings also reduced the payback period for the Level 3 retrofit by about 20%, despite a substantial cost of the air conditioning upgrade. This analysis was based on preliminary cost estimates for supplying and installing a Rinnai packaged unit,[41] and what is

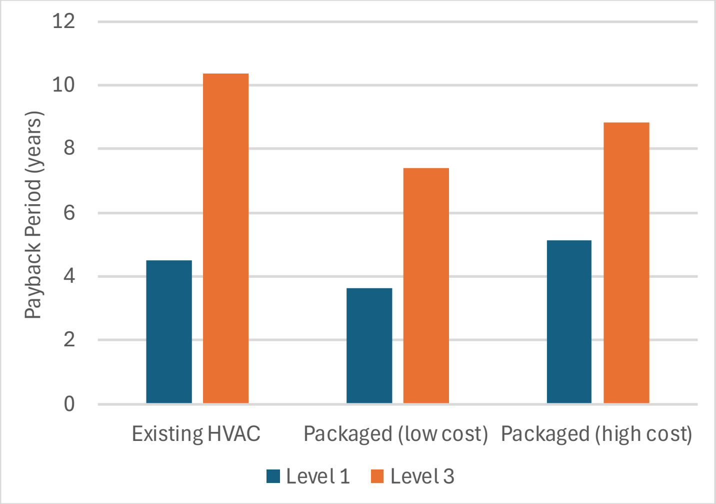

**Figure 21. Payback periods for high/low costing of ducted reverse-cycle air conditioning, installed in houses with Level 1 and Level 3 retrofits, compared to the same house conditions with existing heaters and coolers. These figures use DesignBuilder's Detailed HVAC modelling, so payback periods for the existing heating and cooling scenario differ slightly from those shown in Figure 18. Calculations are based on current climate conditions.**

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[41] From Michael Hamilton, Executive Manager – Memberships and Partnerships, Air Conditioning and Mechanical Contractors Association of Australia Limited.

considered an upper limit cost for the 12 kW ActronAir unit.[42] The modelling only accounted for the energy used for heating and cooling. It did not consider the energy required to pump[43] and treat the bore water used for evaporative cooling.

Under weather conditions projected for 2050, the reduced heating electricity demand more than offsets the increased cooling requirement in the baseline scenario. However, the similar efficiency for both heating and cooling for reverse-cycle air conditioning means an overall increase in energy demand for this approach by 2050, compared to current climate. The savings in heating energy nonetheless remain substantial enough for reverse-cycle to offer savings overall.

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[42] These units are not currently in production, and several proposed design changes have potential to reduce the costs, e.g. downgrading the cyclone-proofing measures not required for this location. The costing used is from several years ago, for a previous model.

[43] This refers to pumping from the bore. The electricity use of the cooler's water pump was included in the cooling energy.

# 9 Broader implications

## 9.1 Policy implications

### 9.1.1 Residential building regulations

A key finding from our initial assessments of the houses was the discrepancy between the “as designed” energy ratings (over eight stars under NatHERS) and the “as built” measured performance. Although the 2022 NCC does include blower-door testing in one energy efficiency compliance pathway,[7] other compliance routes exist that are based only on the design and material specifications. That is, a house must be *designed* to satisfy the Code’s energy efficiency requirements, but there is no national requirement to verify that the *completed building* meets the same standards[44]—that materials, their installation and the thermal/energy performance of the house match those specified in the approvals process.

Several of our retrofit measures were introduced to the Building Code of Australia (now NCC) in 2006: installation of dampers for evaporative coolers, self-closing exhaust fans, and thermal breaks between steel framing and cladding. Our investigations showed that dampers were not installed in houses built after 2006 and only some exhaust fans were self-closing. While a form of thermal break was applied in these newer houses, our testing indicated it was not as effective as assumed by the Construction Code (see 1.2.1).[45] The lack of routine verification (during or after construction) that the NCC’s energy efficiency provisions have been correctly implemented in construction means there is no certainty that these measures are delivering their intended benefits. While the building envelope is only one component contributing to household energy demand, the poor thermal and energy performance of the 8+ star houses in our Pilot, pre-retrofit, makes a case for expert verification of energy efficiency measures as one of the mandatory inspections conducted during construction.

In the absence of routine building inspections or testing, the disparity between the claimed energy efficiency compliance at the approval stage[46] and the delivered thermal and energy performance of the houses is likely to continue. The current national housing shortage, construction trade skills shortage, and the push to build quickly and cheaply is likely to exacerbate this problem, increasing the risk of material substitutions, installation defects, and poor practices and shortcuts being taken in construction. We therefore anticipate a growing need for skilled retrofitting, to bring not only millions of existing homes, but also recently constructed houses, up to their intended energy efficiency and thermal comfort standards.

Our Level 2 and 3 retrofits addressed thermal bridging across the framing of ceilings and walls, and it is this type of bridging that is addressed in the NCC. However, the dominant path of heat through the thermal shell of the houses in our retrofit models was via thermal bridging at junctions between surfaces, such as walls and floors, and between adjoining walls (see 10.5). Our results support a recent report’s recommendation that

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[44] Adoption and implementation of the NCC is state-based, and most states have no provision for verification inspections.

[45] The NCC requires thermal breaks have a rated thermal resistance of 0.2 $m^2K/W$, but does not require verification that this performance or its impact on thermal bridging is achieved in practice.

[46] Deemed-to-Satisfy (via NatHERS or Performance Solution), or Verification Using a Reference Building and airtightness testing. See NCC 2022 Volume Two - Building Code of Australia Class 1 and 10 buildings, Part H6 Energy efficiency, https://ncc.abcb.gov.au/editions/ncc-2022/adopted/volume-two/h-class-1-and-10-buildings/part-h6-energy-efficiency.

linear/point thermal bridging, and a method to calculate its impact, should be considered for future NCC updates.[47]

## 9.2 Climate change adaptation and risk management

The climate impacts of greenhouse gas emissions driven by human activity are already a severe threat to public health.[48] In 2024, infants and elderly people were exposed to over 300% more heatwave days than the 1986–2005 averages (globally).[49] Aboriginal people are among the populations most vulnerable to adverse health impacts of climate change.[50] The Australian Climate Service[51] places the APY Lands in the "most vulnerable" category of the Australian Climate Social Vulnerability Index[52] and the "higher risk" category for heat-related health risks. The warming climate increases the heat-related risks of health problems and, if living conditions become unsafe, of psychosocial and cultural harm to Aboriginal people unable to live on Country. An increasing rate and severity of extreme weather events also increases the risk and frequency of power outages, again with flow-on effects on human health. In this scenario, improving the performance of the thermal envelope of houses offers increased protection from both extreme temperatures and failures of cooling and heating appliances at either household or network level.

It is critical to note that a warming climate does not preclude cold extremes; rather it makes a broad range of extremes in weather and temperature more likely, more frequent, and more severe.[53] Resilience will require preparation for a broad range of extremes. A well-insulated and draught-proof house will be better prepared for a both extremes of temperature, and less dependent on high energy consumption to maintain a healthy and comfortable environment. This should be a key consideration for policy makers with a responsibility to public health and safety in a warming climate, outside of the standard cost–benefit analysis.

## 9.3 Co-benefits

### Electricity supply and load management

The stability, resilience, and environmental and climate impacts of the closed electricity grid serving the APY Lands are all impacted by energy demand, and peak loads in particular. Weather extremes cause outages both directly and through their effect on heating and cooling demand, and the increase in extremes predicted by climate modelling is already evident. With heating dominating demand and peak loads in our simulations, and projected to remain dominant to at least 2050 (assuming no change in the heating or cooling appliances used),

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[47] Green, A, Beltrame, S, Kokogiannakis, G, Cooper, P, 2022, Thermal Bridge Simulation Method Development Final Report, Sustainable Buildings Research Centre, University of Wollongong, Australia.

[48] Climate and Health Alliance (2017) Framework for a national strategy on climate, health and well-being for Australia. https://d3n8a8pro7vhmx.cloudfront.net/caha/pages/40/attachments/original/1498008324/CAHA_Framework_for_a_National_Strategy_on_Climate_Health_and_Well-being_v05_SCREEN_%28Full_Report%29.pdf

[49] Romanello, M, et al. The 2025 report of the Lancet Countdown on health and climate change: climate change action offers a lifeline. The Lancet, 406: 2804–57, https://doi.org/10.1016/ S0140-6736(25)01919-1

[50] Hunter, E (2009) '*Radical Hope*' and Rain: Climate Change and the Mental Health of Indigenous Residents of Northern Australia. Australasian Psychiatry, 17(6), https://doi.org/10.1080/10398560903062927; Duckett, S, et al. (2020) Climate change and health: preparing for the next disaster. Grattan Institute, https://grattan.edu.au/report/climate-change-and-health-preparing-for-the-next-disaster/

[51] https://www.acs.gov.au/pages/data-explorer

[52] Australian Climate Service, Australian Climate Social Vulnerability Index (ACSVI) (Beta), 2025

[53] Cresswell, I, et al. (2021) Australia State of the Environment 2021. Independent report to the Australian Government Minister for the Environment, Commonwealth of Australia, Canberra. https://soe.dcceew.gov.au/

all three levels of retrofit positively impact the sustainability of the local electricity supply. Any future investigation of heating and cooling upgrades will need to consider energy grid impacts. Our preliminary appraisal (8.6) shows potential for substantial reductions in peak demand during the colder months with a switch to reverse cycle air conditioning for heating. Although summer peak loads would increase under this scenario, they would be similar to those for heating. Any increase in cooling demand would need to be evaluated in conjunction with maintenance costs, water savings, and the relative ability of each technology to meet cooling demands in a changing climate.

By delivering energy savings, the retrofits also reduce the required capacity for future solar energy installations (or expansion of the existing solar farm), the need for transformer upgrades and, critically, the incidence of overload-related power outages.

### Environmental impacts

The appropriateness of heating and cooling systems for the environment as well as the climate should be considered. For the heating season, foraging for wood for combustion heaters may have effects on the surrounding ecosystem and possibly further impacts on availability of flora and fauna as additional food sources, as well as materials for traditional practices. In the summer, an arid climate allows evaporative coolers to work but also creates massive draw on limited aquifers and drinking water.

### Health impacts

Our analysis has focussed on energy savings, but improved thermal performance delivers additional benefits. Extremes of heat and cold pose significant health risks, particularly for children, those with existing illnesses and elderly, as shown by significantly higher hospitalisation rates for Aboriginal people in the Northern Territory.[54] Extreme heat can cause dehydration, heatstroke, aggravation of pre-existing illnesses and conditions, increase heart and respiratory rates, muscle cramps and discomfort, as well as psychological stress and inability to sleep.[55] The consensus from the literature is that the effects of climate change "further exacerbate existing vulnerabilities" for Aboriginal and Torres Strait Islander people in remote areas.[56] A number of households reported, in our interviews, that houses were excessively hot when evaporative coolers were not working, or when the weather was too humid for coolers to work effectively. When active cooling or heating fails, upgraded insulation and airtightness offers additional protection against extreme temperatures.

In winter, increases in cardiovascular and respiratory illnesses are especially dangerous for high-risk populations, especially when the household lacks funds or ability to warm themselves or their home. Likewise, a recent longitudinal study demonstrated strong impacts of energy poverty on mental health in a large Australian cohort.[57] The Victorian Healthy Homes program highlighted the importance of energy efficient

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[54] Green et al. (2015) Differential effects of temperature extremes on hospital admission rates for respiratory disease between Indigenous and non-Indigenous Australians in the Northern Territory. Int J Environ Res Pub Health, 12: 15352-65; Webb et al. (2014) Effect of ambient temperature on Australian Northern Territory public hospital admissions for CVD among Indigenous and non-Indigenous populations. Int J Environ Res Pub Health, 11: 1942-59.

[55] Kimberley Community Legal Services - Stuck in the heat 2022, CH3: Lived Experience Feedback

[56] Landsbury, Hall & Crosby (2020) Climate change impacts on health in remote Indigenous communities in Australia. Int J Environ Health Res, 1-16.

[57] Bentley, R., Daniel, L., Li, Y., Baker, E., & Li, A. (2023). The effect of energy poverty on mental health, cardiovascular disease and respiratory health: a longitudinal analysis. The Lancet Regional Health–Western Pacific, 35: 100734. https://doi.org/10.1016/j.lanwpc.2023.100734.

retrofits on health during winter, increasing quality of life and reducing medical costs.[58] In the baseline simulation a, 2500W heater failed to meet the 24°C heating setpoint in the living room for 45% of the time, on days with outdoor mean temperature < 17°C. The level 1 retrofit resulted in a 27% reduction in these hours (down to 33%), and level 3, a 47% reduction (down to 24%). These improvements in thermal comfort are also achieved at lower cost, due to reductions in heating energy demand. Monitoring data agrees that 24°C is rarely attained on cold days. The lowest mean daily living room temperature over a year was 19.7°C for the baseline simulation, 21.3°C for L1 retrofit, and 22.0°C for the L3 retrofit.

Substandard buildings and community infrastructure have been associated with greater cardiometabolic-related mortality and morbidity in remote Aboriginal communities in the Northern Territory.[59] Conversely, if the retrofits help to maintain healthy indoor temperatures, they can help Aṉangu (and Aboriginal people living in other remote locations) to continue living on Country, which is vital to mental, cultural and spiritual wellbeing. In addition to improving resilience to extreme temperatures, training a local workforce to install retrofits such as trialled in this Pilot also fosters capacity-building and employment opportunities.

### Maintenance

Although too early to assess, the building envelope retrofits could reduce the maintenance burden and improve the longevity of the houses, e.g. by minimising openings for dust and vermin ingress and better protecting the building fabric from extremes of temperature. Although condensation risks are low in the desert environment, evidence of condensation was observed in some houses. Mitigating thermal bridging and air infiltration can reduce condensation risk, which has flow-on health benefits associated with a lower mould risk.

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[58] The Victorian Healthy Homes Program Research Findings 2022

[59] Le Gal C, Dale MJ, Cargo M, Daniel M (2020) Built Environments and Cardiometabolic Morbidity and Mortality in Remote Indigenous Communities in the Northern Territory, Australia. Int J Environ Res Pub Health. 17:769. https://doi.org/10.3390/ijerph17030769.

# 10 Limitations and recommendations

A pilot study of short duration inevitably has limitations. While these made some evaluations inconclusive, they also highlighted issues needing further investigation.

## 10.1 Data availability

A substantial proportion of the monitoring data is missing, due primarily to the inability of modems to restart themselves following power supply interruptions. Classifying days according to weather conditions (in this case, daily mean temperatures) allowed us to evaluate performance when complete data for matching dates and or certain time periods were not available. While more robust modem-routers may be available, local storage with battery backup and intermittent download is likely a more failsafe approach. A further precaution is to place any monitoring hardware in an external meter box or similar, where it can be reset without disrupting the residents. Industry partners and IRG members have also recommended alternatives such as using a low power wide area network to serve Internet-of-Things-equipped sensors in multiple households.

Sources of variability for which we could not account included: changes in household size and occupants during the study period, unoccupied periods,[60] use of the combustion heaters, the extent to which windows and doors were open on any given day, electricity being supplied to caravans or for other external use, and details of heat-generating appliances in each household. Moreover, thermal comfort is highly personal and varies even between occupants within a home. Monitoring electricity usage on the general-purpose outlet circuits would help to measure heating energy in particular, although this is an imprecise approach. Direct monitoring of heaters at the socket proved to be insufficiently robust. Future projects may benefit from embedded software that recognises the “signatures” of common household appliances at the smart meter.[61]

With small sample sizes and gaps in data, large effect sizes are needed to reach statistical significance. Because evaporative coolers are highly efficient, typical daily usage falls within the variability in energy use between households and over time. For 10 of the 12 houses in our study, monitoring commenced in May 2024, and some early data from the other houses were unreliable, precluding before-and-after comparisons for hot conditions. Insufficient data were available to permit a full analysis of stove and hot water boost usage for the different retrofit scenarios in cold weather. The metering equipment for both Level 3 houses was offline from April 2025 until the end of data collection.

Ideally, all households (including reference houses) would have been interviewed for both summer and winter, before and after the retrofit. This would have allowed full comparisons in matching weather conditions. However the limited availability of energy education workers and the same household members in up to four narrow time-windows when the project team was on site led to prioritising the retrofit houses for follow-up interviews. With sufficient resources, more informative responses could be obtained from more frequent interviews, covering a range of weather conditions, with more immediate questions such as “how hot did you feel today?” and “how much did you use a heater yesterday?”

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[60] Although we inferred these from low total daily electricity consumption.

[61] See e.g. https://sense.com/

## 10.2 Airtightness strategies

While conducting a trial in social housing limits variability between houses to some extent, our 12 monitored houses nonetheless included four known designs and four houses of unspecified (pre-SAHT) design. Wall and ceiling linings varied, which particularly affected gap sealing.

The problem-solving associated with adapting gap sealing strategies on site added to the labour costs. In the current large-scale retrofit program (see 11.5.3), SAHT has been able to save time by identifying the individual house designs in a town, then scoping materials and procedures in one representative house of each design.

Two households commented about the smell of the (curing) sealants. This should be considered when scheduling the work to ensure households are informed ahead of time and can make alternative plans while the work is being done, if need be.

## 10.3 Modelling limitations

Both software limitations and data availability constrained the accuracy of our simulations. Examination of individual heat transfer routes in our models revealed that heat exchange with the ground beneath the slab and linear thermal bridging (see 10.5 below and Appendix C) are two of the largest contributors to heating and cooling demand. The suitability of the associated parameters needs to be tested with respect to Australian conditions and construction types. The limited technical and behavioural data available and the constraints of the modelling software precluded exact representations of heating, cooling and ventilation options in our simulations (8.6). In terms of climate change impacts, CSIRO's projected weather datasets provide a useful reference for annual energy demand, but do not capture the expected increases in incidence and severity of extreme weather events. We recommend further research to address each of these issues.

### Ground heat transfer

While the software vendor and experienced users agreed that using DesignBuilder's Kiva Basic ground model[62] was appropriate, a study of the models' sensitivity to changes in the ground modelling parameters would be useful. We also recommend examining the pros and cons of reducing heat exchange with the ground via slab insulation.

### Heating and cooling behaviour

Energy demand simulations calculated the heating and cooling needed to perfectly maintain temperatures in the 24–26°C range at all times, without any controlled use of natural ventilation. While the models' perfect temperature control and lack of natural ventilation may be considered as representing ideal occupant behaviour, it also precludes positive interventions such as opening windows to purge hot air. Because the models often require active cooling to remove heat from e.g. cooking (particularly in shoulder seasons), it is highly likely this drastically overestimates energy usage. Restricting analyses to a defined "cooling season" and "heating season", or incorporating responsive natural ventilation, could reduce this artificial behaviour and provide insights into further potential energy saving measures.

The detailed heating and cooling models were configured so that the evaporative cooler would run only as needed to maintain a set temperature, but we know from monitoring data and resident feedback that systems

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[62] DesignBuilder Simulation Documentation for DesignBuilder v7, DesignBuilder Software Ltd, https://designbuilder.co.uk/helpv7.0/#GroundModelling.htm.

are allowed to over-cool before being switched off. Therefore, in reality, the cooling energy penalty of switching to reverse cycle air conditioning (8.6) is likely lower than the simulations suggest. Likewise, the heating and cooling demand simulations likely underestimate the electricity consumption for cooling by assuming a constant energy efficiency ratio for the evaporative cooler.

The low sensitivity of cooling demand to building envelope upgrades in our models relates to the relative scale of the heat transfer paths in the building. The fixed component of heat gains (activity-related and solar gains through windows), along with ground heat transfer and linear bridging, account for almost all of the peak cooling demand in the Level 3 simulations, leaving little scope for further improvement. If advanced modelling, measurement, and survey data can improve the accuracy of these model components, the accuracy of predicted demand changes will in turn be improved.

### Weather data and climate change

Using "business as usual" emissions scenario (RCP 8.5[63]), the dominant trend in the weather projections for the climate zone encompassing the APY Lands is a year-round increase in temperatures. In our modelling, the associated increase in cooling demand is greater than the reduction in heating demand, although the impact on energy consumption depends on the relative efficiencies of each process. However, weather projections based on a "typical meteorological year" inherently exclude extreme weather events, and thus the impacts of extremes on energy demand and human health. Australia's National Climate Risk Assessments states: "The change in distribution, timing and severity of extreme weather events means that historical observations on their own are not likely to be a good indicator of future risk."[64] To best target adaptation and risk mitigation measures, specialised weather datasets or other approaches for energy modelling are needed, to account for the likely impacts of extreme weather events such as heatwaves.

## 10.4 Cost–benefit analysis

In the analysis presented, we did not attempt to quantify the financial value of non-energy impacts on aspects such as thermal comfort, health or maintenance, nor the value to the local economy of training and using local labour. Similarly, we do not yet have data to evaluate potential behavioural impacts of the education materials developed in the Pilot (see section 5).

### Heating and cooling upgrades

SAHT is currently offering ceiling fans to households across the APY Lands, with an estimated 99% uptake rate. Installation commenced in winter 2025. While not included in our cost–benefit analysis, we anticipate substantial energy savings from the ability to maintain comfort with a higher thermostat temperature (this will be addressed in future research; see 10.6). The expected energy impacts will take time, as they depend on changes in behavioural patterns, but the benefits of fans are highlighted in our household education materials. At a unit cost of $147, and allowing two fans for the living area and one in each bedroom, the cost per 3-bedroom house is $735. Labour costs are estimated at about $1600 per house.

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[63] Although considered by many to be a "worst case" scenario, RCP 8.5 is presently "the best match (for atmospheric greenhouse gas levels) out to mid-century under current and stated policies." (Schwalm et al., 2020, Proc Natl Acad Sci USA. 117:19656; doi: 10.1073/pnas.2007117117).

[64] Australia's National Climate Risk Assessment: An Overview. Australian Climate Service, Australian Government, 2025. https://www.acs.gov.au/pages/national-climate-risk-assessment

## 10.5 Further research: thermal bridging

The implicit assumption in our retrofit simulations that continuous insulation applied to walls and ceilings does not mitigate linear thermal bridges is highly conservative (see Appendix C). This produces simulation results contrary to the residents' reports of improved thermal comfort following installation of wall insulation retrofits in particular. Simulating the opposite extreme—complete elimination—gives us an upper limit for the benefits of the Level 3 retrofit. This best-case scenario more than doubles the reduction in cooling demand from November to March (when the spurious cooling loads described in 10.3 are minimal). It delivers a positive cost saving in 2042 (Figure 22) and reduces the per-house payback period to six years, based on current climate and supply-side energy costs. We expect the true outcomes to lie between these two limits, but the greater extent to which thermal bridges at junctions can be mitigated, the stronger the justification for a high-level retrofit.

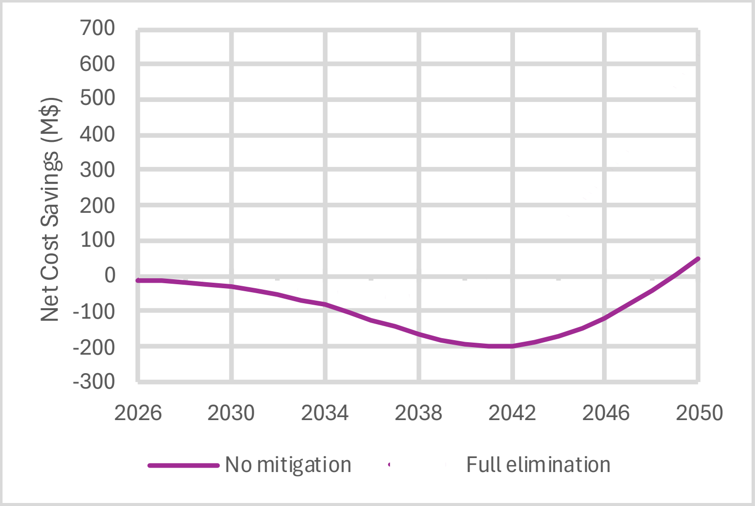

**Figure 22. Comparison of net cost savings nationally between non-mitigated and fully mitigated linear thermal bridges, under modest adoption rates for a level 3 retrofit. These two curves represent likely lower and upper limits of the direct economic benefit.**

A recent study for the Australian Commonwealth Department of Climate Change, Energy, the Environment and Water found poor agreement between the method DesignBuilder uses to calculate linear thermal bridging and two-dimensional transient finite element modelling of heat flows, in a non-residential building context.[65] While the report proposed a method to more accurately evaluate linear and point thermal bridges, further research is needed to accurately quantify the impact of linear thermal bridges and potential mitigation measures in Australian housing. To accurately evaluate linear thermal bridging parameters requires specialised modelling (such as finite element analysis), which was beyond the scope of the Pilot. Judging by the Sustainable Buildings Research Centre study,[65] such an evaluation could produce order-of-magnitude improvements in model accuracy. This has implications for the NCC's Verification Using a Reference Building compliance pathway, as well as in design and retrofitting for energy efficiency.

The best method to calculate repeating thermal bridge impacts on insulation performance remains a contentious issue. For example, the NCC-prescribed "isothermal planes" approach to thermal bridge calculation[10] has questionable relevance to ceiling insulation below a pitched roof space.[66] Our testing also raised doubts about the ability of thermal break materials to perform as rated.

We are developing a research proposal, in collaboration with industry stakeholders, to investigate these issues in depth. Using both simulation and measurement in test rooms similar to those used in this Pilot (2.2), we aim

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[65] Green, A, Beltrame, S, Kokogiannakis, G & Cooper, P, 2022, Thermal Bridge Simulation Method Development Final Report, Sustainable Buildings Research Centre, University of Wollongong, Australia.

[66] Green, A, Kempton, L, Cooper, P & Kokogiannakis, G 2021, Thermal Bridging of Horizontal Ceilings under Pitched Roofs, Sustainable Buildings Research Centre, University of Wollongong.

to quantify thermal bridging impacts for each major construction element, and identify best practices for mitigation and any barriers currently limiting their implementation.

## 10.6 Further research: heating and cooling upgrades

Although a trial of heating and cooling retrofits was initially planned within the Pilot, it was contingent on partnership with industry. Despite productive discussions with multiple companies, this could not be achieved within the narrow timeframe of the Pilot and with the prospective partner's available resources. We are developing a proposal to conduct a full exploration of heating and cooling retrofit options for remote Aboriginal housing across South Australia, including industry partnership to adapt appliance designs to suit the conditions. A full project will allow detailed modelling of a broad range of options, and analysis of capital, labour and maintenance costs. The industry partnerships embedded in the proposal, along with the existing collaboration between Adelaide University (AU), SAHT and DEM, will facilitate on-site testing of promising solutions in both heating and cooling seasons.

# 11 Scalability of retrofit program

## 11.1 Economy

Implementing the building envelope upgrades at scale offers opportunities to reduce costs per house. Labour costs were the largest component in our Pilot and the cost–benefit analysis. During the retrofit implementation, the speed of each task increased with experience. Using a dedicated labour force for a large-scale retrofit program thus offers efficiencies, with the learning curve comprising a diminishing fraction of the total time involved. For example, the labour costs for ceiling insulation upgrades were initially estimated at approximately $6000 per house, and are now approximately $3000 in the wide-scale retrofit program currently underway (see 11.5.3). Likewise, the external insulation is now being installed at about half the initial labour cost.[67]

Similarly, working with larger volumes of materials reduces costs through greater purchasing power and more efficient batch transportation. The impact of increased volumes on the supply chain must be considered, though. Manufacturers and distributors need more time to produce or source products at large scale. Materials being collected centrally (e.g. in shipping containers), then batch-shipping according to the installation schedule, buffers this source of potential delays. In the Pilot, the maintenance contractor performing the installation used their storage depot in the nearby town of Marla, on the Stuart Highway. Delays are minimised by working in partnership with the retrofit contractors and coordinating ahead of time. The savings in materials and transport in SAHT's experience outweigh the costs of the central storage capacity (with appropriate security) needed to accumulate materials before transporting to the remote locations.

Further efficiencies in planning and installation are afforded by any standardisation of methods. Social housing and other volume builds allow work and materials to be planned according to one example of each house design, saving time at this stage and in problem-solving on site. Nonetheless, any retrofit program needs to provide for material trials and adaptation of methods to the construction details specific to any project.

## 11.2 Workforce training

A key takeaway from the Pilot was the value of retrofit contractors learning the "why" as well as the "how" of their work in achieving high quality outcomes. We found the workers wanted to understand and were eager to see measurable outcomes. Having the retrofit leaders talk with contractors on site also helped to understand complications in the process. The value of the current wider program has been reinforced by Aboriginal members of the retrofit crews describing the impact of the work for their families. In turn, the greater understanding of energy efficiency that they develop in installing the upgrades is taken back to their communities.

## 11.3 Energy savings

Building envelope upgrades provide the ability to improve thermal comfort and reduce energy demand and associated costs, but behavioural change from occupants is needed to realise this potential. Buy-in from the community is essential. To this end, we have tailored household education materials to the local culture and conditions. The effect of education will take time to be reflected in measurable impacts. SAHT's managing the maintenance and leasing of the APY Lands houses, and DEM's Remote Area Energy Supply program providing

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[67] The more conservative figure of 100 person-hours per house was used in the cost–benefit analysis.

electricity allow a degree of long-term follow-up. The continued presence of DEM's energy support personnel is also expected to improve the chances of lasting impact.

Even if the share of renewables in local electricity generation increases over time, reducing demand is a key component of constraining capital and operating costs and embodied carbon. As described above, reducing heating and cooling demand via building envelope upgrades also increases thermal comfort (even if appliances or electricity supply should fail; see 9.3) and decreases vulnerability to the health impacts of extreme weather events (see 9.2). This is a key component of climate change resilience.

## 11.4 Retrofit triage

An important question from IRG discussions is which retrofits should be given priority. While airtightness appears an obvious first choice, consistent with advice across the household energy efficiency sector, reducing energy demand even more than restoring entirely absent insulation, we only examined one type of construction. The proportion of heat entering houses via each route will differ with glazing materials and areas, different wall and roof constructions, and the degree to which windows in particular are shaded from direct sun. The climate of a location will also shift the weightings. With rigorously validated modelling, or a large volume of real-world data, a retrofit triage system would be highly valuable. Nonetheless, it is likely that ensuring houses are sealed to the maximum permeability of 10 $m^3/(m^2h)$ specified in the NCC will be a cost-effective step in any retrofit program.

As in our Pilot, blower-door testing and thermal imagine can help to identify target issues for upgrades, but accurate modelling (or extensive data) is essential for prioritising retrofits according to their likely impacts on energy usage. Constraining the uncertainties in building energy models (see 10.33) is thus critical to obtaining the maximum impacts and best returns on investment in building upgrades.

## 11.5 Implementation of Pilot findings

### 11.5.1 Capacity building

Trade training materials developed for the Net Zero Energy Builder Learning Hub[1] and APY Retrofit Pilot specifically will remain accessible on the Hub for future use Australia-wide. This will provide practical skills and learning resources to regional and First Nations communities seeking to engage in energy-focussed building improvements. Together, the reporting, research and analysis, and the implementation expertise of personnel engaged in the APY Pilot will provide a valuable and practical resource to the Energy Upgrades for Australian Homes project and in particular to their future work in Residential Retrofit Workforce Development.

### 11.5.2 Dissemination and broader impact

The project team has worked closely with the Industry Reference Group, which included government agencies, not-for-profit organisations and other First Nations community focused groups across Australia. This has resulted in findings from the Pilot informing work already underway in other jurisdictions as well as being used as an advocacy piece for future policy reform.

The Pilot's findings are already reaching stakeholders across Australia. HVAC in the Outback,[68] an article on the project by Australian Institute of Refrigeration, Air Conditioning and Heating, was published in August 2025 and

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[68] https://theecolibrium.com/2025/08/20/hvac-in-the-outback/

a webinar event[69] was hosted by the Adelaide Sustainable Building Network.[70] Plans for further dissemination of findings are underway upon release of this report.

### 11.5.3 Full-scale implementation

With finance from the Housing Australia Future Fund, SAHT is currently conducting a retrofit program across all its houses in the APY Lands (411 in total), based on the approach developed in this Pilot. Retrofit works will also be expanded to other remote Aboriginal communities across SA. The retrofit program commenced on APY Lands with ceiling insulation upgrades in May 2025, followed by installation of continuous external wall insulation. Airtightness improvements will be carried out over summer 2025/26.

The ceiling insulation retrofit uses an additional layer of batts to cover the truss bottom chords and any other gaps; this was the most cost-effective solution with similar outcomes to the other variants in our analyses. Kooltherm boards are being installed over existing wall cladding as the quicker and less complex of the two solutions tested. The SAHT team plans to conduct airtightness testing and thermography at the conclusion of the retrofit program. This verification step, along with the energy efficiency measures trialled in this Pilot, are now standard for new SAHT remote housing constructions.

As discussed in 11.1 above, the program is demonstrating scope for reduced costs when working at scale. Feedback from residents has been positive, indicating that houses are staying cooler for longer in summer, and warmer in winter.

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[69] https://www.youtube.com/watch?v=PoorWeROCXo

[70] https://www.adelaidesbn.com.au/

# Acknowledgements

We are deeply grateful to the households participating in the Pilot and the broader Indulkana/Iwantja community.

Our sincere thanks to the many people and organisations integral to the project's success:

- Sean Maxwell—honorary member of the project team—for contributing much more than testing,
- The industry partners who contributed time, funding, products and a wealth of expertise,
- Our Industry Reference Group for helping us to maximise benefits for stakeholders,
- APY Lands maintenance contractor, Furnell Plumbing, for making the retrofits happen with engagement and care,
- Professor Frank Bruno, Prof. John Boland, and Dr Tim Lau at UniSA/AU for contributing their expertise in heating, ventilation and air conditioning, building physics, and energy analysis, and Prof. Rameez Rameezdeen for supply chain expertise,
- Companies who donated test room materials,
- Rui Chua at DEM for statistical analysis,
- Dr Henry Senko, Ren Ren, and Dr Patrick Keane in UniSA STEM for support in setting up our roof truss temperature logging trial (Appendix C).

**Industry Partners**

Aboriginal Affairs & Reconciliation, SA Attorney-General's Department
Air Tightness Testing & Measurement Association
Deep Space (incorporating CodeSafe Solutions)
Efficiency Matrix
Healthabitat
Insulation Council of Australia & New Zealand
    (with contributions from members Fletcher Insulation and CSR Bradford)
Kingspan
Nganampa Health Council
Pointsbuild
Powertech Energy
Sika Australia
TAFE SA

**Industry Reference Group**

Aboriginal Housing Northern Territory
Department of Communities, Government of Western Australia
Department of Energy, Mines, Industry Regulation and Safety, Government of Western Australia
First Nations Clean Energy Network
Gething Pty Ltd
Menzies School of Health Research

### Industry Reference Group

Mobile Language Team

Moneymob Talkabout

National Indigenous Australians Agency

NSW Department of Climate Change, Energy, the Environment and Water

Pointsbuild (for ongoing NZEB Site hosting and maintenance for training access)

RACE for 2030

Regional Engagement (APY Lands), University of South Australia

Resilient Building Council (to September 2024)

Sustainability Victoria (to November 2024)

Wilya Janta

### Donors of test room materials

Air Tightness Testing & Measurement Association

Efficiency Matrix

Fletcher Insulation

Insulation Council of Australia & New Zealand

Kingspan

Lysaght

Neata Glass

OptiSeal

Steeline Roofing Mt Gambier

Weathertex

# Appendices

# Appendix A

## Baseline responses from all 20 APY Lands households interviewed

**Table 5. Interview responses from baseline interviews, for all 20 households surveyed in October 2023 (c.f. Table 2, which includes only the 6 retrofit households, for direct comparison pre- and post-retrofit).**

| Question | Responses |
|---|---|
| Is your home too cold in winter? | 55% all the time<br>45% sometimes<br>5% never |
| Do you use oven as heater? | 55% yes |
| Comfort without using heater? | 70% cold<br>20% little bit warm |
| If heating is used how warm are you? | 70% warm<br>10% very warm |
| How long do you keep the heater on? | 45% all day and night / when home<br>55% few hours a day / until warm |

**Table 6. Interview responses from all 20 households surveyed prior to the retrofit, concerning summer comfort and cooling (c.f. Table 3, which presents pre- and post-retrofit responses for the 6 retrofit houses only). EC = evaporative cooler.**

| Question | Responses |
|---|---|
| Is your home too hot in summer? | 40% always<br>60% sometimes |
| How long to you keep EC on?[15] | 35% few hours a day<br>75% when home / all/most of day |
| How cool are you in summer when cooling is used?[15] | 40% cool<br>45% very cool |
| Are you too hot in summer with no EC? | 65% hot<br>35% little bit hot |

# Appendix B

## Heating and cooling upgrades: preliminary investigations

Consultation with IRG members and a preliminary literature review indicated that reverse cycle air conditioning (and split systems in particular) is the “go to” solution for energy-efficient heating and cooling, including for remote Aboriginal housing.[71] While considerably less efficient than evaporative coolers, their ability to operate across a wider range of climates, ability to deliver a greater degree of cooling, and the scale of energy saving in heating mode can offset the cooling penalty. The units are relatively inexpensive in terms of supply, installation and ongoing maintenance. In our discussions with manufacturers, however, we found that vermin ingress was only addressed as standard in outdoor units. We believe further work is needed to prevent short-circuiting due to insects in the head units. Moreover, installing multiple split systems or a multi-head system in each house would (a) add considerably to the maintenance burden and (b) increase the risk of systems being left running when rooms are unoccupied.[72]

In terms of the most common, commercially available appliances for active cooling, evaporative coolers are considered the cheapest to run, followed by split systems, and with ducted reverse-cycle systems typically both expensive to install and relatively expensive to operate. Wall- or window-mounted reverse-cycle air conditioners offer similar advantages and risks as split systems.[73] The maintenance costs and risks of failure likely shift the balance in the APY Lands, justifying a more location-specific evaluation.

With evaporative cooling generally meeting demand efficiently at present, and heating dominating annual electricity usage, we explored alternatives to electrical resistance heaters. We limited our exploration to off-the-shelf appliances and excluded fuel-based heating from consideration, due to cost of fuel, and health and safety risks. Varieties of storage heater allow heat to be stored while energy is cheaper or available from solar panels, however time-of-use tariffs are not viable due to the already heavily subsidised 10 cent per kWh tariff, and rooftop solar is not currently a consideration due to the community being serviced by a centralised power station with renewable energy. Storage heating could still offer some advantages to the electricity supplier’s load management, and more so if the solar component of local generation increases in future, but would offer little or no benefit in terms of energy savings for the householders. Options exist to direct solar thermal energy into the house, but either work best in a hydronic system or as a complementary approach to reduce demand on another heating method.

Passive approaches to cooling in particular are documented for other arid regions of the world but depend primarily on specific architectural features and construction types, making them difficult to retrofit in this context.

Packaged reverse-cycle air conditioning units appeared to offer a robust solution for both heating and cooling. Although ducted systems are generally considered more expensive than split systems to operate (and to install), the packaged units offer two clear advantages: low risk of vermin ingress, having no electronics within the house, and with sealed external electronics; and the whole unit can be exchanged for maintenance to be

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[71] E.g. The Energy Project (2016) Technical Advice – Mechanical Cooling. Report prepared for New South Wales Aboriginal Housing Office. www.energyproject.com.au.

[72] Multiple, separate controls, rather than a single on/off switch.

[73] They do offer one advantage of unit exchangeability, without any refrigerant piping penetrating the building envelope. However the number of units required is considered a major disadvantage, when compared to ducted systems.

done off-site, without needing local refrigeration mechanics. Although discussions with ActronAir in early 2025 regarding their Vertical Packaged Unit (designed for remote housing) were productive, the company's resources did not permit joining the Pilot as a partner. A previous design of their packaged unit was however used for our energy modelling comparison.

In addition to air-source heat pumps (reverse cycle air conditioning), ground-source heat pumps are a further option to exchange heat with the surrounding environment. Because temperatures below ground are relatively stable year-round, ground-source heat pumps can be highly efficient. While commercially available in Australia, it can take a variety of forms, depending on local geology, available space for earthworks, and the choice of circulating fluid. Due to this complexity, it was considered beyond the scope of this Pilot, but we consider it worth investigating, either as a per-household appliance and as community infrastructure.

Ceiling fans can provide cooling with minimal running cost during milder conditions, and the additional air movement can increase thermal comfort at higher temperatures. Thus, by allowing a higher setpoint for air conditioners, cooling energy demand can be decreased. One study showed no decrease in thermal comfort of office workers when the thermostat setting was raised from 24 to 26.5°C with increased air movement, reducing energy demand by about a third.[74] They also offer cooling under humid conditions in which evaporative coolers are ineffective.

### Preliminary findings

Improving the energy efficiency of heating in particular is complementary to the building envelope retrofits already implemented. Our preliminary modelling shows that heat pumps (such as reverse cycle air conditioners) present an opportunity for considerable energy savings in heating, despite consuming more electricity in cooling than the evaporative systems. Any efforts to reduce heating costs must also anticipate a continually warming climate for the foreseeable future, although 2050 projections still show a substantial enough heating demand to produce a net energy reduction in our modelling. In both climate scenarios, reductions in cooling demand are a priority for minimising the efficiency penalty, should the decision be made to move away from evaporative cooling. Ground-source heat pumps may offer a further efficiency boost over reverse-cycle air conditioners (air-source heat pumps), and their performance is less susceptible to weather conditions, but their suitability will require modelling using detailed information from manufacturers, along with ground temperature, moisture, and conductivity profiling. Their installation cost is usually much higher than for reverse-cycle systems due to excavation/drilling requirements.

An alternative target is to bring more ambient heat into the houses during colder months, in which daytime temperatures are often mild. This is difficult to accomplish in the existing houses, due to their highly effective shading and relatively small glazing area, which is highly beneficial in summer. Approaches could include a rooftop solar collector to heat air or another fluid that is then directed into the house. This would be most effective in combination with heat storage (e.g. in water or a phase-change material), to allow heat to be collected when available (daytime) and released when it is needed most (overnight).

While evaporative cooling is highly energy efficient, energy demand is not the only cost or consideration. The existing systems do not maintain a constant temperature, there are upper limits to intake temperature for sufficient cooling, and performance diminishes with increasing humidity. Water scarcity is likely to increase and water quality decrease in future, so evaporative cooling may not remain viable for the desert regions.

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[74] See e.g. Kent et al. (2023) Building and Environment, 243: 110674.

Maintenance costs will be a critical element in a more detailed exploration of potential upgrades. Coolers are currently serviced twice annually to maintain evaporator pads and as mentioned above, split systems have previously proven highly susceptible to failure due to vermin ingress, and are more likely to require qualified technicians to travel to remote locations to perform maintenance or repair.

# Appendix C

## Commentary on thermal bridging calculation methods

Thermal bridging through planar surfaces such as walls is calculated as a reduction in the thermal resistance (R-value) of the interrupted insulation.[10] Linear thermal bridges are localised to junctions between surfaces and penetrations such as window and door frames lintels. DesignBuilder represents these as abstract one-dimensional components. In the absence of detailed modelling of each linear bridge, conservative parameters are used to define these components, according to the British National Calculation Methodology (NCM).[75] The NCM, however, is intended for non-residential buildings and is based on construction types substantially different from the light-weight construction of the houses in our Pilot. To improve the accuracy of household energy simulations, detailed 2- and/or 3-dimensional modelling of Australian housing construction details is essential, as recently conducted for non-residential housing by the Sustainable Buildings Research Centre.[65]

## Thermal bridging via roof trusses

To address concerns that heat may also be conducted between ceilings and roof cladding, we monitored temperatures at multiple locations in the roof trusses of one house in our study. This indicated minimal heat conduction along the webs of the trusses, consistent with advice from the steel-framing industry[76] that convective heat transfer is dominant in the roof space. Covering exposed bottom chords will nonetheless reduce convective thermal bridging as well. The exception to the dominance of air temperature in the roof occurs towards the pitching point, where the top chord and bottom chord of the trusses are connected, and connected to the top plates of the exterior walls; in this region, there is a clear coupling of the temperature response of the bottom chord to both the top chord and the house interior. We expect that this non-uniform bridging can also be accommodated in linear thermal bridging calculations.

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[75] DesignBuilder Simulation Documentation for DesignBuilder v7, DesignBuilder Software Ltd, https://designbuilder.co.uk/helpv7.0/#LinearThermalBridges.htm; National Calculation Methodology (NCM) modelling guide, 2013 edition (20 November 2015) https://www.uk-ncm.org.uk/.

[76] Discussions with Bluescope Steel and the National Association of Steel-framed Housing.

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