The Victorian Healthy Homes Program

Research findings

August 2022

Authorised and published by
Sustainability Victoria
Level 12, 321 Exhibition Street
Melbourne Victoria 3000 Australia

The Victorian Healthy Homes Program: Research findings

August 2022

Funding
The Victorian Healthy Homes Program was funded by the Sustainability Fund of the Victorian Government and by Sustainability Victoria.

This report is dedicated to the memory of Dr Matt Soeberg and draws heavily from:
Page, K., Hossain, L., Wilmot, K., Kim, Y., Liu, D., Kenny, P., van Gool, K. & Viney, R (2022). Evaluation of the Victorian Healthy Homes Program – Final Report. Sydney: University of Technology Sydney.

Accessibility
This document is available in PDF and Word format on the internet at sustainability.vic.gov.au

This report should be attributed to Sustainability Victoria.

Sustainability Victoria acknowledges Aboriginal and Torres Strait Islander people as the Traditional Custodians of the land and acknowledges and pays respect to their Elders, past and present.

The Victorian Healthy Homes Program

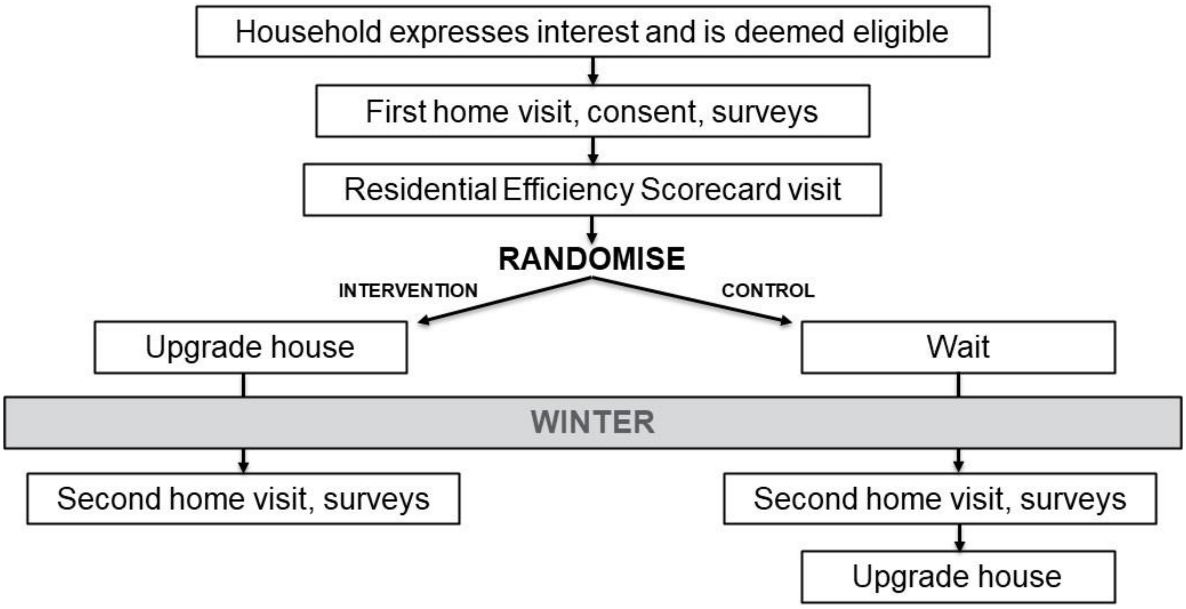
1. Table of Contents

Abstract

The Victorian Healthy Homes Program was a randomised controlled trial designed to measure the impact of an energy efficiency and thermal comfort home upgrade on temperature, energy use, health and quality of life. Analysis indicated that a relatively minor upgrade (average $2,809) had wide-ranging benefits over the winter period. Average indoor temperature was increased by 0.33^{o}C, with increases particularly strong in the morning, when temperatures are lowest. Exposure to cold temperatures (<18^{o}C) was reduced by 43 minutes per day. Subjective experience of warmth is important; it does not always match temperature measurements. Householders in the intervention group were more than twice as likely as controls to report that their home felt warmer over winter. These gains in thermal comfort were obtained despite a significant reduction in gas use in upgraded homes, and no change in electricity use. There was no evidence of a rebound effect, with intervention participants less likely than controls to use their main heater and less likely to resort to other options to stay warm. Householders in the intervention group reported less condensation over winter. Importantly, the upgrade was associated with benefits in health, with reduced breathlessness, and improved quality of life, particularly its mental health and social care aspects. Health benefits of the upgrade were reflected in cost savings, with $887 per person saved in the healthcare system over the winter period. Cost-benefit analysis indicated that the upgrade would be cost-saving within 3 years – and would yield a net saving of $4,783 over 10 years – due to savings in both energy and health. Savings were heavily weighted towards healthcare: for every $1 saved in energy, more than $10 is saved in health.

Executive summary

The Victorian Healthy Homes Program delivered thermal comfort and energy efficiency upgrades to 1000 homes of low-income Victorians with a health or social care need. It ran over 3 study years (2018, 2019, 2020) across western Melbourne and the Goulburn Valley. The program was designed as a randomised controlled trial, with households randomised to either the intervention (upgraded before winter) or control (upgraded after winter) group. The purpose of the trial was to evaluate the difference between groups over winter on thermal comfort, energy use, healthcare utilisation, health, and quality of life.

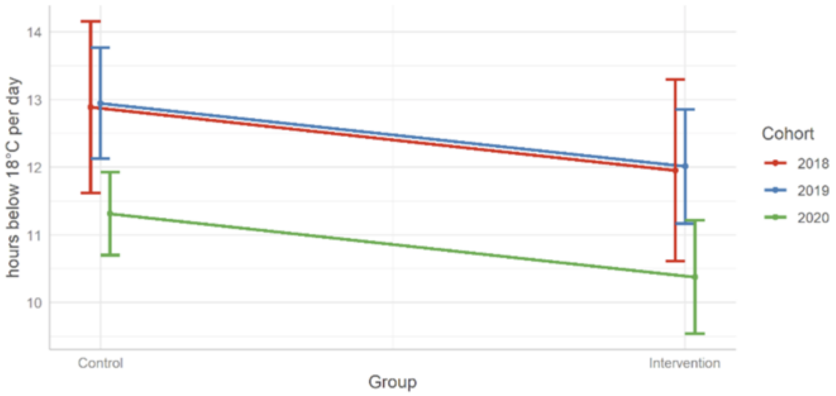


Upgrade | Each household received a pre and post upgrade Victorian Residential Efficiency Scorecard assessment of their home by a qualified assessor. This informed the choice of upgrades delivered to the home, prioritising energy efficiency and warmth. The range of upgrades included insulation (ceiling, underfloor), draught sealing, space heating (reverse cycle air conditioning or gas heater replacement), and internal window coverings. Target average cost per upgrade was $3500.

Sample | There was a total sample size of 1312 individuals across 984 households (493 randomised to control, 491 to intervention). Note that not all homes received their allocated intervention – particularly in the COVID-affected 2020 year, when many intervention group upgrades were not completed before winter. A total of 488 control households and 276 intervention households received their allocated intervention as per protocol.

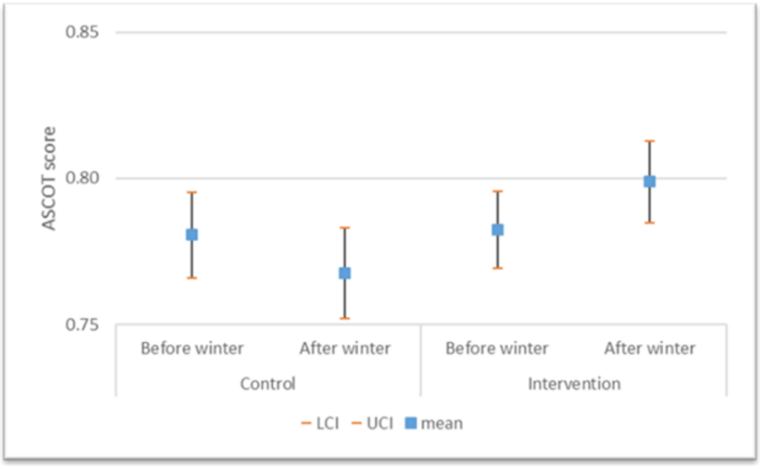
	Control	Intervention
Mean age (SD)	74.9 (11.8)	74.8 (11.7)
Female (%)	67.2	63.7
Mean floor area (m^2)	115.2	115.4
Mean pre-upgrade VRES rating	4.96	4.96
Solar PV (%)	26.4	27.1
Gas heater - pre-upgrade (%)	66.3	68.6

Analysis | Results presented in the executive summary are from the primary, intention-to-treat analysis (analysing all households according to how they were randomised) and include 95% confidence intervals (CI). All regression models included adjustment for local government area, study year, and other potentially confounding variables. The extent of clustering by household was assessed for individual level outcomes.



Thermal comfort | Intervention households were significantly warmer than control households over winter, by 0.33°C (95% CI 0.05, 0.60; p=0.022). Home upgrades had the largest impact during the mornings (8am-12), increasing indoor temperature by 0.47°C (95% CI 0.10, 0.84; p=0.012). Intervention households spent less time exposed to cold temperatures (<18°C) over winter, by 43 minutes per day (95% CI -88, 2; p=0.060). These temperature measurements were matched by the subjective experience of householders. The likelihood of perceived thermal comfort having increased in the intervention group was 2.3 times that of the control group (95% CI 1.8, 3.0; p<0.001). Mean winter humidity was very similar between groups (intervention = 48.5%, control = 47.9%). The intervention group, however, was 37% more likely to report reduced damp or musty smells (odds ratio 1.37; 95% CI 0.99, 1.89; p=0.061) and 48% more likely to report a reduction in condensation (odds ratio 1.48; 95% CI 1.12, 1.95; p=0.006).

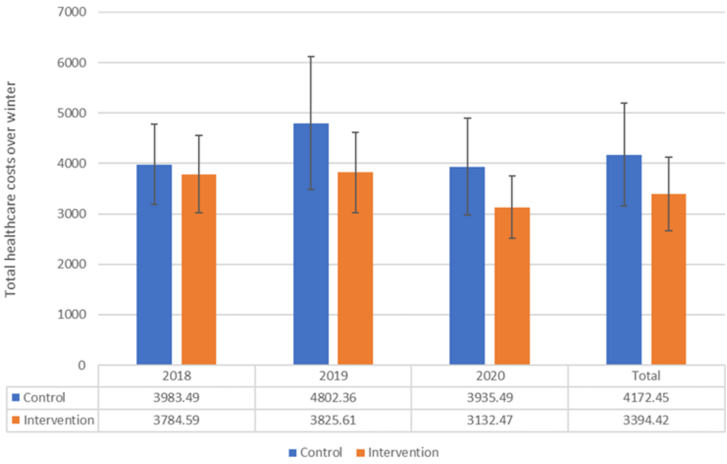
Energy use | Gas data were translated from MJ to kWh for comparability with electricity data. There was lower winter gas use in intervention (56.2 kWh/day) than control (61.7 kWh/day) households. In regression, intervention was associated with significantly lower gas use, by 7.1 kWh/day (95% CI 2.2, 12.0; p=0.005). Use of electricity was slightly higher in intervention (14.3 kWh/day) than control (13.8 kWh/day) households. In regression, though, intervention was associated with lower electricity use, by 0.9 kWh/day – this group difference was not significant (95% CI -0.5, 2.3; p=0.18). Participants were asked behavioural questions about use of their main heater and about other ways they kept warm. Intervention households were 37% more likely to report using their main heater 'only when feeling cold' (odds ratio 1.37; 95% CI 1.00, 1.87; p=0.052) and 20% less likely to use their main heater 'all the time' (odds ratio 0.80; 95% CI 0.60, 1.07; p=0.13). At night, the intervention group was 57% less likely to resort to a portable electric heater (odds ratio 0.43; 95% CI 0.21, 0.88; p=0.021) and 49% less likely to go to bed early (odds ratio 0.51; 95% CI 0.35, 0.74; p<0.001) to stay warm.



Quality of life | The Short-Form 36, a measure of health-related quality of life, has 2 summary scores: the mental component and the physical component. After winter, the intervention group had significantly higher mental component scores than controls (coefficient = 1.73; 95% CI 0.21, 3.25; p=0.026) and also had higher physical component scores, though this difference was not significant (coefficient = 0.81; 95% CI -0.30, 1.92; p=0.15). Health-related quality of life was also evaluated with the EuroQol (EQ-5D-5L) – there was no significant difference between the groups after winter (coefficient = 0.01; 95% CI -0.03, 0.04; p=0.60). Aspects of quality of life that can be affected by social care were assessed using the Adult Social Care Outcomes Toolkit (ASCOT). ASCOT scores showed improved quality of life over winter for intervention (mean 0.78 to 0.80) but not for controls (mean 0.78 to 0.77), with a significant group difference (coefficient = 0.024; 95% CI 0.006, 0.042; p=0.009).

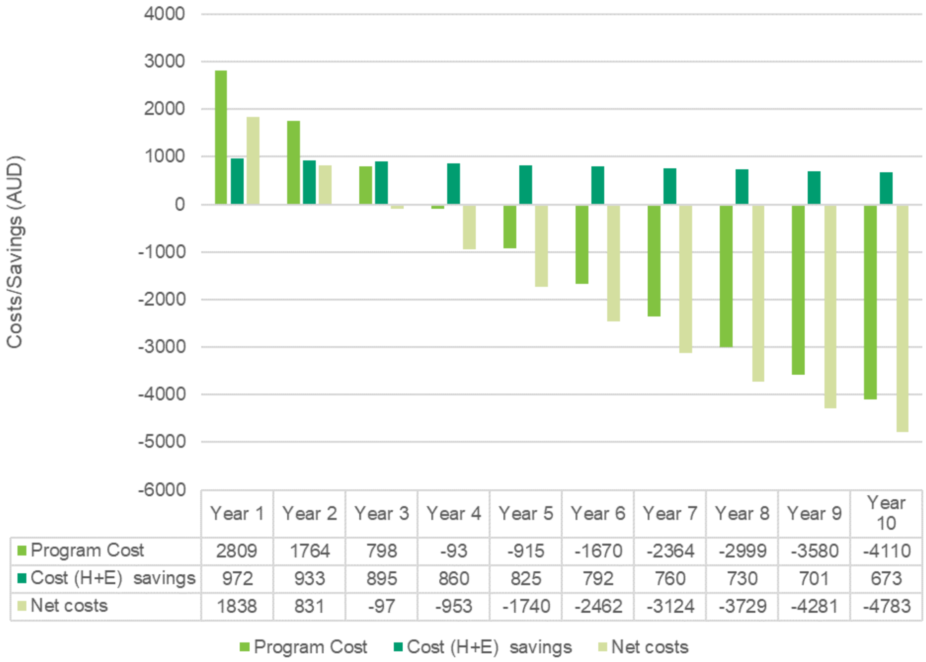
Self-reported health | At baseline, 37% of participants reported having cardiovascular disease, 28% reported having asthma, and 22% reported having COPD. These conditions can all be exacerbated by unhealthy housing and cold exposure. Analysis showed no significant difference between intervention and control groups in asthma control or in COPD symptoms over winter. There was a group difference in breathlessness, as assessed by the modified British Medical Research Council (mMRC) dyspnoea scale. Regression showed that the intervention group had a reduction in breathlessness relative to controls over winter (coefficient = -0.38; 95% CI -0.61, -0.15; p=0.001). The intervention group had fewer days (mean = 5.4) absent from usual activities than controls (mean = 7.3), though this difference was not significant (coefficient = -0.22; 95% CI -0.62, 0.18; p=0.28).

Healthcare utilisation | Four datasets (Medicare Benefits Scheme, Pharmaceutical Benefits Scheme, hospital admissions, emergency department visits) were combined to quantify total healthcare usage and cost for each participant over the winter period. Total healthcare costs were lower for the intervention (mean $3394) than control (mean $4172) group. In regression, the intervention was associated with $887 less healthcare cost (95% CI: -106, 1879; p=0.08).



	2018	2019	2020	Total
■ Control	3983.49	4802.36	3935.49	4172.45
■ Intervention	3784.59	3825.61	3132.47	3394.42

Cost-benefit analysis | Average upgrade cost was $2809. Savings over the single 3-month winter period were $887 in healthcare and $85 in energy. In cost-benefit analysis, extrapolating outcomes over 10 years using a 4% discount rate, the upgrade was cost-saving within 3 years. When benefits are assessed against full program cost (upgrade costs plus administration costs), the payback period was less than 7 years.



	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
■ Program Cost	2809	1764	798	-93	-915	-1670	-2364	-2999	-3580	-4110
■ Cost (H+E) savings	972	933	895	860	825	792	760	730	701	673
■ Net costs	1838	831	-97	-953	-1740	-2462	-3124	-3729	-4281	-4783

Conclusion | A relatively minor thermal comfort and energy efficiency upgrade has multiple benefits over winter: higher indoor temperatures, less gas use, lower energy bills, reduced emissions, improved quality of life, and less healthcare utilisation. Even using conservative cost-benefit assumptions, the upgrade is cost-saving within 3 years.

Background

Victoria has a temperate climate, but the combination of cold winters and thermally inefficient housing stock creates a serious population health risk. There are 2,091,385 Class 1 (domestic or residential) dwellings in Victoria, according to the 2016 Census. CSIRO data on the NatHERS star rating distribution indicates that 65.4% of Class 1 dwellings in Victoria are 2 stars or below – this equates to a stock of 1,367,766 sub-standard homes.

In their systematic review on housing and health, the World Health Organisation found strong evidence for a link between cold indoor temperatures and poor health outcomes (WHO, 2018). They concluded that, for countries with temperate or colder climates, 18ºC is a safe and well-balanced indoor temperature to protect the health of general populations during cold seasons. A large European study investigated cold exposure and winter mortality rates across different regions, finding that temperate areas had greater risk than colder areas. For example, in Athens (where winter temperatures are very similar to Melbourne), there is a 2.2% increase in mortality for every degree below 18ºC, whereas in much colder Finland, the increase is only 0.3% (Eurowinter group, 1997). The thermal efficiency of housing is a major factor in this risk – when it was 7ºC outside, average living room temperature in Athens was 19.2ºC, whereas in Finland it was 21.7ºC. Data from the UK indicate that there is seasonal variation in mortality risk, and this risk differs by residential energy efficiency, with energy efficient homes having lower mortality risk than inefficient homes (Wilkinson et al., 2007).

There is evidence that improving a home's thermal comfort results in health benefits to its occupants. A New Zealand randomised trial in 1350 households showed that retrofitting insulation leads to a warmer and drier indoor environment, better health outcomes, fewer days off school and work, and reduced energy use (Howden-Chapman et al., 2007). A subsequent randomised controlled trial found that installing more effective heating in homes of children with asthma led to a reduction in their asthma symptoms, fewer days off school, and less healthcare utilisation (Howden-Chapman et al., 2008). These research findings led to the Warm Up NZ: Heat Smart program, which ran from 2009-2013 and provided subsidies for retrofitting insulation and efficient heating. A total of NZ$347 million was invested in the program. Cost-benefit analysis indicated that every $1 spent resulted in a return to society of $3.88, with health benefits making up 99% of the total benefits (Grimes et al., 2012).

In 2017, Sustainability Victoria (SV) was given responsibility for running the Victorian Healthy Homes Program (VHHP). The objective was to deliver 1000 home upgrades, while at the same time building on the New Zealand evidence base with research data from a Victorian setting. Initial program funding was granted by the Sustainability Fund of the Victorian Government and additional funding was provided by SV.

References

Eurowinter Group (1997). Cold exposure and winter mortality from ischaemic heart disease, cerebrovascular disease, respiratory disease, and all causes in warm and cold regions of Europe. *Lancet, 349,* 1341-6.

Grimes, et al. (2012). Cost benefit analysis of the Warm Up New Zealand: Heat Smart Programme. *Report prepared for the Ministry of Economic Development.*

Howden-Chapman, et al. (2007). Effect of insulating existing houses on health inequality: Cluster randomised study in the community. *BMJ, 334,* 460.

Howden-Chapman, et al. (2008). Effects of improved home heating on asthma in community dwelling children: Randomised controlled trial. *BMJ, 337,* a1411.

WHO Housing and Health Guidelines (2018). Geneva: World Health Organisation.

Wilkinson, et al. (2007). Energy, energy efficiency, and the built environment. *Lancet*, *370(9593)*, 1175.

Program design

The VHHP was established to deliver home thermal comfort and energy efficiency upgrades to vulnerable households in Victoria and to assess their impact on thermal comfort, wellbeing, health, energy use and costs to society. Improving residential energy efficiency has the potential to provide health benefits (and reduce the risk of adverse health outcomes) through improvements in indoor temperatures and indoor air quality. Health risks associated with cold temperatures tend to have greater impact on specific population groups, including those with cardio-respiratory disease, children, and older people. High indoor humidity can adversely affect health, exacerbating asthma and allergies through increases in dust mites and mould. Vulnerable people, including the elderly, and those with disability or chronic illness, are often at higher risk. They are likely to spend more time at home and therefore have greater exposure to health risks associated with cold homes. Those on low incomes have limited means to improve the quality of their homes or afford increasing heating costs.

Figure 1. Household recruitment target areas.

The program was implemented across the western suburbs of Melbourne (metropolitan) and in the Goulburn Valley (regional). The recruitment target was 800 households across 5 western Melbourne local government areas (Brimbank, Hobsons Bay, Maribyrnong, Melton, Wyndham), where average daily minimum and maximum winter temperatures are 5.4ºC and 13.2ºC. Another 200 households were targeted for recruitment across 4 Goulburn Valley local government areas (Campaspe, Greater Shepparton, Moira, Strathbogie), where average daily minimum and maximum winter temperatures are 3.4ºC and 13.3ºC. These local government areas were selected by SV based on social or economic disadvantage and less favourable health outcomes compared with other parts of Victoria. The program allowed for an average (not a cap) of $3,500 per home to be spent on labour and materials to improve thermal comfort in an energy efficient way. The upgrade was fully paid for by the Victorian Government through SV; involvement in the program was free to participating households.

Program partners

The VHHP was designed and led by SV. The Australian Energy Foundation (AEF; formerly Moreland Energy Foundation Ltd) was engaged to manage Victorian Residential Efficiency Scorecard (VRES) assessments, home upgrade delivery and the pre and post winter home visits for data collection. The University of Technology Sydney (UTS) was engaged to oversee and manage the research and evaluation aspects of the program. The UTS team included 2 research groups: The Centre for Health Economics Research and Evaluation (CHERE) and the Institute for Sustainable Futures (ISF). SV engaged 9 local councils to disseminate promotional materials and recruit potentially eligible participants into the VHHP. Several healthcare bodies were also engaged to recruit participants. Potential participants completed an Expression of Interest and were then contacted by AEF so their eligibility to participate in the VHHP could be determined. AEF engaged staff from Uniting (for western Melbourne) and Goulburn Valley Community Energy (for the Goulburn Valley) to undertake the home visits for data collection, including obtaining informed consent at the initial visit. These staff were called Energy Liaison Officers. AEF was responsible for managing all aspects of home upgrade works, including safety checks of the home prior to upgrade and for arranging appropriate certification of all work by contractors. AEF staff checked photographic evidence of all upgrades, were the first point of contact for participants with any upgrade-related issues, and were responsible for addressing and reporting any problems that arose. In addition to these checks, SV engaged ITP Renewables to conduct upgrade audits on at least 10% of the homes.

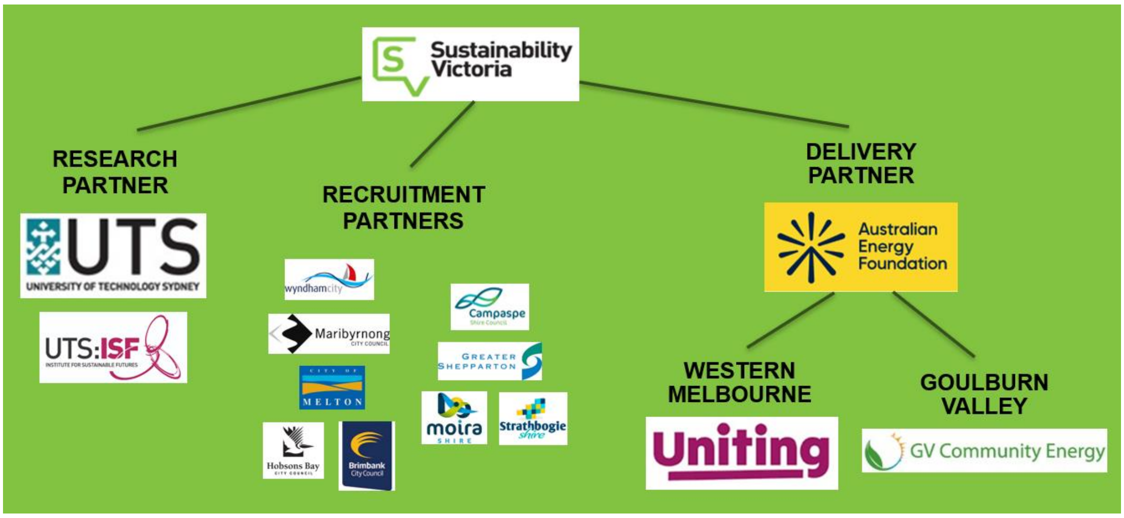


Figure 2. Partners involved in the VHHP.

Randomised controlled trial design

The VHHP was implemented over a 3-year period commencing in 2018, and had a staggered parallel group randomised controlled trial (RCT) design. Households (rather than individuals) were randomly assigned to group (either intervention or control) after baseline data had been collected (at their first home visit and VRES assessment). All households received a home upgrade. The intervention group received their upgrade prior to winter and the control group received their upgrade after winter. The trial was single-blinded. Householders and AEF delivery staff could not be blinded to the timing of the intervention, but all SV and UTS project staff remained blind to group allocation for the duration of the project. All intention-to-treat analyses were conducted with group assignment in coded form only so that data analysts were blind to each household's group allocation. Recruitment was staggered by local government area in each of the program's two geographic regions. This enabled a pragmatic balance between the logistical constraints of implementing a large-scale home upgrade program and the scientific design requirements needed to conduct an outcomes evaluation.

The VHHP was originally designed to be conducted across two winter periods, 2018 and 2019. However, resolution of OHS issues resulted in recruitment and upgrade delays, and the program was extended for a year. This extension into 2020 meant that the program was affected by the COVID-19 pandemic and associated lockdowns. Many of the 2020 intervention households did not receive their intervention prior to the 2020 winter, and upgrades for control households were also significantly delayed into 2021. All upgrades included in this report were completed by March 2022.

Eligibility

To be eligible for the program, a participant had to:

- Be an adult (≥18 years).
- Be living in a dwelling of any tenure type (home-owner, private rental, or managed by state housing authority) within one of the designated local government areas.
- Be low-income – defined as having a Commonwealth Concession card (Centrelink Health Care or Pensioner) or Department of Veterans' Affairs card (Pensioner Concession or Gold Card).
- Have an existing health condition or a need for home care support services.
- Have lived in the current home for at least 1 year, with plans to remain there for at least 2 more years.
- Be capable of providing informed consent.

Upgrade

Each household received a pre and post upgrade VRES assessment of their home by a qualified assessor. The pre-upgrade assessment involved a visit to the home whereas the post-upgrade assessment was a desktop exercise, amending the initial assessment based on details of the upgrade. The assessments provided a variety of metrics, including an overall star rating out of 10, which reflects the modelled energy costs of the home (NB: not equivalent to a NatHERS star rating). This assessment informed the choice of specific home energy upgrades delivered to the home. The selection of upgrade measures for each home was decided by the program manager at AEF, based on 3 factors:

(1) winter thermal comfort considerations from householders,

(2) subjective assessment by the Energy Liaison Officer of measures to improve winter thermal comfort,

(3) recommended energy efficiency remediation actions from the VRES assessment.

Ethics and consent

Informed written consent was sought from participants at the beginning of the first home visit, which included consent to access their energy use data and administrative health data. The trial was conducted in accordance with the NHMRC's guidelines for the ethical conduct of human research. Ethical approval for the original study protocol was received from Victorian Department of Human Services (DHS) Human Research Ethics Committee on 02/08/2017 (Reference number: 04/17) and the University of Technology Sydney (UTS) Human Research Ethics Committee on 20/04/2018 (Reference number: ETH18-2273).

Outcomes

The hypothesis is that the home upgrade will lead to improved thermal comfort which, in turn, will lead to better health outcomes. As specified in the published protocol, the primary outcome investigated is the change in indoor air temperature within the home's main living area during the winter period (defined as 22 June to 21 September). The evaluation also considers multiple secondary outcomes, including self-rated health and wellbeing, self-reported respiratory symptoms, and healthcare utilisation (hospital admissions, emergency department attendances, GP visits, specialist visits and use of prescription medicines). Other secondary outcomes include household energy consumption, residential energy efficiency, and subjective thermal comfort.

Statistical analysis

To estimate the effects of the intervention, we compare outcomes from the control and intervention groups over the 3-month winter period of their study year. Regression models included the outcome of interest and relevant covariates that applied to all analyses (e.g., study year, LGA), household analyses (e.g., floor size, RES rating) and individual analyses (e.g., age, sex). As some households included multiple participants, all analyses were clustered by household. Primary analysis was intention-to-treat (ITT) – analysing all households (individuals) according to how they were randomised, irrespective of whether they actually received their allocated intervention. Secondary analysis was per protocol (PP) – analysing only those households (individuals) that received their allocated intervention as intended. For the intervention group, this meant full upgrade completion prior to 21 June of their study year.

Energy data limitations

Electricity usage data were not available for the following:

- 278 households had rooftop solar photovoltaics (PV). Smart meters only measure energy flow across the meter, they do not include PV-generated electricity consumed by the household.
- Approximately 70 households were units in retirement villages that were part of an embedded electricity network. These units did not have stand-alone smart meters.

Gas usage data were not available for the following:

- 107 households did not use gas; they were all-electric, or use other forms of heating.
- At least 16 of the Goulburn Valley households used bottled (not reticulated) gas.

Participant sample

There were 1331 individuals (1000 households) in the full sample. Withdrawals (19 individuals, 16 households) left a total sample size of 1312 individuals across 984 households. Figure 3 shows the VHHP recruitment flowchart. Of the 1999 households assessed for eligibility, 984 were included and randomised, 493 to the control group and 491 to the intervention group. These households constitute the sample for ITT analysis.

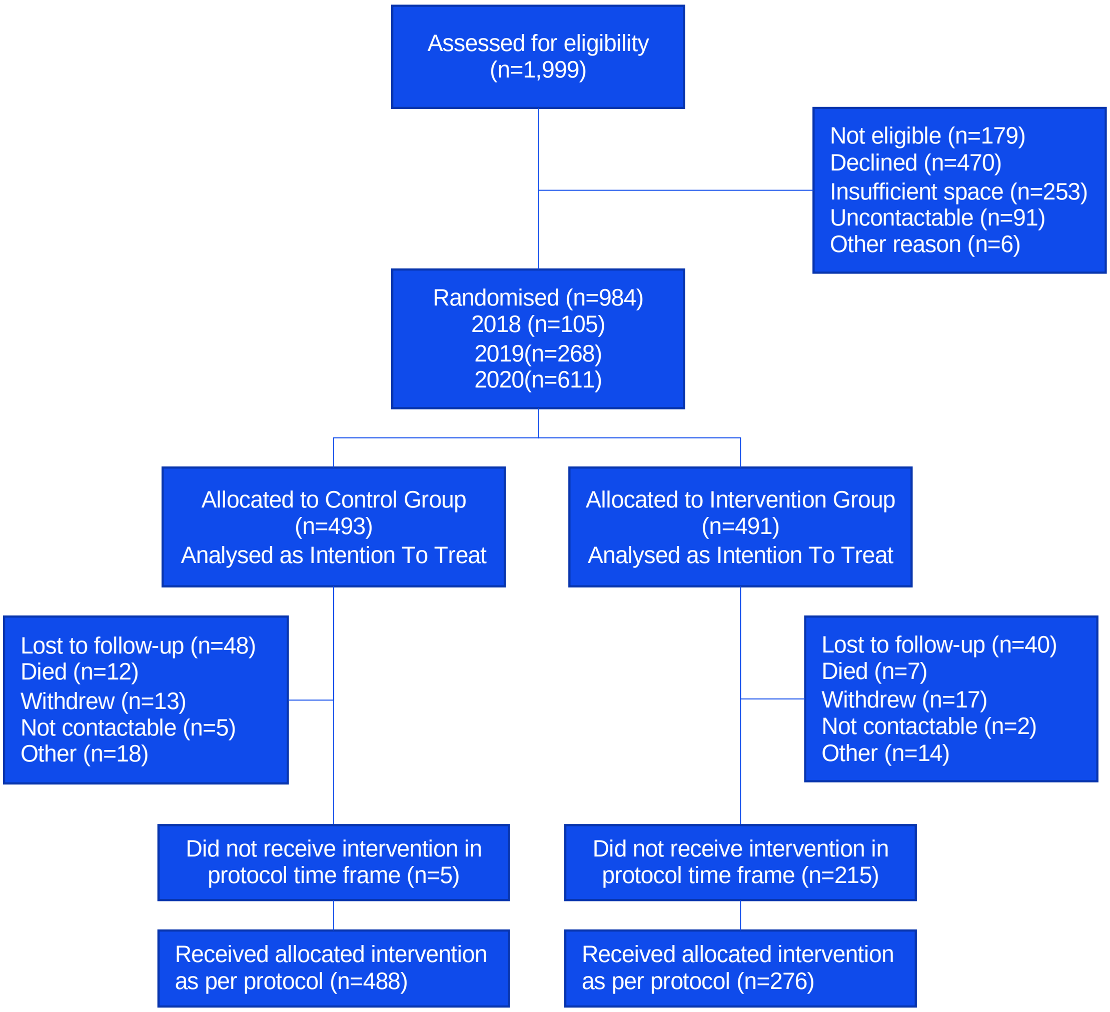


Figure 3. Participant flow diagram (CONSORT).

Most households either had 1 participant (N=516) or 2 participants (N=396), with smaller numbers having 3 (N=60), 4 (N=10) and 5 (N=2) participants. Most households had either 1 or 2 occupants (N=896, 91%), with the same level in control (N=450, 91%) and intervention (N=446, 91%) groups. Any change in number of occupants over winter was tracked, and was no different between groups.

Table 1. Participant numbers by study year.

Study year	**Individuals**	**Households**
2018	143	105
2019	356	268
2020	813	611
Total	1312	984

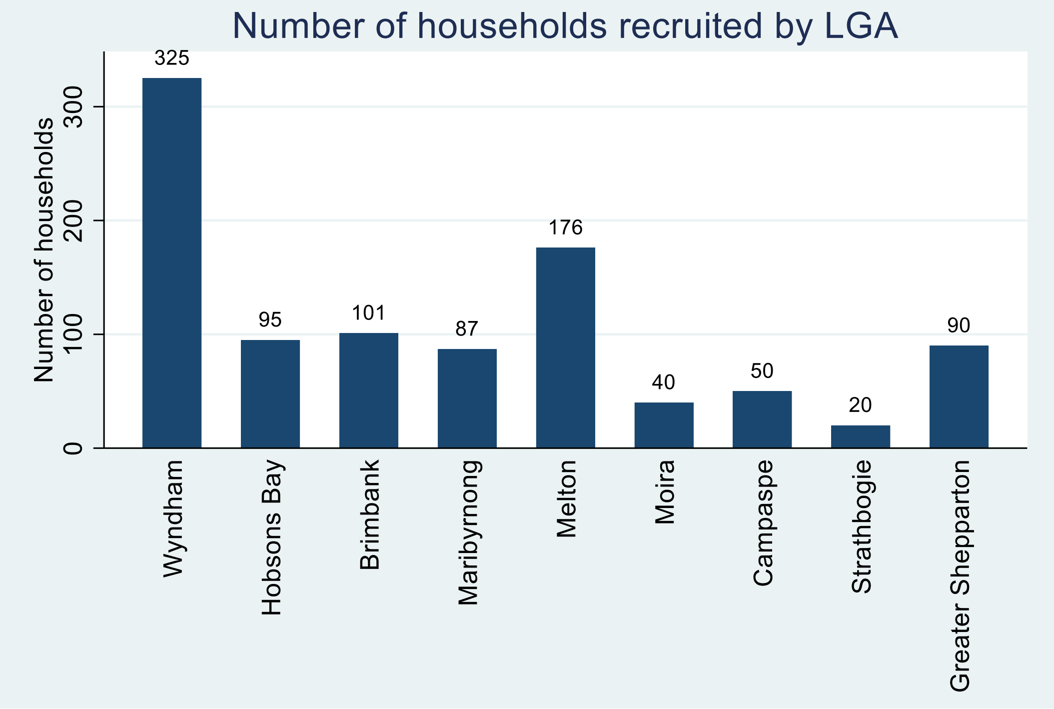


Figure 4. Households recruited by Local Government Area.

There were no significant group differences in age and sex profile. Mean age of participants was 74.8 years (SD 11.5) and 65% were women. Participant and household characteristics are shown in Table 2. Most participants had either never smoked (52%) or had given up >12 months ago (39%); only 3% were current smokers. Most homes were owned outright (N=674; 68%), reflecting the older age of this cohort, with similar levels in control (N=340; 69%) and intervention (N=334; 68%) groups. Others were owned with mortgage, private rental, other rental, public housing, or community housing.

Table 2. Participant and household characteristics by group.

	Control	**Intervention**
Female (%)	67.2	63.7
Mean floor area (m^2)	115.2	115.4
Mean pre-upgrade RES rating	4.96	4.96
Solar PV presence (%)	26.4	27.1
Gas heater presence - pre-upgrade (%)	66.3	68.6

Per protocol

COVID disruption to the 2020 study year meant that secondary PP analysis was important. A State of Emergency was declared from 16 March 2020 to 15 December 2021, with lockdowns and stay-at-home orders applied at various periods. Of the 304 intervention households in the 2020 study year, only 133 received their complete upgrade prior to the start of winter. The PP sample consisted of 1015 participants (641 control, 374 intervention) across 764 households (484 control, 280 intervention). Age (mean = 75.1, SD 11.6) and sex (65% female) profile of the PP sample was very similar to the ITT sample.

Upgrade works

The goal of upgrading homes was to create a warmer, drier indoor environment and to improve air quality and energy efficiency. A list of upgrade options was compiled by experts in home energy efficiency, taking into consideration the Australian context of often poorly insulated houses, budget constraints and ease of installation. The menu of program upgrades was drawn from this list, with priority given to items that would improve winter thermal comfort. Options included:

1. Draught sealing – seals to external doors, wall vent covers, extractor fan caps.
2. Insulation – new or top-up ceiling, underfloor.
3. Space heating and cooling – existing heaters serviced, replacement gas heaters, new reverse cycle air conditioners.
4. Window Furnishings – new or replacement blinds, new drapes and pelmets, window film.
5. Lighting – replacement of downlights with IC rated LED downlights (allows for continuous ceiling insulation over).

Table 3. Upgrade works completed (as of December 2021).

Type of work	N
Underfloor insulation	24
New ceiling Insulation	25
Ceiling insulation top up or adjustment	208
Draught proofing	391
LED lights	79
Electrical audit	258
Curtains and blinds	244
Low-E window film	16
Split system service (reverse cycle A/C)	82
New split system (reverse cycle A/C)	386
Gas heater service	441
New gas heater (e.g., furnace, space heater, ducted)	45
Carbon monoxide testing (before and after works)	623
Other (e.g., patch and paint)	25
Service calls	7

The target for average upgrade cost was $3500, though this was reduced to a target average of $2600 in the final year of the program, due to the delays caused by COVID lockdowns. Actual costs were assessed in March 2022, with invoiced amounts available for the first 821 households (Table 4).

Table 4. Upgrade cost by study year.

Study year	N	Average cost
2018	102	$3,397
2019	258	$3,119
2020	461	$2,514
Total	821	$2,814

Note that average upgrade cost for intervention households ($2988) was higher than for control households ($2618). This imbalance is not problematic for the trial design, as our results compare the upgraded intervention homes to the non-upgraded control homes during the winter period. The value of the post-winter upgrade to control homes has no bearing on our research outcomes.

Energy efficiency

Modelled outputs from each home's VRES assessment included:

- A performance rating of the building shell.
- Hot weather efficiency rating.
- Total Winter Fabric Load (i.e., winter heat loss) in MJ per year.
- Total Summer Fabric Load (i.e., summer heat gain) in MJ per year.
- An overall star rating out of 10, calculated by directly converting the total modelled energy cost for the home.

VRES methodology sets a 3-star house as 'average' for its climate zone, based on the developers' understanding of the distribution of the housing stock and the appliance mix in them. To incentivise home improvements, there is a step change in the algorithm after 3, so the rating trajectory is not linear. Note that the star rating represents overall energy cost, and it is possible that a house with shortcomings (e.g., a small house, poor insulation, one room heated by a gas space heater) may get a higher star rating than a more efficient house (e.g., a large house, well insulated, gas central heating) due to the lower cost.

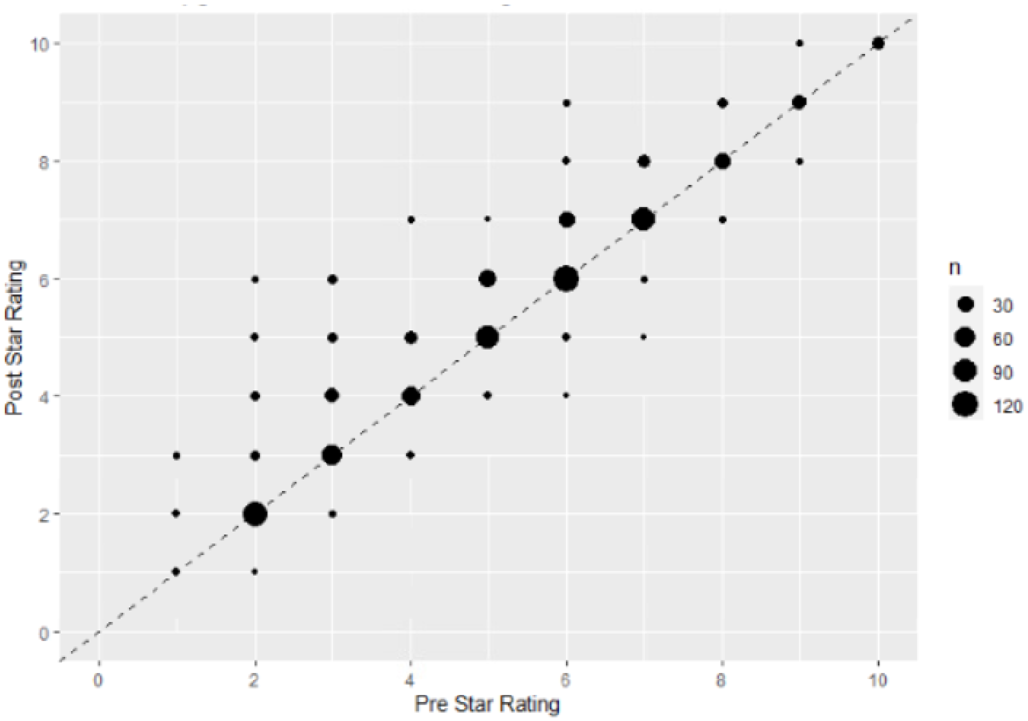


Figure 5. Effect of home upgrade on VRES star rating (full cohort).

The star rating system is in integers, with decimal points rounded down, potentially obscuring changes up to 1 star. For the whole cohort (intervention and control together), there was an average increase of 0.3 stars from pre- to post-upgrade (see Figure 5). Decreases in rating can be explained by homes having heaters installed, or broken heaters fixed, resulting in greater energy use than before upgrades. On average, home upgrades reduced modelled energy cost by $124.41 per year (see Figure 6).

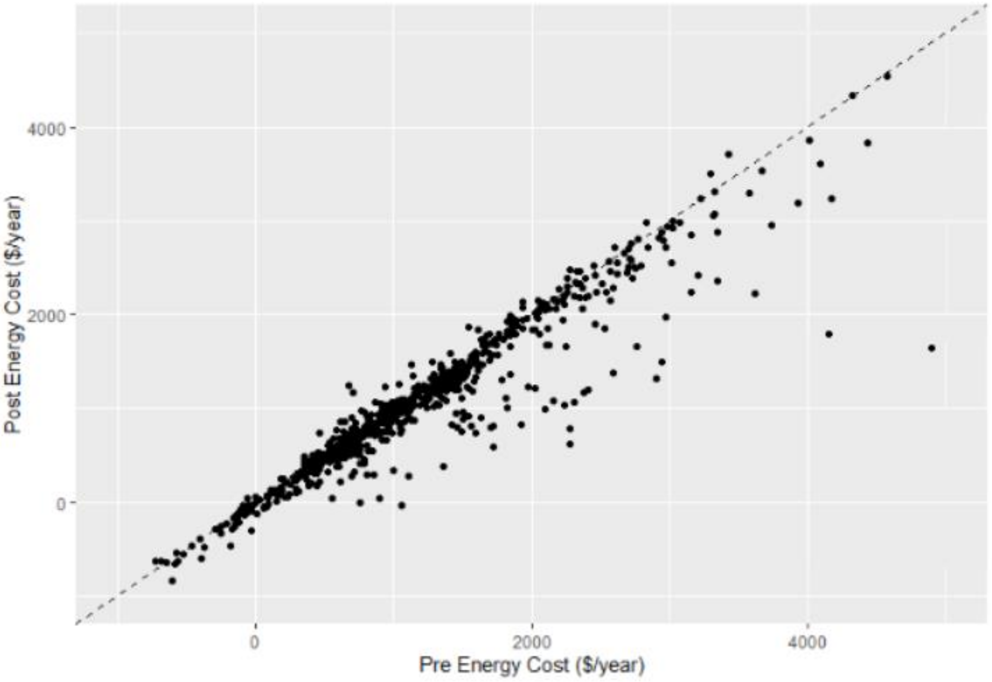
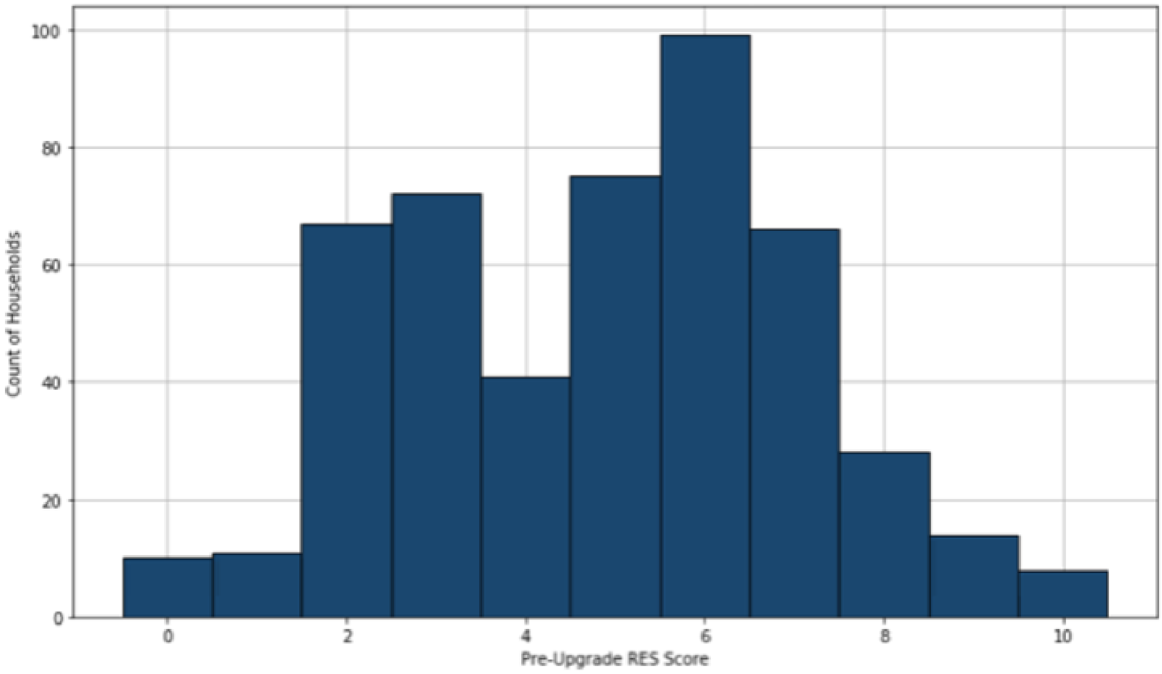


Figure 6. Effect of home upgrade on modelled energy cost (full cohort).

The intervention group had an average pre-upgrade star rating of 4.96, which increased to a post-upgrade average of 5.34 stars (see Figure 7).



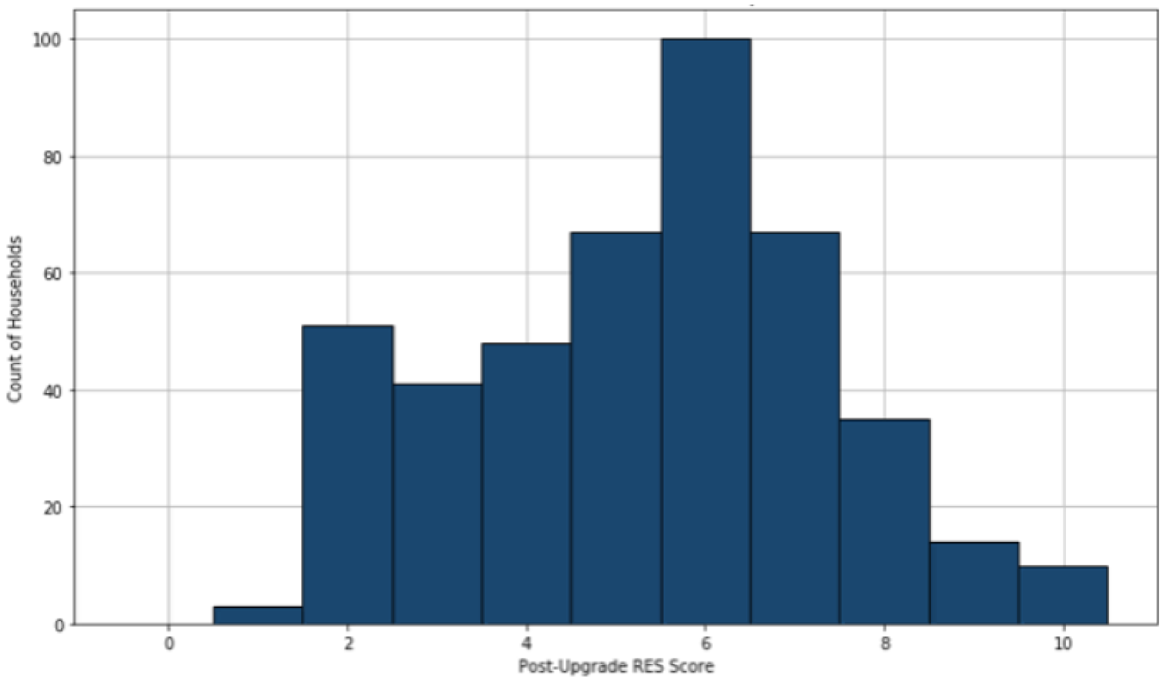


Figure 7. VRES star ratings in the intervention group pre-upgrade (above) and post-upgrade (below).

Primary outcome: Thermal comfort

Winter temperatures

After removal of households with incomplete data, there were 661 households for ITT analysis (512 households for PP analysis). Temperature thresholds used in this analysis were taken from the WHO *Housing and Health Guidelines*, which recommends an indoor temperature of at least 18°C for the general population and 20°C for vulnerable groups, including the elderly and those with existing health conditions.

Table 5. Average winter outdoor temperature by study year and location.

	2018	2019	2020
Shepparton (Goulburn Valley)	8.7°C	9.2°C	9.5°C
Laverton (western Melbourne)	10.4°C	10.6°C	10.8°C

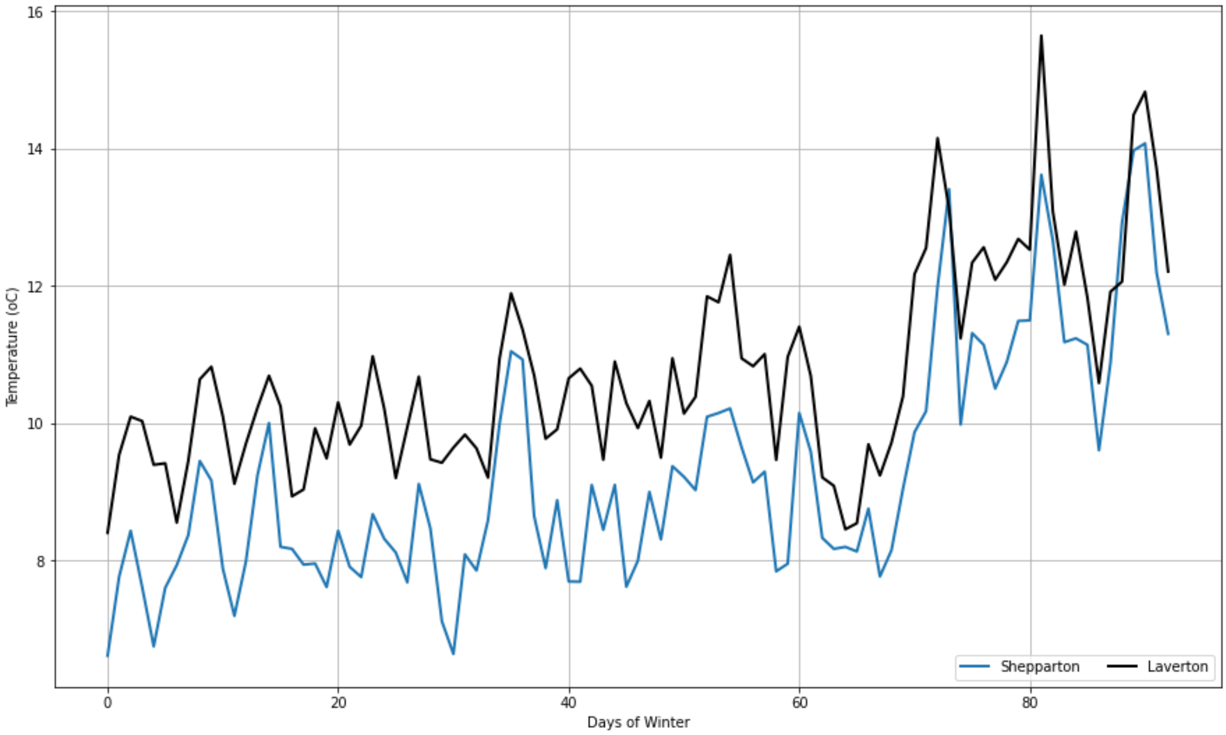


Figure 8. Average outdoor temperature (from BoM stations) across the 92 days of winter.

Indoor temperatures were lowest in the early morning hours, with most households consistently experiencing temperatures below 18°C during this time (see Figure 9).

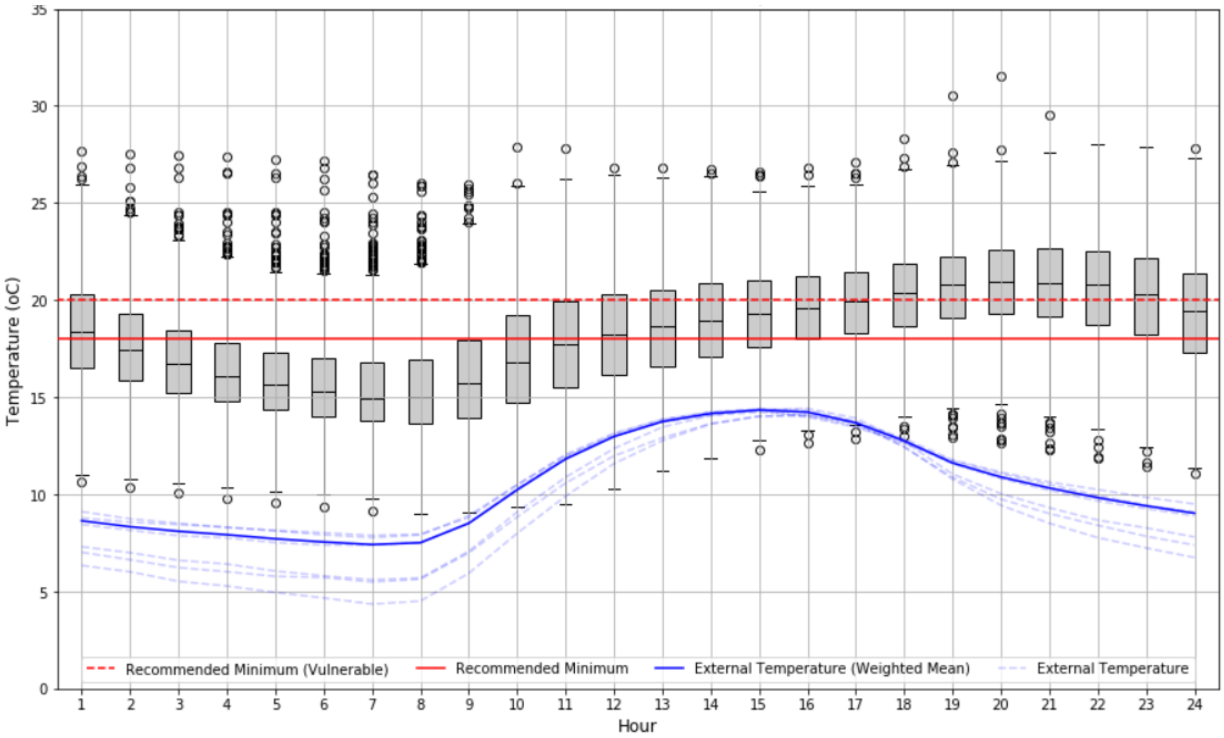


Figure 9. Boxplots (25th-75th percentile, with median) of indoor temperatures (full cohort) against recommended and external temperatures across the day.

Indoor temperature

Indoor temperature was measured every 30 minutes using a data logger installed in the main living area. A multiple regression model was developed to determine if households with a home upgrade exhibit higher average internal temperatures when compared to dwellings without a home upgrade. The dependent variable was household average temperature (°C) over the winter period. In addition to group (intervention versus control), the independent variables included in the model were: daily gas use (kWh), daily electricity use (kWh), floor area (log m^2), study year, baseline VRES rating, solar PV (yes/no). ***ITT analysis indicated that intervention households were significantly warmer over winter, by 0.33°C (95% CI 0.05, 0.60; p=0.022).*** The effect estimate was similar for PP analysis, with a difference of 0.36°C (95% CI 0.04, 0.68; p=0.029).

To assess whether the impact of the upgrade varies over the time of day, the half-hourly temperature readings from data loggers were grouped into 4 clusters: mornings (8am-12pm), afternoons (12pm-5pm), evenings (5pm-10pm), and overnight (10pm-8am). Note the pattern – in Figure 10 – for intervention homes to be warmer than control homes in 2018 and 2019 at all times of day, whereas there was little group difference in temperatures in 2020 (when many intervention group upgrades weren't completed before winter).

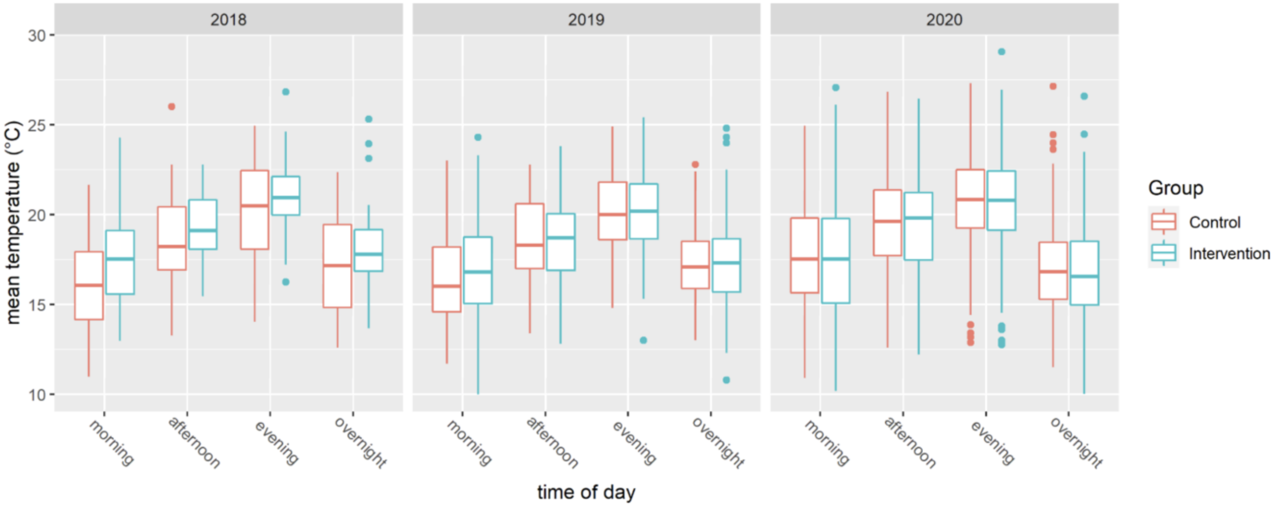


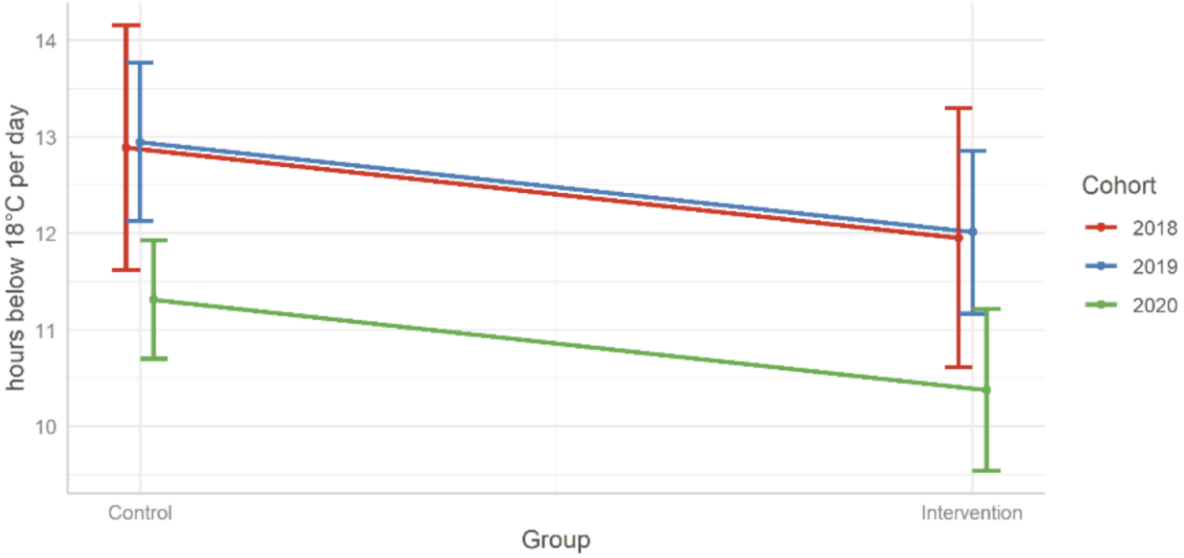
Figure 10. Boxplots of indoor temperature by group and time of day (ITT).

Results show that when indoor temperature is assessed separately by time of day, home upgrades had the largest impact during the mornings, increasing temperature by 0.47°C (95% CI 0.10, 0.84; p=0.012) in ITT analysis. A similar result was observed in PP analysis, with an increase of 0.55°C (95% CI 0.13, 0.96; p=0.010). It makes sense for morning to have the largest effect – typically heating is off overnight, so thermal efficiency of the house is the main determinant of maintaining temperature at this time of day.

Analysis across the whole cohort showed that homes with higher baseline VRES ratings were warmer in winter: each additional star equates to an increase of 0.30°C (95% CI 0.21, 0.39; p<0.001) in ITT analysis. To assess the impact of upgrades across various conditions of housing stock, households were split on baseline VRES star rating (0-4 versus 5-10). In ITT analysis, the upgrade-related temperature increase was similar in the 283 0-4 star houses (0.30°C) and the 379 5-10 star houses (0.34°C). In PP analysis, the upgrade had a stronger impact on temperature in the 0-4 star houses (estimate = 0.55°C, 95% CI 0.09, 1.02; p=0.020) than the 5-10 star houses (estimate = 0.23°C, 95% CI -0.20, 0.66; p=0.30).

Cold exposure

Time that occupants spent exposed to cold indoor temperatures (<18°C) was measured. ***Intervention homes spent less time exposed to cold temperatures over winter, by 43 minutes per day (95% CI -88, 2; p=0.060) in ITT analysis.*** The effect was even stronger in PP analysis, at 56 minutes per day (95% CI -109, -4; p=0.037). The group difference was consistent across study years (Figure 11).



note: error bars have been shifted horizontally to avoid overlap

Figure 11. Means (with 95% CIs) of hours spent in cold temperatures by group and study year.

Intervention homes spent less time exposed to cold across all 4 times of day, with confidence intervals shortest in the morning period (Table 6).

Table 6. Upgrade-related reduction of time spent <18°C by time of day, for both ITT and PP analysis.

	ITT			PP		
	Mins	**95% CI**	**p**	**Mins**	**95% CI**	**p**
Morning	-10	-19, 1	0.058	-13	-25, -2	0.023
Afternoon	-8	-21, 4	0.17	-16	-30, -1	0.040
Evening	-8	-19, 2	0.14	-12	-25, 1	0.06
Overnight	-17	-37, 4	0.11	-14	-38, 10	0.25

The significant PP morning difference of 13 minutes per day may seem small, but this is equivalent to ~10% reduction in exposure to cold during the morning, given that the entire group experiences an average of 2.3 out of the 4 morning hours below 18°C.

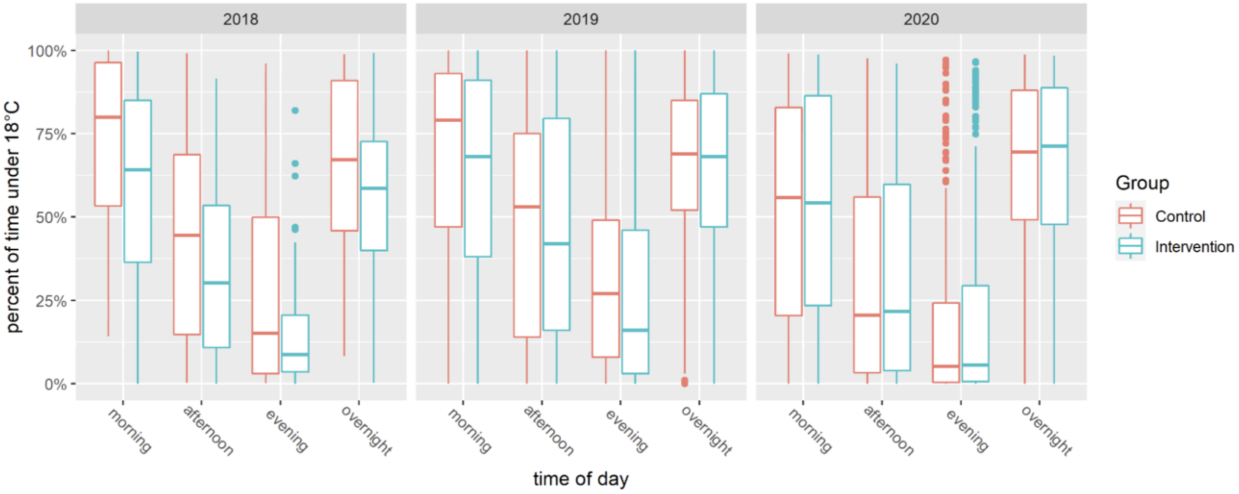


Figure 12. Boxplots of percentage time spent <18°C by group, time of day and study year.

Households were again split on baseline VRES star rating (0-4 versus 5-10). In ITT analysis, the upgrade-related reduction in time spent exposed to cold temperature was similar in the 0-4 star houses (-39 mins/day) and the 5-10 star houses (-43 mins/day). In PP analysis, the upgrade had a stronger impact on reduction in time spent exposed to cold in the 0-4 star houses (-89 mins/day; 95% CI -172, -6; p=0.035) than the 5-10 star houses (-34 mins/day; 95% CI -102, 34; p=0.33).

Subjective thermal comfort

At baseline, 63% of all participants reported their home being colder than they would have liked at some point during the previous winter. At the extreme end, 20% of participants reported their home being colder than they would have liked every day during winter.

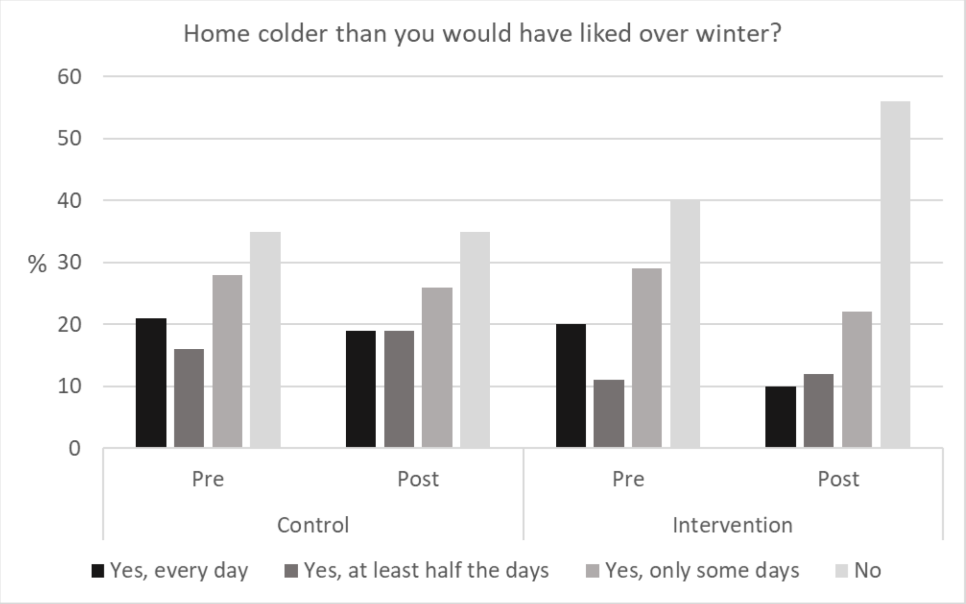


Figure 13. Subjective thermal comfort at pre and post winter by group.

There was a significant difference between groups in perceived thermal comfort over winter (see Figure 13). The likelihood of perceived thermal comfort having increased in the intervention group was 2.3 times that of the control group in ITT (95% CI 1.8, 3.0; p<0.001). This finding was even stronger in PP analysis (2.8 times; 95% CI 2.1, 3.8; p<0.001).

Participants were asked to rate their subjective thermal comfort over winter in 2 conditions: (i) when heating was being used, and (ii) without heating (the passive state). When heating was being used, the odds of perceived thermal comfort having increased in the intervention group were 1.7 times that of the control group in ITT (95% CI 1.3, 2.1; p<0.001). This effect was stronger in PP analysis (1.9 times; 95% CI 1.4, 2.6; p<0.001). Without heating being used, the odds of perceived thermal comfort having increased in the intervention group were 1.9 times that of the control group in ITT (95% CI 1.4, 2.4; p<0.001). Again, this effect was stronger in PP analysis (2.3 times; 95% CI 1.7, 3.1; p<0.001).

Humidity

Figure 14 shows the distribution of indoor relative humidity recorded from all participating households over winter, by time of day. Humidity levels were typically around 50%.

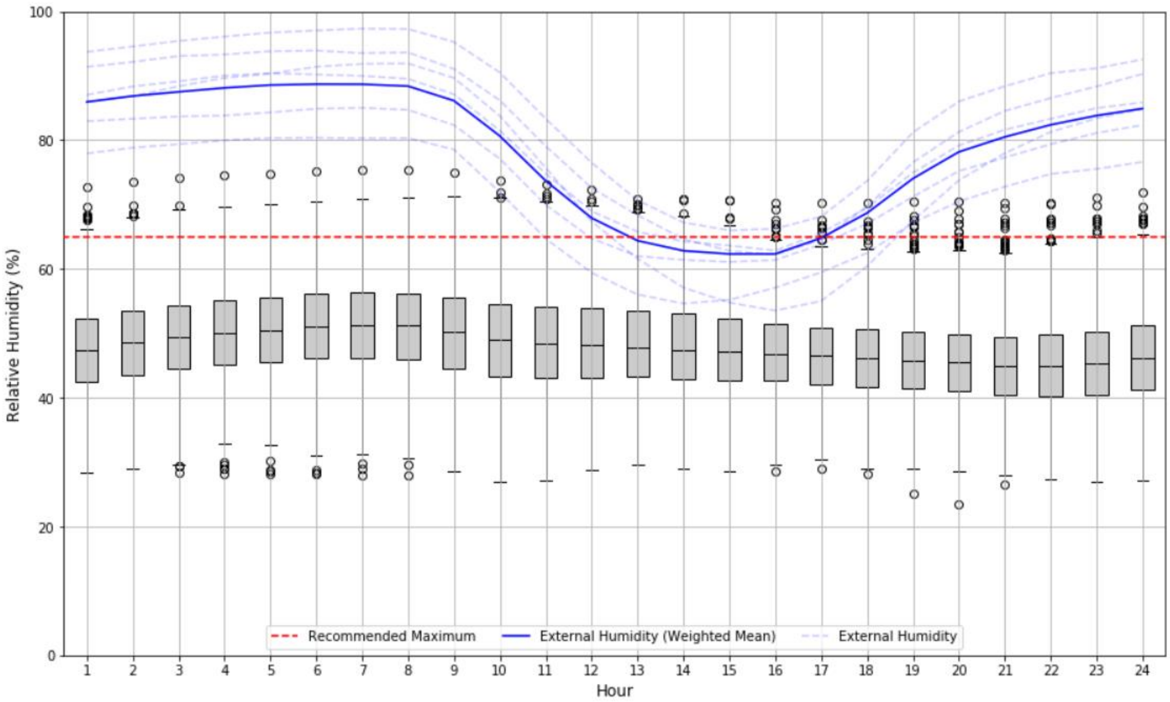


Figure 14. Boxplots of indoor relative humidity (full cohort) against recommended and external humidity levels across the day.

Mean winter humidity was similar across groups (intervention = 48.5%, control = 47.9%). WHO benchmarks a combination of relative humidity over 65% and temperatures below 16^{o}C as hazardous to health. When considering the percentage of homes that experienced at least 30 minutes of exposure to hazardous conditions, the groups were again similar (48.6% of intervention homes, 49.7% of control homes). Figure 15 plots the correspondence of mean temperature and humidity across winter for each household at each hour (i.e., 24 data points per household). Hazardous conditions are highlighted with grey shading. There were 6.6% of intervention households and 4.9% of control households that experienced at least 1 time point of the day (usually early morning) where the average conditions are considered hazardous.

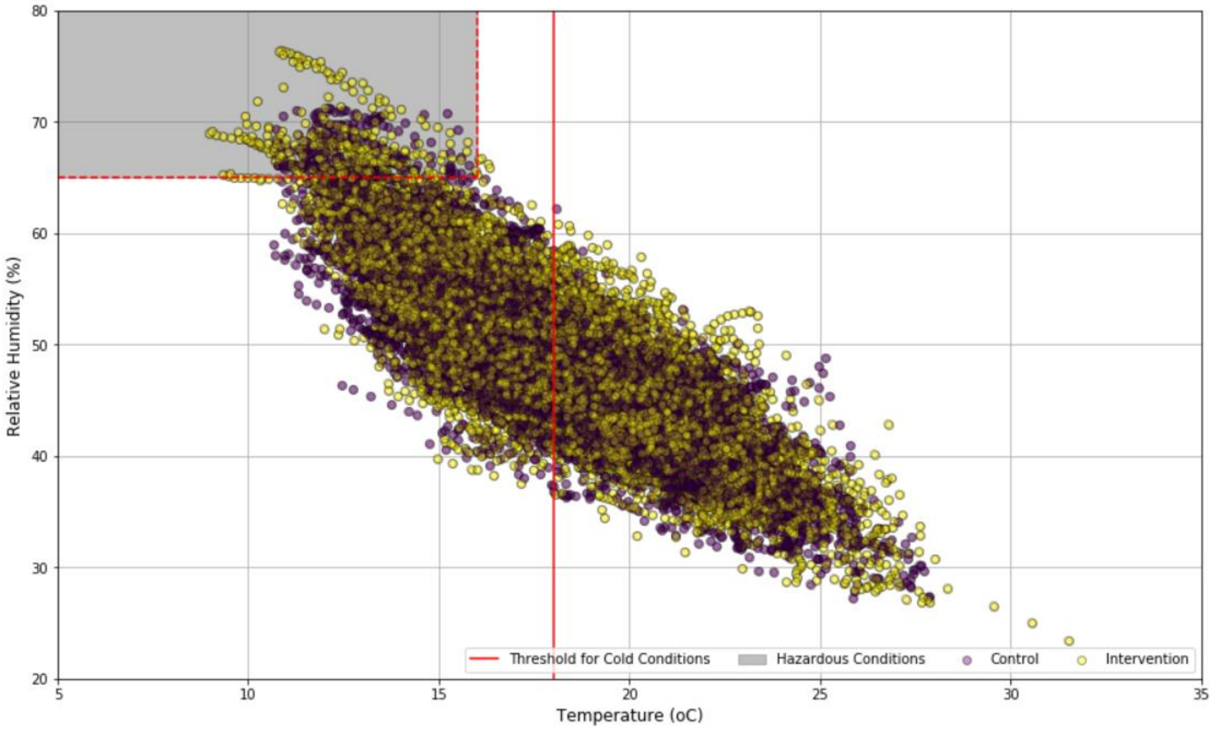


Figure 15. Relative humidity and temperature for each household at each hour (i.e., 24 data points per household).

Mould

When asked about the preceding winter (baseline), there was no difference in the number of households reporting seeing mould (intervention = 17%, control = 17%). When asked about the trial winter, there was a slight difference in favour of intervention (intervention = 13%, control = 15%), but it was not statistically significant (odds ratio = 1.07; 95% CI 0.79, 1.45; p=0.65). Unsurprisingly, the bathroom was the location with the most mould reported.

Damp or musty smell

When asked about the preceding winter (baseline), there was a small difference in the number of households reporting a damp or musty smell (intervention = 14%, control = 11%). When asked about the trial winter, this difference switched in favour of intervention (intervention = 9%, control = 12%). Analysis indicated that the intervention group was 37% more likely to report reduced damp or musty smell (odds ratio = 1.37; 95% CI 0.99, 1.89; p=0.061). When analysed by location, the intervention had a statistically significant impact on reducing damp or musty smell in non-primary bedroom (odds ratio = 1.90; 95% CI 1.13, 3.28; p=0.017), kitchen (odds ratio = 2.18; 95% CI 1.15, 4.31; p=0.020) and hallway (odds ratio = 2.04; 95% CI 1.07, 4.07; p=0.035).

Condensation

When asked about the preceding winter (baseline), there was a small difference in the number of households reporting condensation (intervention = 30%, control = 25%). When asked about the trial winter, this difference switched in favour of intervention (intervention = 18%, control = 25%). Analysis indicated that the intervention group was 48% more likely to report a reduction in condensation (odds ratio = 1.48; 95% CI 1.12, 1.95; p=0.006). Condensation was most often reported in the main bedroom, followed by other bedrooms and the living room.

Energy use

For ITT analysis of energy data, there were 662 households available (332 control, 330 intervention), while for PP analysis there were 512 households (327 control, 185 intervention).

Electricity

Raw data showed an average winter electricity use of 14.0 kWh/day, with little difference between control (13.8 kWh/day) and intervention (14.3 kWh/day) households. When other variables were accounted for in regression, the intervention was associated with a reduction in electricity use of 0.9 kWh/day; this difference was not significant (ITT; 95% CI -0.5, 2.3; p=0.18). This is unsurprising because gas heating dominates in Victoria, with 74% of the study households using gas as their main heating source.

Gas

Gas data were translated from MJ to kWh for comparability with electricity data. Raw data showed an average winter gas use of 59.0 kWh/day, with higher usage in control (61.7 kWh/day) than intervention (56.2 kWh/day) households. When other variables were accounted for in regression, the intervention was associated with a significant reduction in gas use of 7.1 kWh/day (ITT; 95% CI 2.2, 12.0; p=0.005). Similar results were observed in PP analysis (effect = 8.2 kWh/day; 95% CI 2.2, 14.1; p=0.008).

When households were split by baseline VRES rating, intervention impact on reduction in gas use was seen in ITT in both the 0-4 star homes (5.9 kWh/day; 95% CI -2.5, 14.3; p=0.17) and the 5-10 star homes (7.8 kWh/day; 95% CI 2.1, 13.6; p=0.008). PP analysis yielded similar results: reductions in gas use in the less efficient homes (8.5 kWh/day; 95% CI -2.1, 19.1; p=0.12) and the more efficient homes (8.1 kWh/day; 95% CI 1.0, 15.2; p=0.025). Note that relative gas savings were greater in the 0-4 star homes, given that their daily gas use was lower than the 5-10 star homes (47.5 versus 76.4 kWh/day).

Energy and temperature

As expected, there was a link between energy use and indoor temperature. For every 10 kWh additional gas used per day, low-efficiency households (0-4 star) increased mean indoor temperature by 0.23°C and high-efficiency households (5-10 star) increased mean indoor temperature by 0.31°C. The link was even stronger for electricity use, which makes sense given that split systems are more efficient at raising temperatures than gas heaters. For every 10 kWh of additional electricity use, low-efficiency households increased mean indoor temperature by 0.64°C, while high-efficiency households increased mean indoor temperature by 1.0°C.

Energy costs

Tariffs from household energy bills were recorded during home visits. The median electricity tariff was 21.8c/kWh and the median gas tariff was 2.1c/MJ. Billing information, however, was inconsistent and unreliable. Each retailer has a different bill format, tariff types and amounts vary considerably, discount and concession types and amounts vary, and bill totals may or may not have discounts applied or arrears included. Threshold analysis showed significant reliability issues for tariff data collected across the participating households, making it difficult to directly utilise billing data. Instead, the average Victorian electricity rate ($0.29/kWh) and gas rate ($0.107/kWh) were used to quantify financial impact. Using a consistent tariff for all households ensured that the impact of intervention on energy costs was directly proportional to energy consumption. The intervention impact on gas consumption – 7.1 kWh (25.5 MJ) less gas use per day – equates to $69.70 in savings per household over winter.

Main heater use

Self-report results from the preceding winter (baseline) show similar heater usage patterns between control and intervention groups (see Figure 16). A substantial proportion of all households (31%) reported using the heater only when very cold.

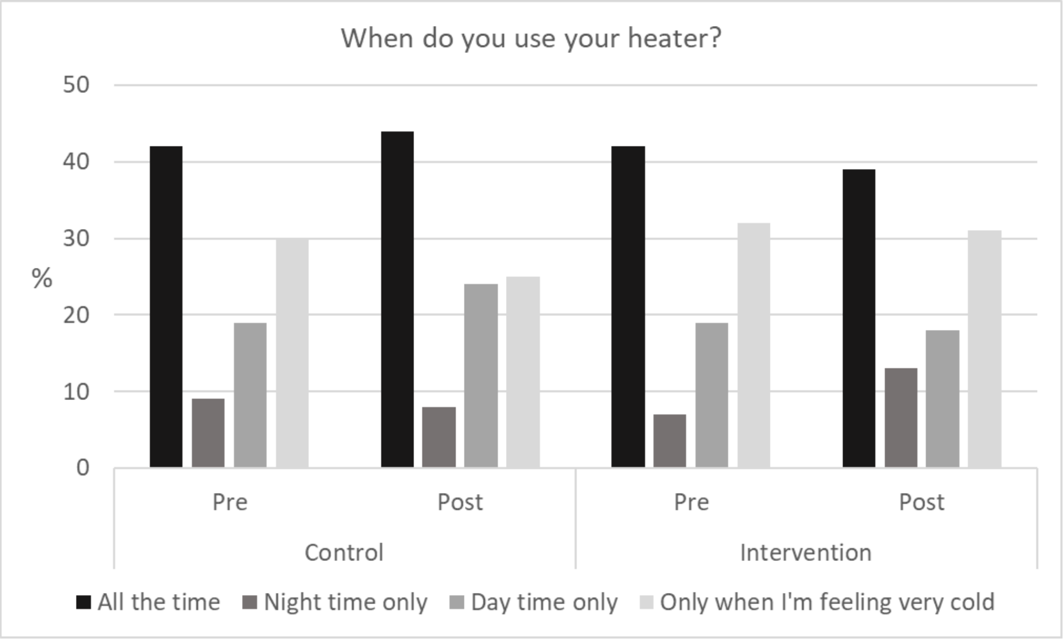


Figure 16. Heater use reported at pre and post winter by group.

ITT analysis indicated that households with upgrades were 37% more likely to report use of the main heater only when feeling cold (odds ratio = 1.37; 95% CI 1.00, 1.87; p=0.052). Intervention households were also 20% less likely to use the main heater “all the time” (odds ratio = 0.80; 95% CI 0.60, 1.07; p=0.13). In PP analysis, intervention households were 31% less likely to use the main heater “all the time” (odds ratio = 0.69; 95% CI 0.49, 0.98; p=0.038).

Keeping warm

Other than the main heater, participants were asked about ways they used to keep warm ‘when feeling cold’, including use of a portable electric heater, lighting a fire or stove, putting on a warm jumper, going to bed early, or turning the oven on and leaving the door open. There were no significant group differences, though the intervention group was 24% less likely than the control group to use a portable electric heater (odds ratio = 0.76; 95% CI 0.55, 1.05; p=0.09). Participants were also asked about ways they used to keep warm at night. The intervention group was 57% less likely to use a portable electric heater (odds ratio = 0.43; 95% CI 0.21, 0.88; p=0.021) and 49% less likely to go to bed early (odds ratio = 0.51; 95% CI 0.35, 0.74; p<0.001) compared to the control group.

Rebound effect?

As homes become more energy efficient from upgrades, residents can allocate this gain towards higher indoor temperatures or reductions in energy bills, or a combination of both. Upgrades may also result in a ‘rebound effect’, where householders increase the use of their new heating appliances, boosting indoor temperature and – despite improved efficiency – increasing energy bills. Our data contained no evidence of a rebound effect, with the impact of the upgrade increasing temperature while reducing gas use and not influencing electricity use. Furthermore, self-report data on behaviour showed reductions, not increases, in the use of heating appliances post-upgrade.

Quality of life

Participants completed 3 different quality of life measures in the before and after winter surveys: the Short-Form 36 (SF-36), the EuroQol (EQ-5D-5L), and the Adult Social Care Outcomes Toolkit (ASCOT). For all 3 scales, higher scores reflect better quality of life. Using the EQ-5D-5L, we calculated quality-adjusted life years (QALYs) and considered change over winter (QALY gain) for the control and intervention groups.

SF-36

The SF-36 is used to measure health-related quality of life. The 8 scales are: physical functioning, role physical, bodily pain, general health perceptions, vitality, social functioning, role emotional, mental health. The SF-36 also generates two summary scores: the physical component summary (PCS) and the mental component summary (MCS).

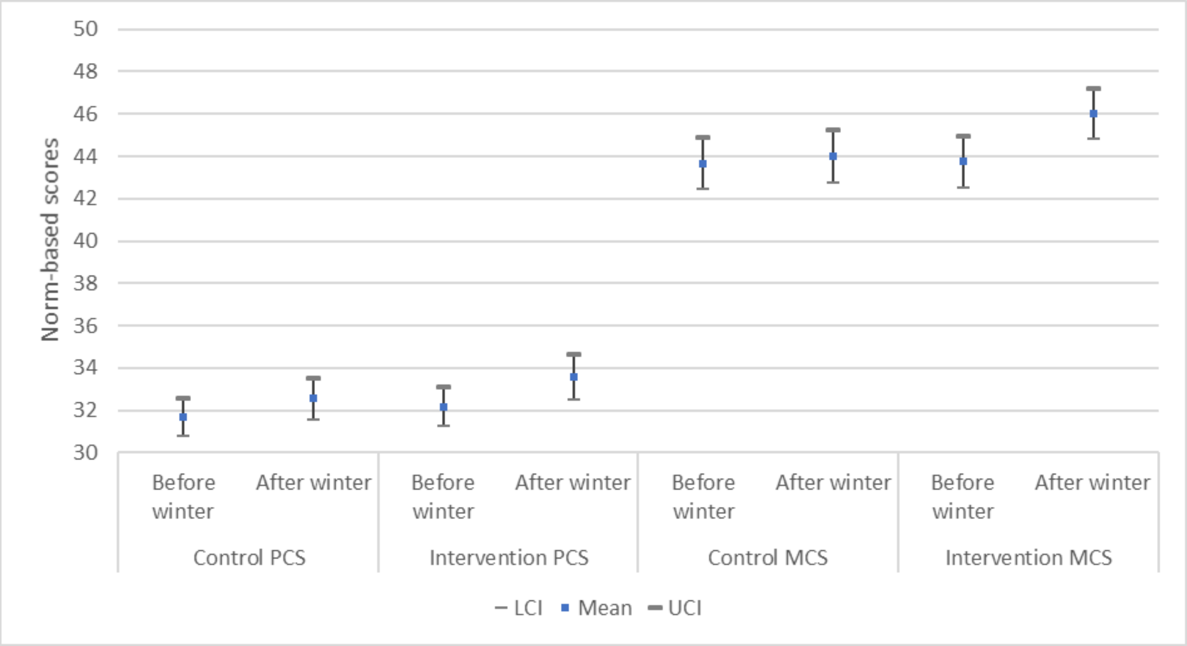


Figure 17. Physical (PCS) and Mental (MCS) SF-36 scores before and after winter by group.

In the MCS scale after winter, scores were significantly higher in intervention relative to control in ITT (Coefficient = 1.73; 95% CI 0.21, 3.25; p=0.026). Results were similar in PP (Coefficient = 1.67; 95% CI -0.09, 3.43; p=0.063). In the PCS scale after winter, those in intervention showed greater improvement than those in control, but the difference was not significant (ITT; Coefficient = 0.81; 95% CI -0.30, 1.92; p=0.15).

EQ-5D-5L

The EQ-5D-5L is a summary measure of health status that can be used in the health economic evaluation of interventions. The instrument has a preference-based scoring algorithm that summarises quality of life changes, allowing estimation of QALYs gained.

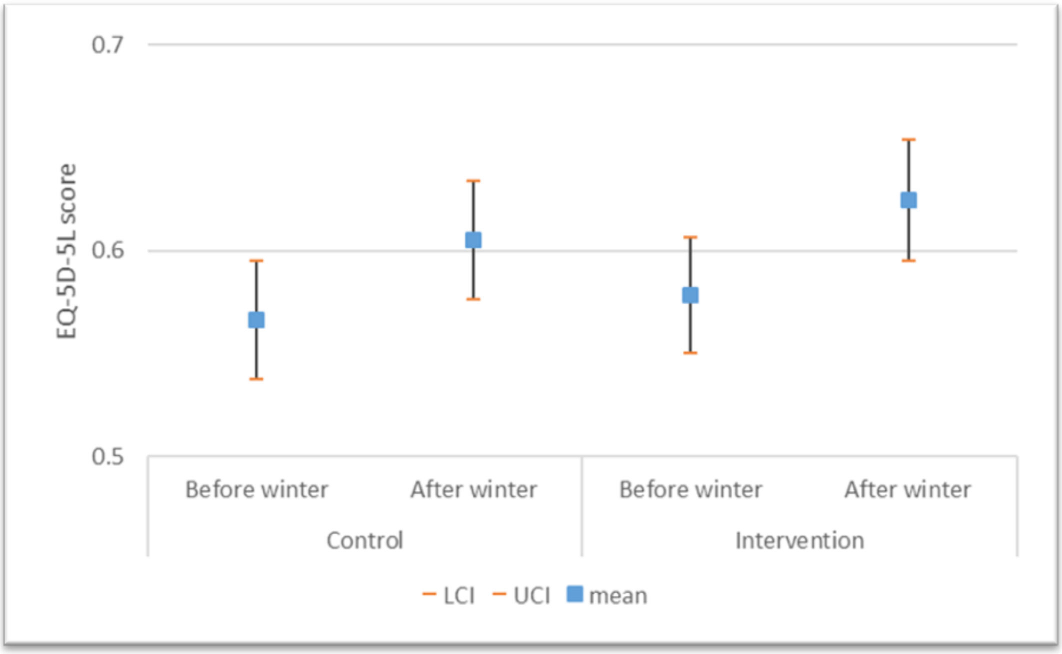


Figure 18. EQ-5D-5L summary scores before and after winter by group.

Summary scores increased from before winter to after winter in both intervention (mean 0.58 to 0.62) and control (mean 0.57 to 0.61) groups (Figure 18). There was no significant difference between the groups in EQ-5D-5L score (ITT; Coefficient = 0.01; 95% CI -0.03, 0.04; p=0.60). Note that our cohort has lower-than-average quality of life; the mean EQ-5D-5L score is 0.83 in a reference population of Australians aged above 75.

QALY gain

The change between the before and after winter EQ-5D-5L utility scores was calculated. This was then weighted by the duration of 3 months (winter period) to yield a QALY gain score. Positive values represent a gain in quality of life and negative values indicate a fall in quality of life. QALY gain scores are small because the duration is short; the maximum QALY gain is 0.25 (i.e., a state of full health for 3 months). Mean QALY gain was 0.01 (SD 0.08) for both control and intervention, with no significant group difference [t(1109) = 0.45, p=0.90].

Health today

One question in the EQ-5D-5L that does not form part of the 5-item utility scale is the ‘health today’ question. This is a single item visual analogue scale that asks individuals to rate their health on the day of completion on a scale from 0-100, where 0 is the worst health they can imagine and 100 is the best health they can imagine. Participants in the VHHP were asked this question in both the before and after winter individual surveys. Scores increased slightly more in intervention (mean 61.9 to 64.6) than control (mean 61.9 to 63.5), but the group difference was not significant (ITT; coefficient = 1.1; 95% CI -1.3, 3.4; p=0.37).

ASCOT

The ASCOT measures aspects of an individual's quality of life that can be affected by social care, according to the extent that needs are met. It has 9 dimensions: control over daily life, personal care, food and drink, safety, social participation, employment, accommodation, dignity (having help), dignity (way of being helped). Figure 19 shows that summary scores increased over winter in the intervention group (mean 0.78 to 0.80) but decreased in the control group (mean 0.78 to 0.77). There was a significant difference between the groups in ITT (Coefficient = 0.024; 95% CI 0.006, 0.042; p=0.009). The effect was slightly weaker in PP (Coefficient = 0.016; 95% CI -0.006, 0.037; p=0.15).

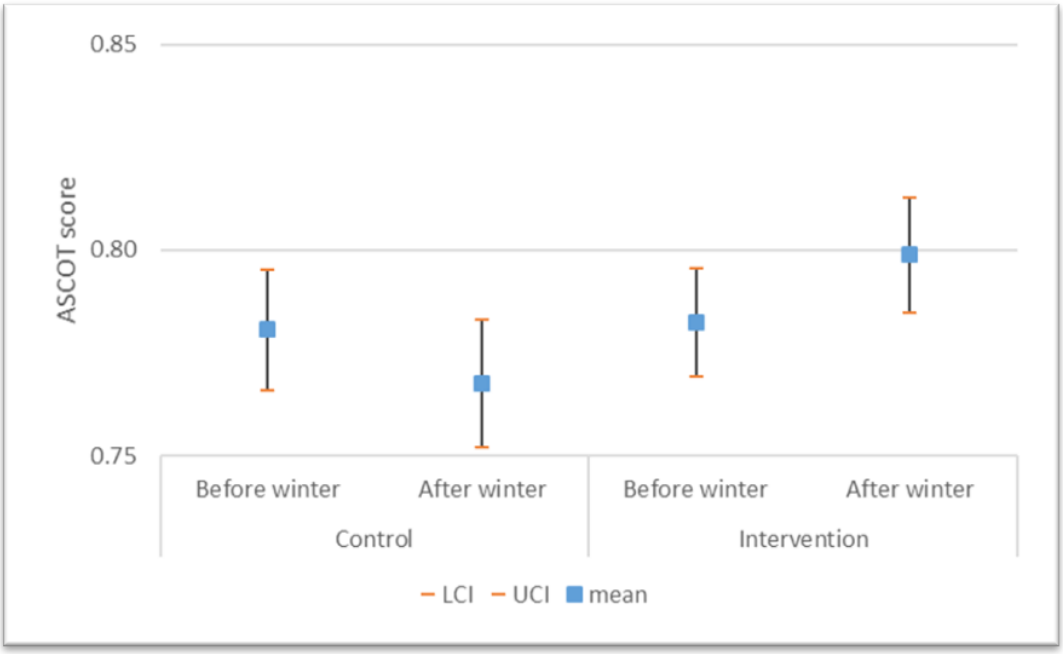


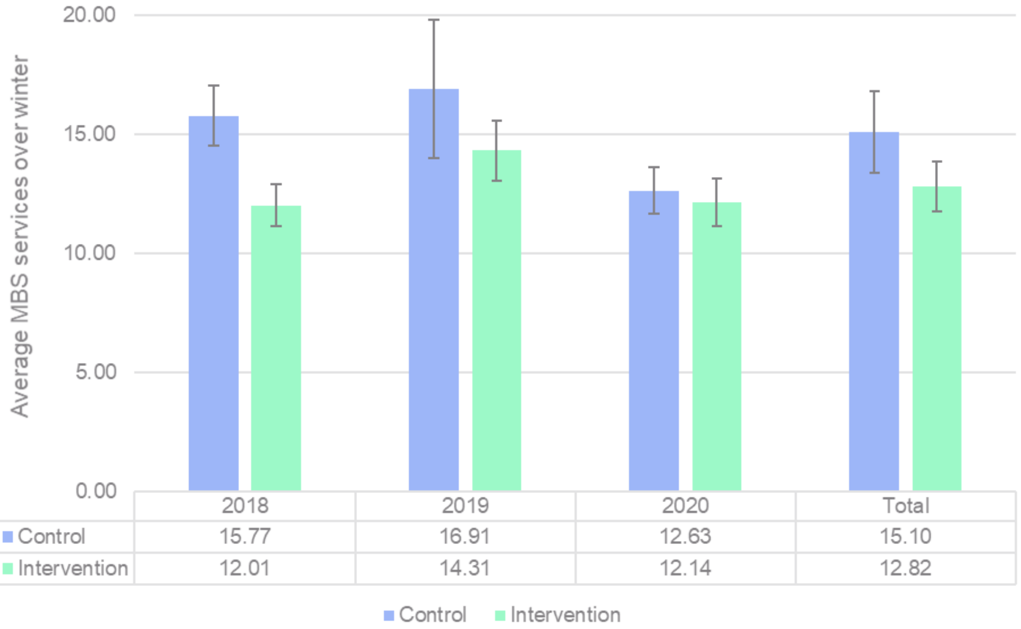
Figure 19. ASCOT summary scores before and after winter by group.

Healthcare utilisation and costs

There are several approaches to estimate the effects of the intervention on healthcare utilisation and costs. For this report, we selected the most simple and direct approach, which is to estimate the impacts of the intervention during the 3-month winter period. This is the same approach as used for the primary outcome. It should be noted that this approach is relatively conservative, as impacts on health care utilisation are likely to extend beyond the winter period in which the household experienced the intervention. Figures show averages over winter, with error bars representing modified standard deviations (given the large variance, they were reduced by a factor of 10 to display them). Data are presented separately by study year, given the COVID-related changes in healthcare utilisation in 2020.

Medicare Benefits Scheme

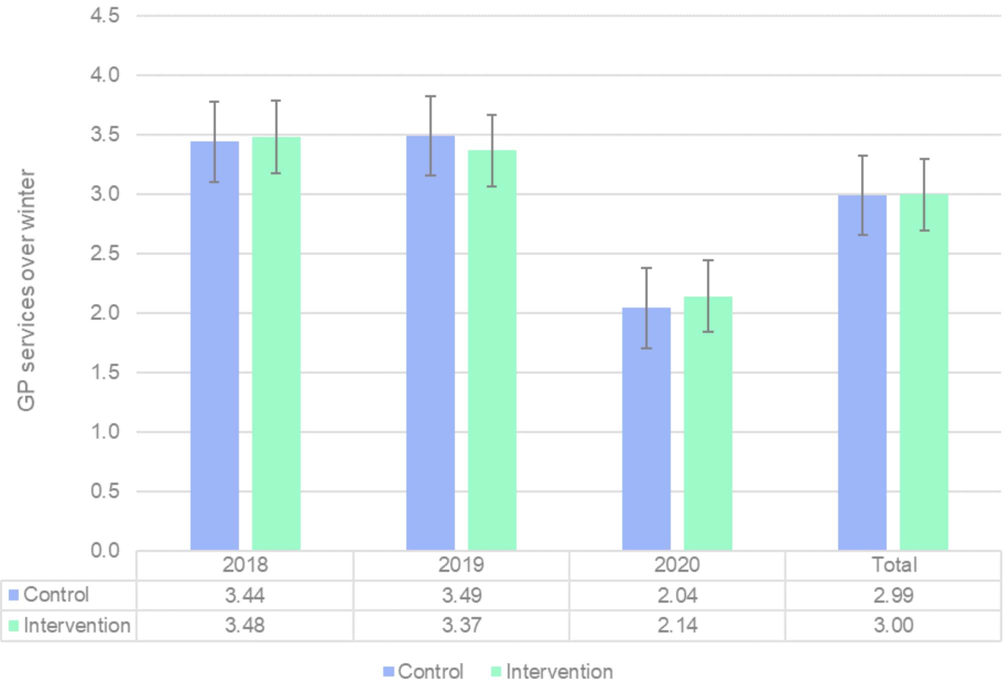
The Medicare Benefits Scheme (MBS) contains information on Medicare services that are subsidised by the Australian government. Of the 1331 VHHP participants, 22 had no MBS data, either because they did not consent or they had no claims over the 5-year period (2015-2020). Sixteen households (and 19 individuals) had MBS data but were not included in analysis as they had withdrawn or dropped out of the study. In total, we have 962 households and 1313 individuals with MBS claim data. Only ITT analyses are presented below (the same regression models were run on the PP sample, and results were similar in both magnitude and direction to the ITT sample for all outcomes).



	2018	2019	2020	Total
■ Control	15.77	16.91	12.63	15.10
■ Intervention	12.01	14.31	12.14	12.82

Figure 20. Medicare Benefits Scheme services used over winter by year and group (ITT).

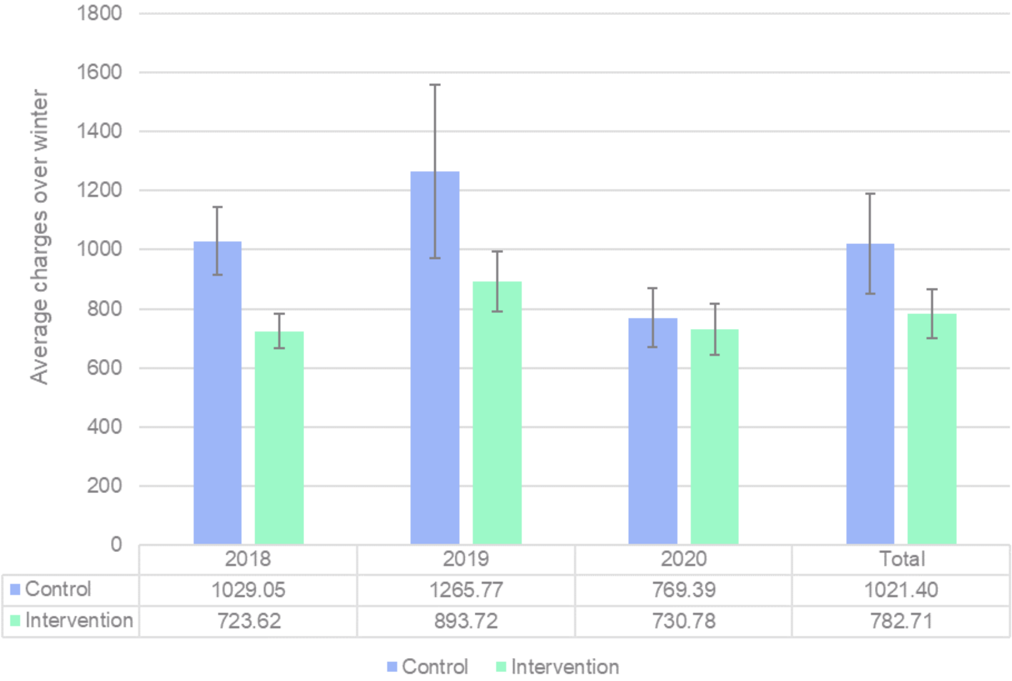
The intervention group used fewer MBS services than the control group over winter, though a negative binomial regression showed that this difference was not significant (coefficient = -0.10; 95% CI -0.21, 0.01; p=0.079).



	2018	2019	2020	Total
■ Control	3.44	3.49	2.04	2.99
■ Intervention	3.48	3.37	2.14	3.00

Figure 21. GP services used over winter by year and group (ITT).

There was no significant group difference in GP services used (coefficient = 0.02; 95% CI -0.11, 0.14; p=0.79). Note the lower GP use in the 2020 study year – negative binomial regression indicated that this was different to the 2018 and 2019 years (coefficient = -0.49; 95% CI -0.99, 0.00; p=0.051).



	2018	2019	2020	Total
■ Control	1029.05	1265.77	769.39	1021.40
■ Intervention	723.62	893.72	730.78	782.71

Figure 22. MBS charges over winter by year and group (ITT).

Linear regression indicated that the intervention group had significantly lower MBS charges than the control group (coefficient = -157; 95% CI -311, -2; p=0.046). There was also a significant effect of year, with the 2020 cohort having significantly lower MBS charges (coefficient = -281; 95% CI -506, -56; p=0.014).

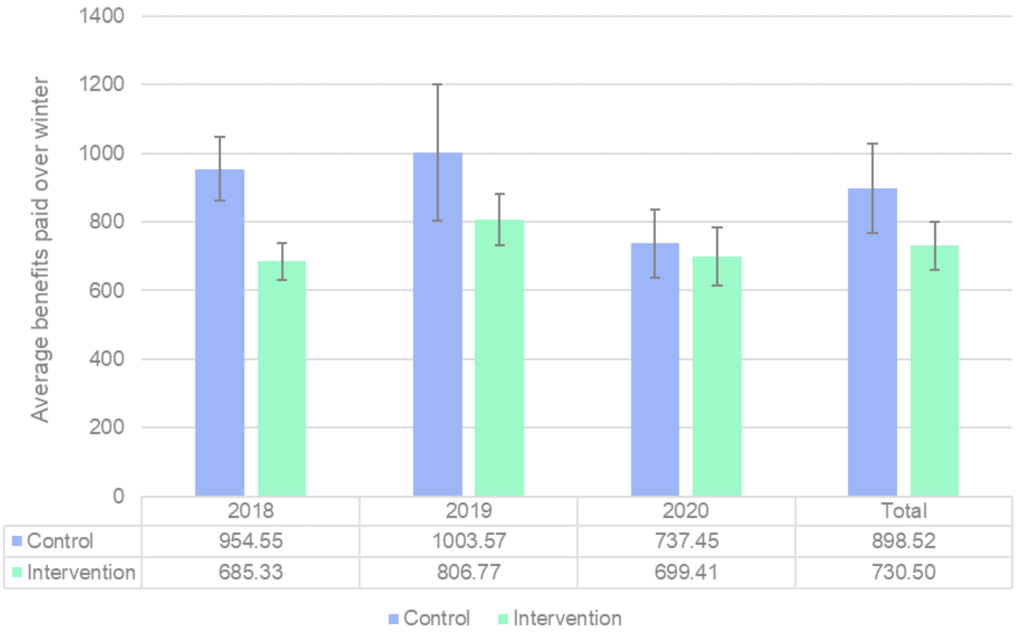


Figure 23. MBS benefits paid over winter by year and group (ITT).

Linear regression indicated that the intervention group had lower MBS benefits paid than the control group, though the difference was not significant (coefficient = -108; 95% CI -230, 14; p=0.084). There was again a significant effect of year, with the 2020 cohort having significantly lower MBS benefits paid (coefficient = -236; 95% CI -425, -46; p=0.015).

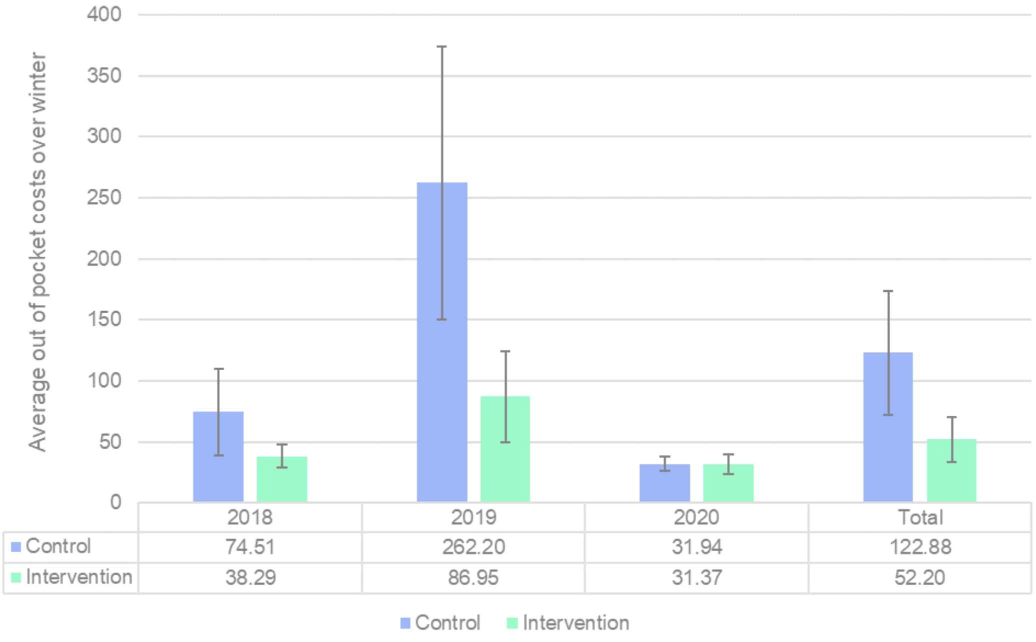


Figure 24. MBS out-of-pocket costs over winter by year and group (ITT).

Linear regression indicated that the intervention group had lower MBS out-of-pocket costs than the control group (coefficient = -49; 95% CI -98, 0; p=0.051). There was a significant effect of year, but this time it was the 2019 cohort having significantly higher MBS out-of-pocket costs (coefficient = 112; 95% CI 19, 206; p=0.018).

Pharmaceutical Benefits Scheme

The Pharmaceutical Benefits Scheme (PBS) data includes all medicines available to be dispensed to patients at a government-subsidised price. Our data extraction included all dispensed medication from the period May 2015 to December 2020 for all consenting participants. Of the 1331 participants, 57 had no PBS data because they had no prescriptions over the 5-year period and 51 did not provide consent for use of their PBS data. Sixteen households (and 19 individuals) had PBS data but were not included in analysis because they withdrew or dropped out of the study. In total we have 962 households and 1165 individuals with PBS claim data (for ITT).

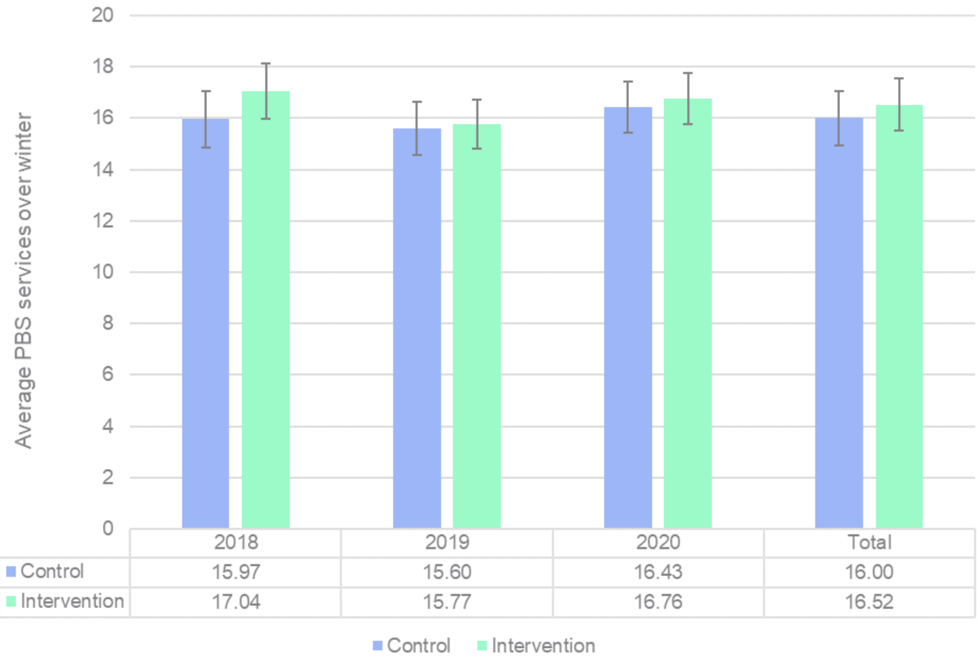


Figure 25. Pharmaceutical Benefits Scheme services over winter by year and group (ITT).

A negative binomial regression showed no significant difference between groups in PBS service use (coefficient = 0.02; 95% CI -0.06, 0.09; p=0.62).

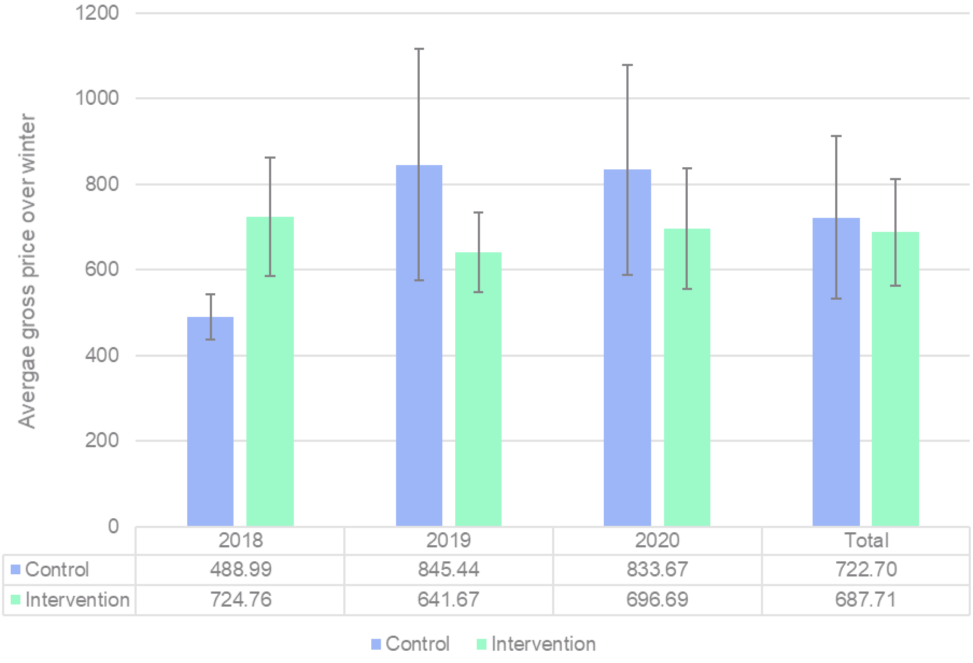


Figure 26. PBS gross price over winter by year and group (ITT).

A linear regression showed no significant difference between groups in PBS gross price (coefficient = -71; 95% CI -283, 141; p=0.51).

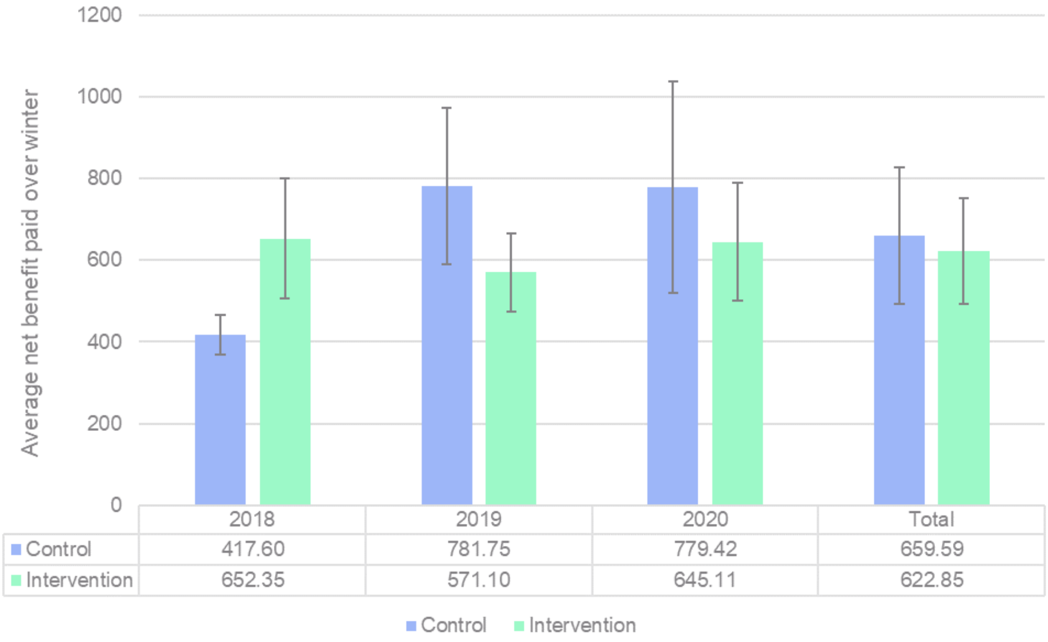


Figure 27. PBS net benefit paid over winter by year and group (ITT).

A linear regression showed no significant difference between groups in PBS net benefit paid (coefficient = -71; 95% CI -283, 141; p=0.51).

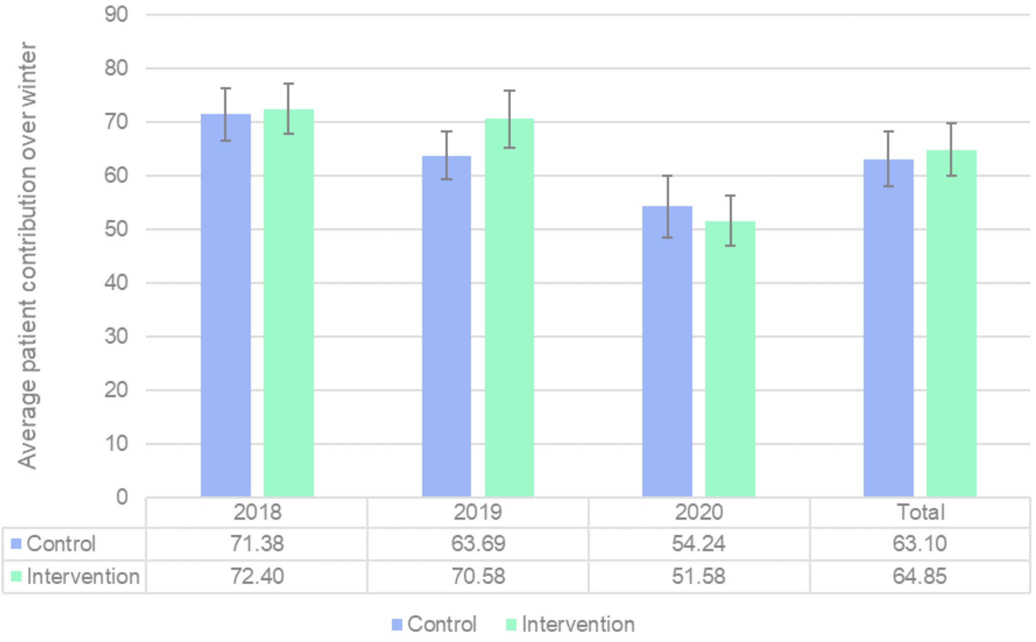


Figure 28. PBS patient contribution over winter by year and group (ITT).

A linear regression showed no significant difference between groups in PBS patient contribution (coefficient = 0.42; 95% CI -5.99, 6.83; p=0.90). There was a significant effect of year, with individuals in the 2020 cohort having a lower patient contribution by $25.66 (95% CI 10.15, 41.17; p=0.001).

Victorian hospital data

The Victorian Admitted Episodes Dataset (VAED) contains morbidity data on all admitted patients from Victorian public and private acute hospitals, including rehabilitation centres, extended care facilities and day procedure centres. Of the 1331 participants, 1159 have hospital data. Sixteen households (and 18 individuals) were not included in analysis because they did not consent, or they withdrew or dropped out of the study. In total we have 913 households and 1141 individuals with hospitalisation data.

The Victorian Emergency Minimum Dataset (VEMD) contains demographic, administrative, and clinical data about presentations at Victorian public hospitals with designated emergency departments (EDs). Of the 1331 participants, 981 have ED data. Fifteen households (and 17 individuals) were not included in analysis because they did not consent, or they withdrew or dropped out of the study. Of the 1331 participants, 64 have died.

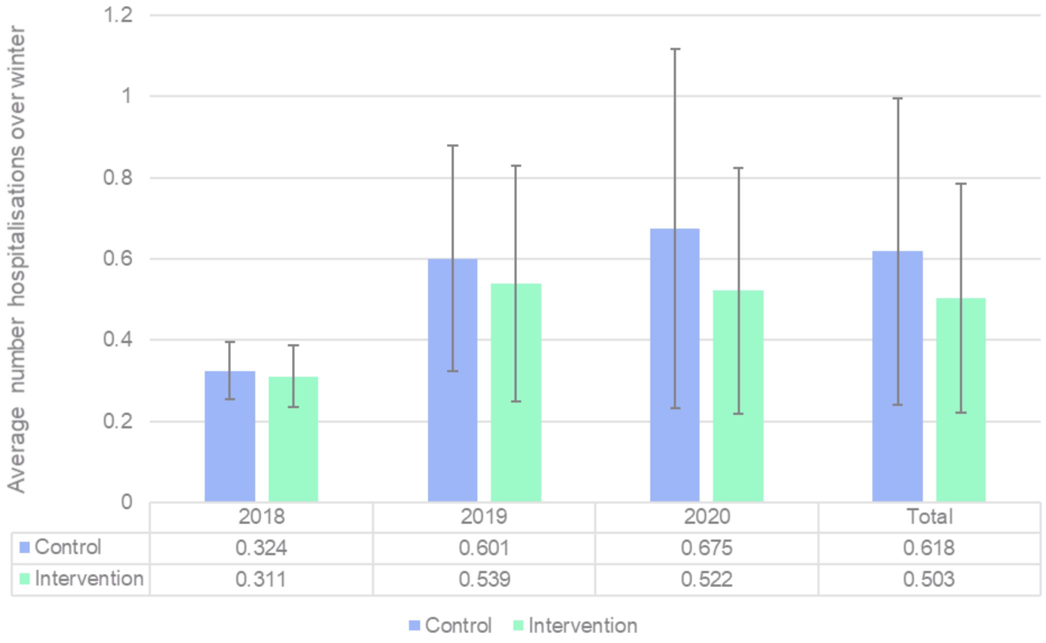


Figure 29. Number of hospitalisations over winter by year and group (ITT).

A negative binomial regression showed no significant group difference in hospitalisations (coefficient = -0.17; 95% CI -0.57, 0.23; p=0.40).

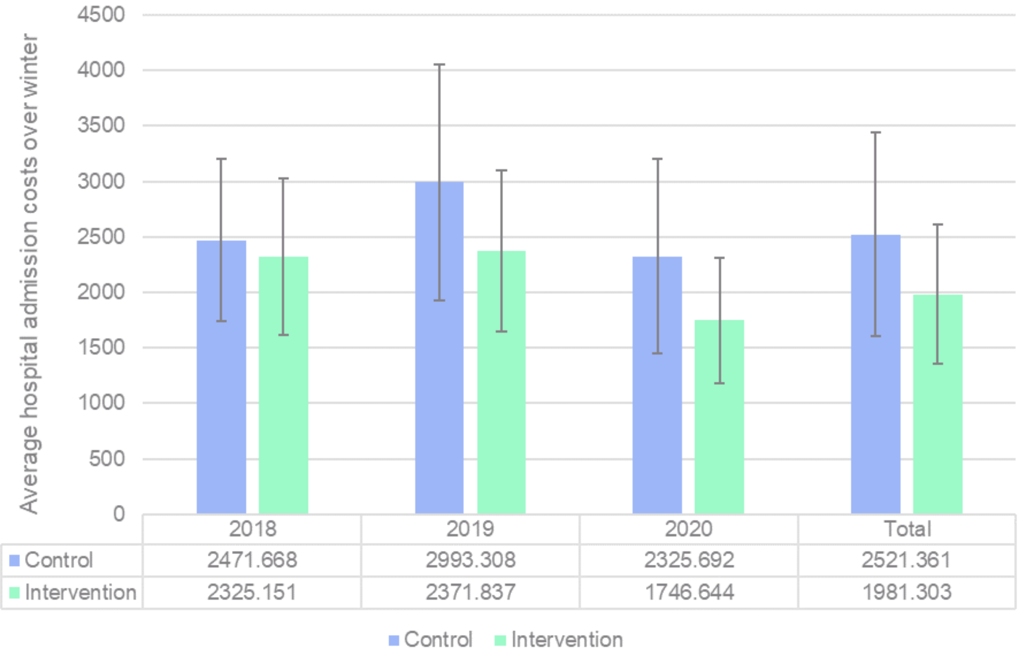


Figure 30. Hospital admission costs over winter by year and group (ITT).

The intervention group had lower hospital admission costs than controls, but linear regression indicated that the difference wasn't significant (coefficient = -557; 95% CI -1417, 302; p=0.20).

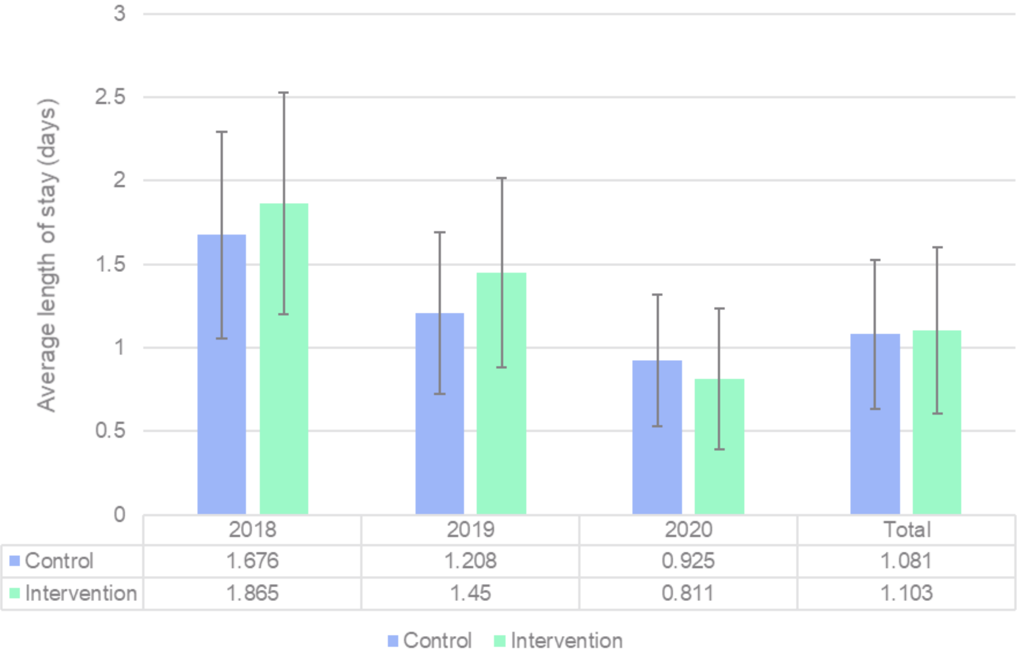
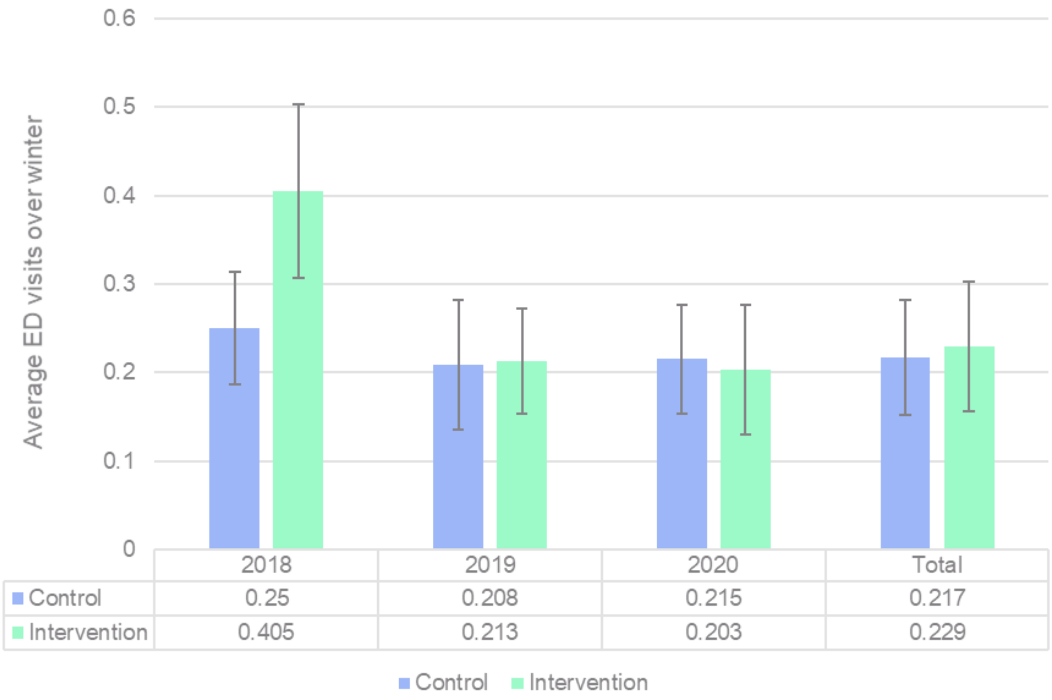


Figure 31. Hospital length of stay over winter by year and group (ITT).

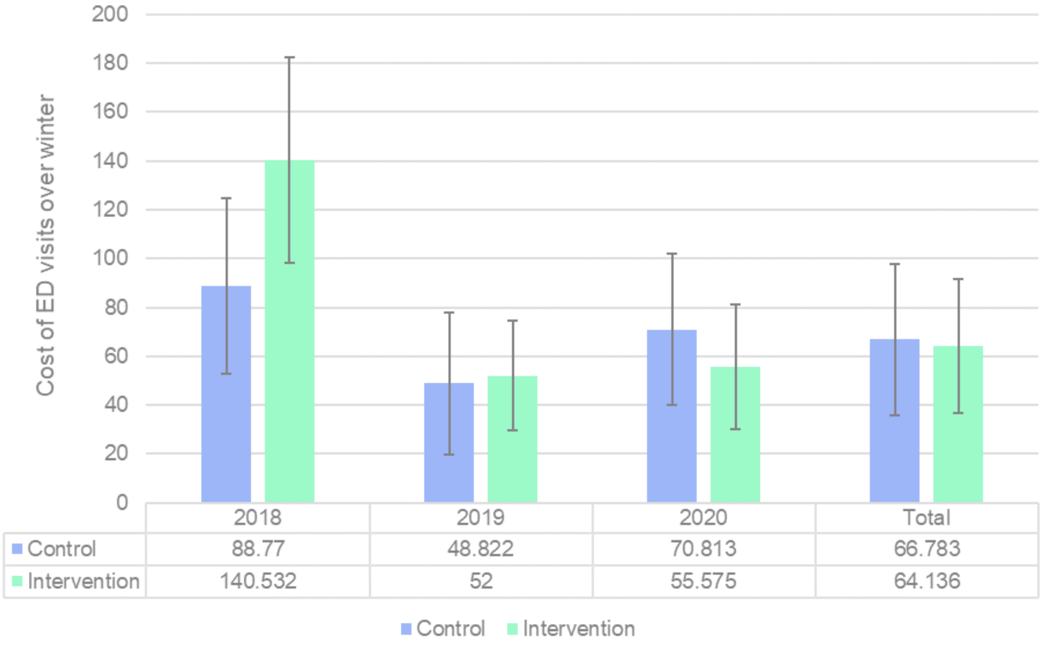
There was no significant group difference in length of stay (coefficient = 0.12; 95% CI -0.33, 0.58; p=0.60). Note the shorter length of stay in the 2020 study year – negative binomial regression indicated that this was different to the 2018 and 2019 years (coefficient = -1.41; 95% CI -2.80, -0.01; p=0.048).



	2018	2019	2020	Total
🟦 Control	0.25	0.208	0.215	0.217
🟩 Intervention	0.405	0.213	0.203	0.229

Figure 32. Number of ED visits over winter by year and group (ITT).

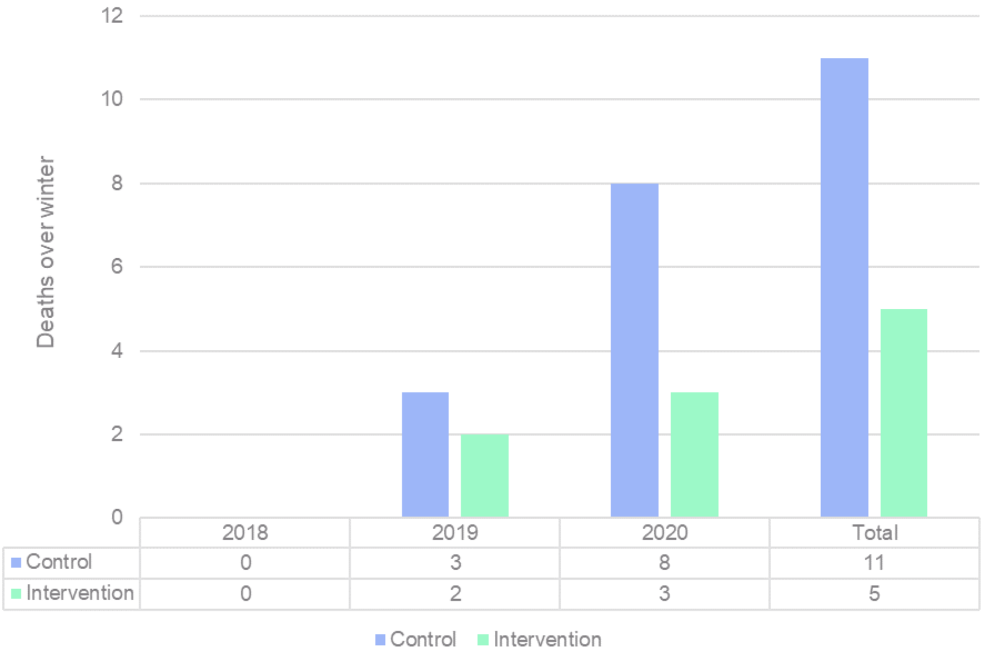
Negative binomial regression indicated no significant group difference in average number of ED visits (coefficient = 0.03; 95% CI -0.31, 0.36; p=0.86). This remained true when the dependent variable was classified as yes/no (whether or not participants had an ED visit) and logistic regression was used.



	2018	2019	2020	Total
🟦 Control	88.77	48.822	70.813	66.783
🟩 Intervention	140.532	52	55.575	64.136

Figure 33. Cost of ED visits over winter by year and group (ITT).

Linear regression indicated no significant group difference in cost of ED visits (coefficient = -4; 95% CI -36, 28; p=0.80).



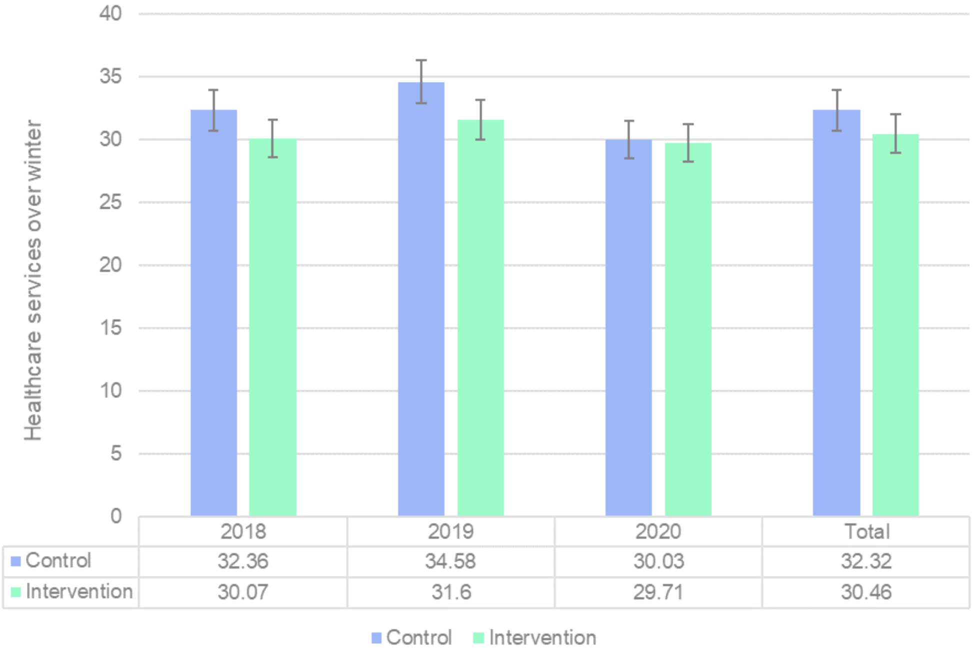
	2018	2019	2020	Total
Control	0	3	8	11
Intervention	0	2	3	5

Figure 34. Number of deaths over winter by year and group (ITT).

Logistic regression showed no significant difference in deaths between the control and intervention groups (coefficient = -0.87; 95% CI -1.97, 0.23; p=0.12).

Total healthcare utilisation and costs

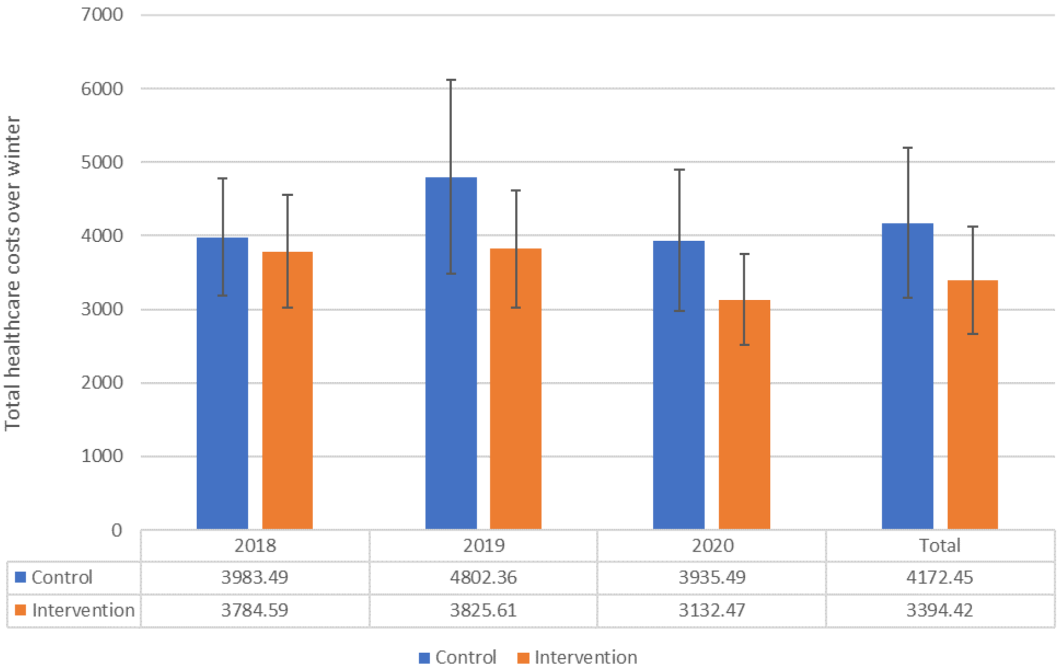
Data from the 4 datasets above (MBS, PBS, VAED, VEDM) were combined to provide an overall picture of total healthcare usage and cost during the 3-month winter period. Note that total service use data should be interpreted with caution, as all services were weighted equally.



	2018	2019	2020	Total
Control	32.36	34.58	30.03	32.32
Intervention	30.07	31.6	29.71	30.46

Figure 35. Number of healthcare services used over winter by year and group (ITT).

There were slightly fewer services used in the intervention group, but the group difference was not significant (coefficient = -1.29; 95% CI -3.67, 1.08; p=0.29).



	2018	2019	2020	Total
🟦 Control	3983.49	4802.36	3935.49	4172.45
🟧 Intervention	3784.59	3825.61	3132.47	3394.42

Figure 36. Total healthcare costs over winter by year and group (ITT).

The average participant used $3778 worth of healthcare services over the 3-month winter period. Regression indicated that the intervention group used $887 less healthcare costs than the control group, though this was not significant (95% CI: -106, 1879; p=0.08).

Health conditions

Linked health data

We examined the differences in hospital admissions and costs for specific health conditions that have been associated with cold temperatures (cardiovascular, respiratory, and mental health conditions). We were unable to run regression models on these data because of the small samples. Due to data limitations with the 2020 year (no December data available), cost calculations are made using only the 2018 and 2019 data.

Hospital admissions over winter for cardiovascular disease (CVD) – including stroke, acute myocardial infarction, angina and other heart conditions – were calculated for both groups. There were 16 control and 12 intervention participants with at least one admission for CVD. Total services were higher in control (n=595; mean = 37.2, SD 18.1) than intervention (n=335; mean = 27.9, SD 17.5). We calculated total cost (hospital, ED, MBS, PBS) for these participants over 3 months from the date of their first hospitalisation for CVD. Those with CVD in the intervention group had lower costs (n=5; total = $74,147; mean = $14,829; SD $11,098) than those with CVD in the control group (n=8; total = $173,383; mean = $21,672; SD $22,196).

Hospital admissions over winter for respiratory conditions – including chronic obstructive pulmonary disease (COPD), asthma, pneumonia and other respiratory conditions – were calculated for both groups. There were 11 control and 9 intervention participants admitted during winter for respiratory illness. Total services, however, were lower in the control group (n=346; mean = 31.5, SD 16.3) than the intervention group (n=441; mean = 49.0, SD 20.8). Those with respiratory conditions in the intervention group had higher costs over the 3-month follow-up period (n=5; total = $105,873; mean = $21,175; SD $10,545) than those with respiratory conditions in the control group (n=5; total = $82,345; mean = $16,469; SD $5,639).

Hospital admissions over winter for mental health conditions – including drug use, alcohol use, anxiety, mood disorder and other mental health conditions – were calculated for both groups. There were 2 control and 3 intervention participants admitted during winter for mental health conditions. Total services were lower in the control group (n=32; mean = 16.0, SD 11.3) than the intervention group (n=108; mean = 36.0, SD 18.3). Total costs were calculated over a 12-month follow-up period, because mental health treatment and recovery are longer than for CVD and respiratory conditions. Those with mental health conditions in the intervention group had lower average costs (n=2; total = $41,495; mean = $20,748; SD $1,765) than those with respiratory conditions in the control group (n=1; total = $39,269).

Self-report health data

The before and after winter surveys included questions on self-reported health conditions (present for more than the last 6 months, or for which medication is taken regularly), including cardiovascular disease, asthma, COPD and breathlessness. At baseline, 37% of participants reported having CVD, 28% reported having asthma, and 22% reported having COPD.

The Global Initiative for Asthma (GINA) assessment measures symptom control over the last 4 weeks. Logistic regression indicated no significant group difference in symptom control in those with asthma (coefficient = -0.01; 95% CI -0.23, 0.20; p=0.92).

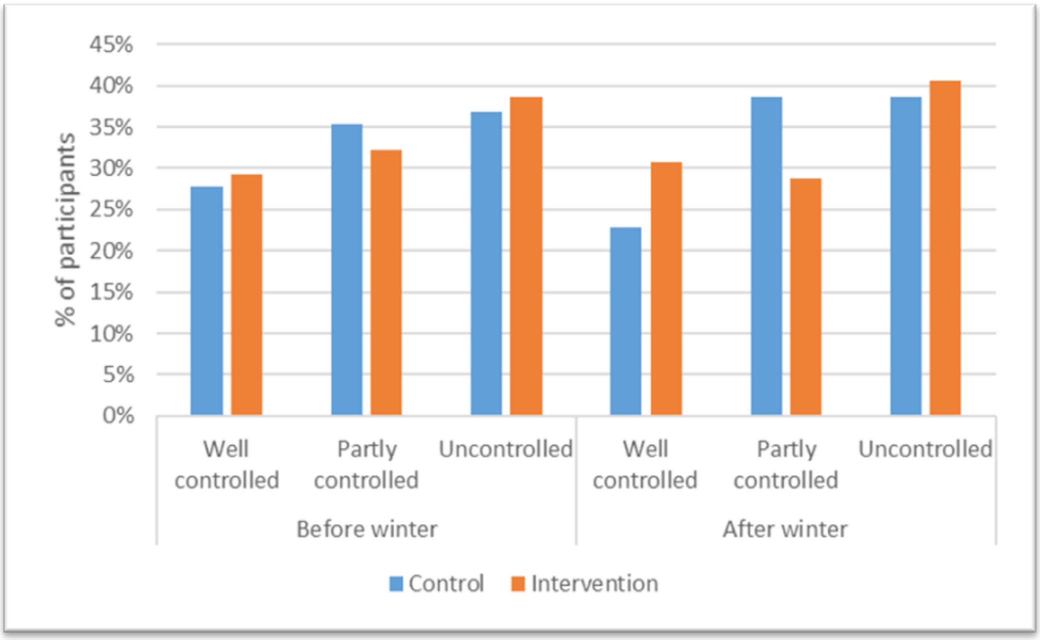


Figure 37. Symptom control in those reporting asthma before and after winter by group.

The COPD assessment test (CAT) is an 8-item measure of symptomatic impact of COPD. The CAT was presented to participants who had a modified British Medical Research Council (mMRC) dyspnoea score between 1 and 4. Logistic regression indicated no significant group difference in COPD symptom impact (coefficient = -0.30; 95% CI -1.05, 0.45; p=0.43).

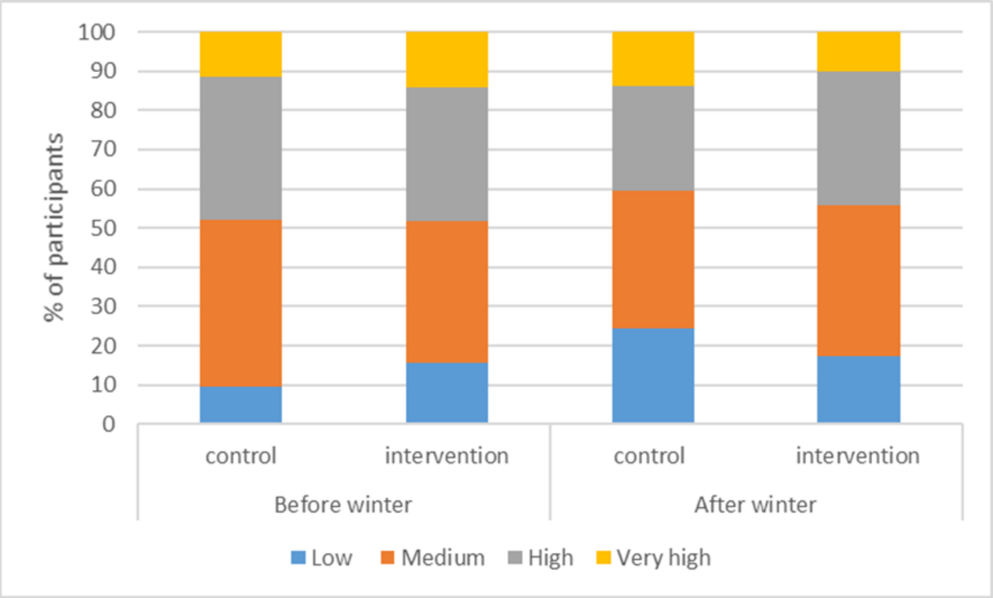


Figure 38. Symptom impact in those reporting COPD before and after winter by group.

The mMRC dyspnoea scale is a simple measure of breathlessness. It is scored as:

0 - I only get breathless with strenuous exercise.
1 - I get short of breath when hurrying on level ground, or walking up a slight hill.
2 - On level ground, I walk slower than people of the same age because of breathlessness, or I have to stop for breath when walking at my own pace on level ground.
3 - I stop for breath after walking about 100 metres, or after a few minutes on level ground.
4 - I am too breathless to leave the house, or I am breathless when dressing.

Logistic regression indicated that individuals in the intervention group had a reduction (improvement) in mMRC score relative to those in the control group over winter (coefficient = -0.38; 95% CI -0.61, -0.15; p=0.001). This finding was similar in PP analysis (coefficient = -0.40; 95% CI -0.67, -0.12; p=0.005).

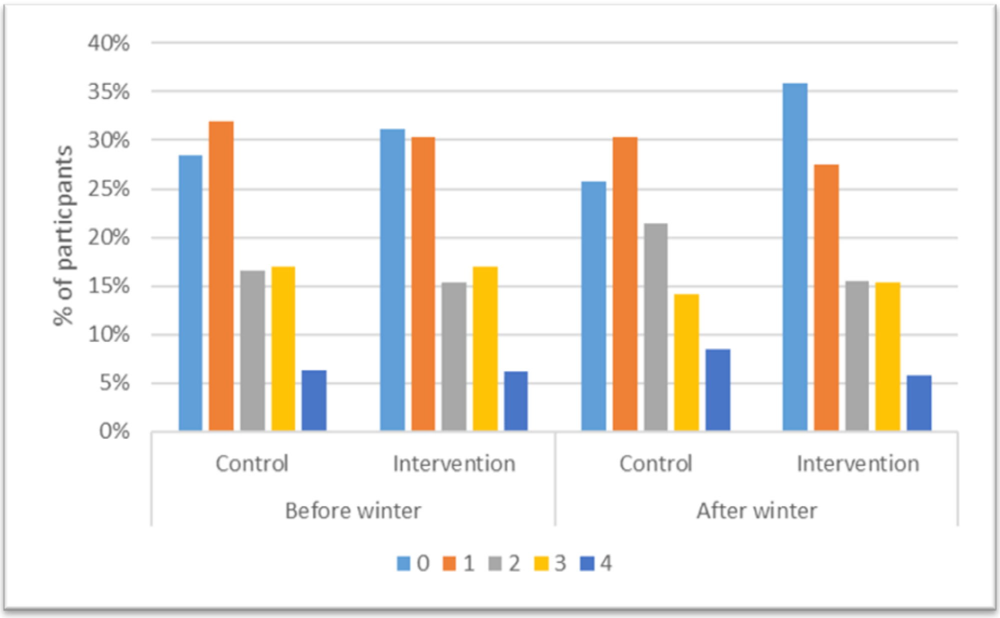


Figure 39. mMRC dyspnoea scale (higher score = more breathless) before and after winter by group.

Other survey findings

Absenteeism was specified in the protocol as an important secondary outcome. In the after-winter surveys, we asked about days absent from (a) work, (b) study, and (c) usual activities for all adults in the household. Given the average age of our sample (76 years), there were very few participants engaged in work (99.5% indicated they had 0 days absent from work) or study (97.6% were not absent from study). The total number of days absent from usual activities over the winter period was summed. The control group had a higher number of days absent from usual activities (mean = 7.3, SD 15.8) than the intervention group (mean = 5.4, SD 13.3). This group difference was not significant in ITT analysis (coefficient = -0.22; 95% CI -0.62, 0.18; p=0.28). It was stronger in PP analysis (coefficient = -0.46; 95% CI -0.94, 0.02; p=0.058).

We asked about the number of times over winter that householders put off seeing a medical specialist when they should have, and the reasons given for the decision. Across the whole cohort, 13.2% reported putting off seeing a specialist. The difference between intervention (11.4%) and control (14.8%) was not significant in ITT (odds ratio = 0.73; 95% CI 0.49, 1.08; p=0.11), but was in PP (odds ratio = 0.55; 95% CI 0.32, 0.95; p=0.032). Reasons given included affordability (20%), COVID issues (19%; note that this response option was only included in 2020 study year), too far (10%), waiting list (9%) and 'other' (41%; including many 'too tired' responses).

COVID questions were added to the 2020 after-winter survey to capture the effects of the pandemic on participants' health behaviours (see Table 7). The only notable group difference was in the likelihood of exercising outside (ITT; coefficient = 0.27; 95% CI -0.02, 0.55; p=0.064).

Table 7. Responses to COVID-related questions in the 2020 study year (full cohort).

	Stayed at home	Had people visit you at home	Exercised outside	Spoke to friends and family	Visited GP	Took medication
A lot more	80%	1%	5%	31%	3%	3%
A bit more	8%	2%	5%	27%	7%	11%
About the same	11%	9%	53%	35%	57%	83%
A bit less	1%	13%	16%	5%	21%	2%
A lot less	1%	75%	22%	3%	12%	0%

Costs

A detailed analysis of costs was conducted. There were 3 broad categories: (a) SV program administration costs, (b) AEF program administration costs, and (c) home energy upgrade costs. Research-associated costs were not included, as they are not relevant to program delivery and potential decisions about future programs. Three relatively distinct program phases were mapped: development, establishment, and expansion (see Table 8). The rationale for categorising costs in these phases was to estimate not only the fixed start-up costs but also the marginal costs of future program expansion, for use in the economic evaluation.

Table 8. The 3 program phases, as defined for cost purposes.

Phase	Time Frame	Resource Inclusions	Overview
Development	July 2016 – Dec 2017	Legal, communications, staff time.	Program design, operating procedures, selection of delivery and research partners.
Establishment	Jan 2018 – Dec 2018	Auditing, risk management, promotional materials, contracts, staff time, home upgrades.	Establishment of contracts, external audit program, risk management, first set of home energy upgrades.
Expansion	Jan 2019 – Dec 2021	Staff time, insurance, communications, contract costs, home upgrades.	Ongoing costs to implement home upgrades and keep the program running over an annual time period.

SV costs were available for the entire program. The total cost was $1,749,626, which consisted of $314,133 in the development phase, $522,484 in the establishment phase, and $913,008 in the expansion phase. The bulk of SV cost was staffing (79%).

AEF costs were available for the period from September 2017 to December 2019, which includes the first 364 home upgrades. Total cost during this period was $1,038,723, which consisted of $138,117 in the development phase, $255,100 in the establishment phase, and $645,506 in the expansion phase. The bulk of AEF cost was staffing (77%). These cost figures were extrapolated out to derive cost estimates for the entire program.

Home upgrade costs were available for the first 856 upgrades. Total cost was $2,404,621, equating to an average upgrade cost of $2809 (SD 969). Average upgrade cost was lower in the 2020 year due to budget constraints caused by COVID disruption: 2018 average cost $3397 (SD 1083), 2019 average cost $3119 (SD 923), 2020 average cost $2527 (SD 859). These cost figures were extrapolated out to derive cost estimates for the entire set of home upgrades.

Note that there was a significantly higher average cost of intervention upgrades ($2976, SD 1057) than control upgrades ($2629, SD 827) across the first 856 homes. The mean difference was $348, which was significant [$t(854) = 5.3$, $p<0.001$]. While this is a surprising finding, it does not impact any of the group comparisons in this report – we only focus on the winter period, when none of the control group had received their upgrade. Therefore, the control group costs are set to zero for all cost effectiveness comparisons.

When considering the cost of expanding this program, a more accurate representation of the costs can be obtained by projecting forward administration costs in the expansion phase, then considering upgrade costs. In the expansion phase, average AEF cost per household was $1773 and average SV cost per household was $913, bringing the total administration cost to $2686 per household. After adding the average upgrade cost of $2809, the cost of expanding this program is $5496 per household. This is the value used in cost effectiveness analyses.

Cost-consequence analysis

Cost-consequence analysis (CCA) is a form of economic evaluation where disaggregated costs and a range of outcomes are presented to allow the decision maker to form their own opinion on relevance and relative importance of attributes to their decision-making context. It allows decision makers to consider a range of outcomes, and assess their value separately, rather than focusing only on a primary outcome or applying values and aggregating disparate outcomes. This approach is appropriate for the VHHP, which has the potential to impact on thermal comfort, quality of life, health services use and energy use.

The total program costs of the VHHP for one additional household is $5496 (upgrade and administration costs). Table 9 shows that the incremental cost of the VHHP is $4684: total costs ($5496) minus total cost savings (raw) in health and energy ($812). It is likely that administration costs would decrease if this program was expanded due to economies of scale.

Table 9. Costs and cost offsets for the cost-consequence analysis.

COSTS	**Control mean**	**Intervention mean**	**Raw difference (95% CI)**	**Model difference (95% CI)**
PROGRAM COSTS				
Upgrade costs	0	2809	2809	NA
Administration costs	0	2686	2686	NA
COST SAVINGS Health*				
MBS costs	930	774	-156 (-311, 2)	-157 (-311, -2)
PBS costs	801	685	-116 (-336, 105)	-71 (-283, 141)
Hospital costs	2521	1981	-540 (-1392, 312)	-557 (-1417, 302)
Emergency costs	67	64	-3 (-34, 29)	-4 (-36, 28)
Total health costs	4172	3394	-778 (-1739, 183)	-887 (-1879, 106)
COST SAVINGS Energy				
Gas costs	521	474	-47 (-95, 2)	-60 (-101, -19)
Electricity costs	368	382	13 (-35, 64)	-25 (-62, 12)
Total energy costs	869	822	-34 (-115, 20)	-85 (-378, 76)
TOTAL VHHP COSTS (costs - cost savings)	**5061**	**9745**	**4684**	

*Small discrepancies in sample size for each health domain mean that costs do not sum to total.

Table 10 shows the full CCA for the main temperature, energy and health outcomes over the 3-month winter period. It is interpreted by evaluating the total cost difference ($4684) against each outcome separately. For example, $4684 results in an average temperature increase of 0.09ºC (raw difference) or 0.33ºC (accounting for covariates in the model). Similarly, a $4684 investment results in 1.04 fewer MBS services over winter (raw difference) or a 9% reduction in MBS services (modelled difference).

Table 10. Cost-consequence analysis of main effects (OR – odds ratio; IRR – incidence rate ratio).

Outcome	Control mean	Intervention mean	Raw difference (95% CI)	Model difference (95% CI)
Winter temperature (^{0}C)	18.24	18.33	0.09 (-0.22, 0.39)	0.33 (0.05, 0.60)
Morning temperature (^{0}C)	17.18	17.38	0.20 (-0.17, 0.59)	0.40 (0.04, 0.77)
Days below 18^{0}C	45.23	43.70	-1.50 (-4.45, 1.84)	-2.22 (-5.14, 0.69)
Hours per day below 18^{0}C	11.8	11.4	-0.40 (-1.16, 0.48)	-0.71 (-1.46, 0.03)
∆ Perceived thermal comfort	-0.02	0.35	0.37 (0.16, 0.57)	2.34 (1.83, 3.01) (OR)
Gas use, per day (MJ)	222	202	-20 (-40, 1)	-25 (-43, -8)
Electricity use, per day (kWh)	13.78	14.32	0.54 (-1.32, 2.39)	-0.94 (-2.33, 0.45)
MBS Services	14.11	12.70	-1.41 (-3.01, 0.20)	0.91 (0.81, 1.01) (IRR)
GP Services	2.58	2.62	0.05 (-0.28, 0.37)	1.02 (0.90, 1.15) (IRR)
PBS Services	16.17	16.53	0.04 (-0.80, 1.52)	1.02 (0.95, 1.10) (IRR)
Hospital admissions	0.62	0.50	-0.12 (-0.48, 0.25)	1.05 (0.75, 1.46) (IRR)
Hospital length of stay (days)	1.08	1.10	0.02 (-0.49, 0.54)	1.13 (0.72, 1.79) (IRR)
ED admissions	0.23	0.22	-0.01 (-0.09, 0.06)	1.03 (0.74, 1.44) (IRR)
Deaths (total)	11	5	-6	0.42 (0.14, 1.26) (OR)
Death rate (%)	1.71	0.76	-0.95 (-2.15, 0.25)	not modelled
∆ MRC Dyspnoea score	-0.06	0.19	0.25 (0.10, 0.39)	0.38 (0.15, 0.61)
∆ SF-36 MCS	0.34	2.00	1.66 (-0.01, 3.34)	1.52 (-0.25,3.29)
∆ EQ-5D-5L utility score	0.033	0.035	0.003 (-0.036, 0.041)	0.002 (-0.037, 0.040)
∆ ASCOT utility score	-0.009	0.010	0.020 (0.001, 0.039)	0.020 (0.000, 0.039)
Absent usual activities (days)	7.28	5.36	-1.92	0.80 (0.54, 1.20) (IRR)

Cost-effectiveness analysis

Cost-effectiveness analysis (CEA) is a method to examine both the costs and outcomes of an intervention. In our case, we explore the primary outcome of change in the average indoor temperature across winter, with the control group as the status quo (no home upgrade) and the intervention group (received home upgrade prior to winter) as the comparator.

All estimates used in the CEA are from the ITT regression analysis. We present the results of each CEA on cost effectiveness planes where the cost and effect outcomes have been bootstrapped 10,000 times. In addition, we calculate the incremental cost-effectiveness ratio (ICER), which is a summary measure capturing the economic value of an intervention against an alternative (no intervention). The ICER is calculated by dividing the difference in total costs (incremental cost) by the difference in the chosen outcome measure (mean temperature across winter) or effect (incremental effect) to provide a ratio of ‘extra cost per extra unit of an effect’.

The results from this analysis are shown in Table 11 and Figure 40. The incremental effect of the intervention is 0.32ºC and the incremental cost of this increase in warmth is $4810. Mean ICER is $15,232 (the cost of increasing indoor winter temperature by 1ºC).

Table 11. Bootstrapped cost-effectiveness analysis for change in modelled mean temperature (ITT).

	Coefficient	95% CI	Std error	z	p
Mean temperature	0.32	0.04, 0.59	0.14	2.22	0.026
Costs VHHP	4810	3350, 6270	745	6.46	<0.001

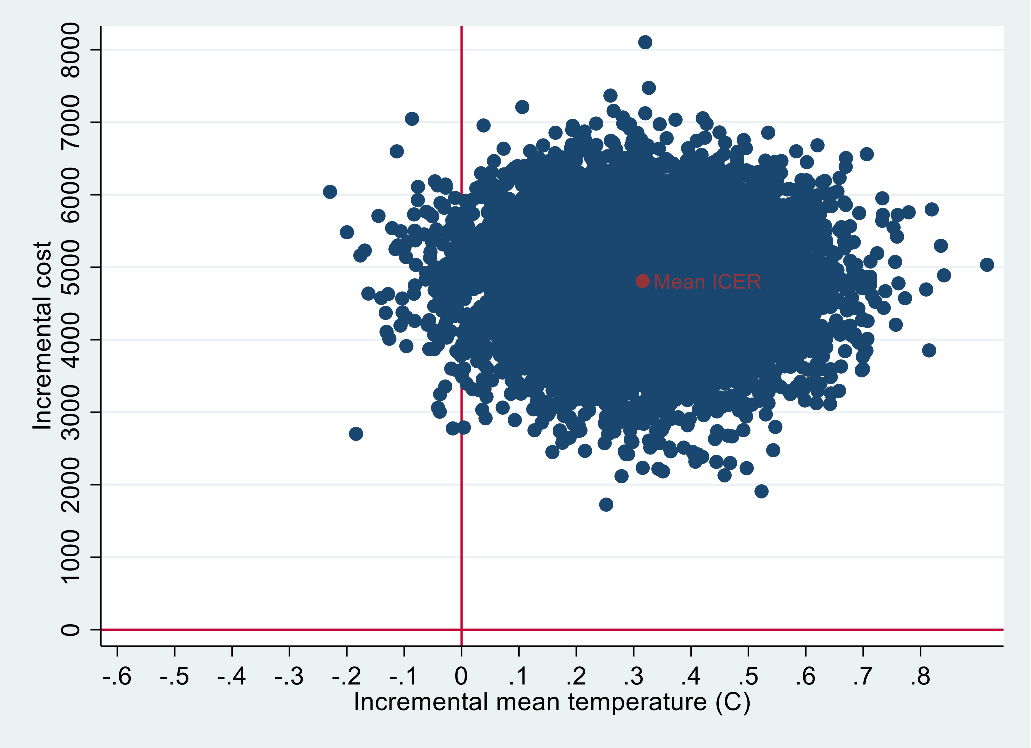


Figure 40. Cost-effectiveness plane with 10,000 bootstrapped estimates for change in modelled mean indoor temperature (ITT).

The same analysis was conducted for the outcomes of mean morning indoor temperature and for exposure to cold (<18ºC). The ICER was $10,307 for every 1ºC increase in morning temperature and $7,207 for every cold hour avoided.

Cost-benefit analysis

The beneficial effects of the upgrade last well beyond a single winter period. In this cost-benefit analysis, we explore the cost savings associated with extrapolating the outcomes over a 10-year time horizon. Using a 4% discount rate for both costs and benefits, we examined how long it would take for the VHHP to be cost-saving. In year 1, the total costs of the VHHP are $5496 and the modelled cost savings are $972 (including both health and energy savings). Therefore, at the end of year 1 the net (incremental) costs of having the upgrade versus not having it are $4524. By year 7, the program is cost-saving (see Table 12, Figure 41). Based on this analysis, the VHHP would pay for itself fully in just over 6.5 years. This model includes the assumption that benefits are the same over time. For this elderly sample, it is possible that health benefits would increase over time. This approach considers only the costs and cost savings, so does not account for the value of thermal comfort or improved quality of life, or the intrinsic value of reduced healthcare utilisation.

Table 12. Program cost, cost savings (health + energy) and net costs over 10 years (per household).

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Program cost	5496	4497	3569	2708	1910	1172	490	-140	-720	-1364
Cost savings	972	933	895	860	825	792	760	730	701	673
Net costs	4524	3564	2673	1848	1085	380	-271	-870	-1420	-2036

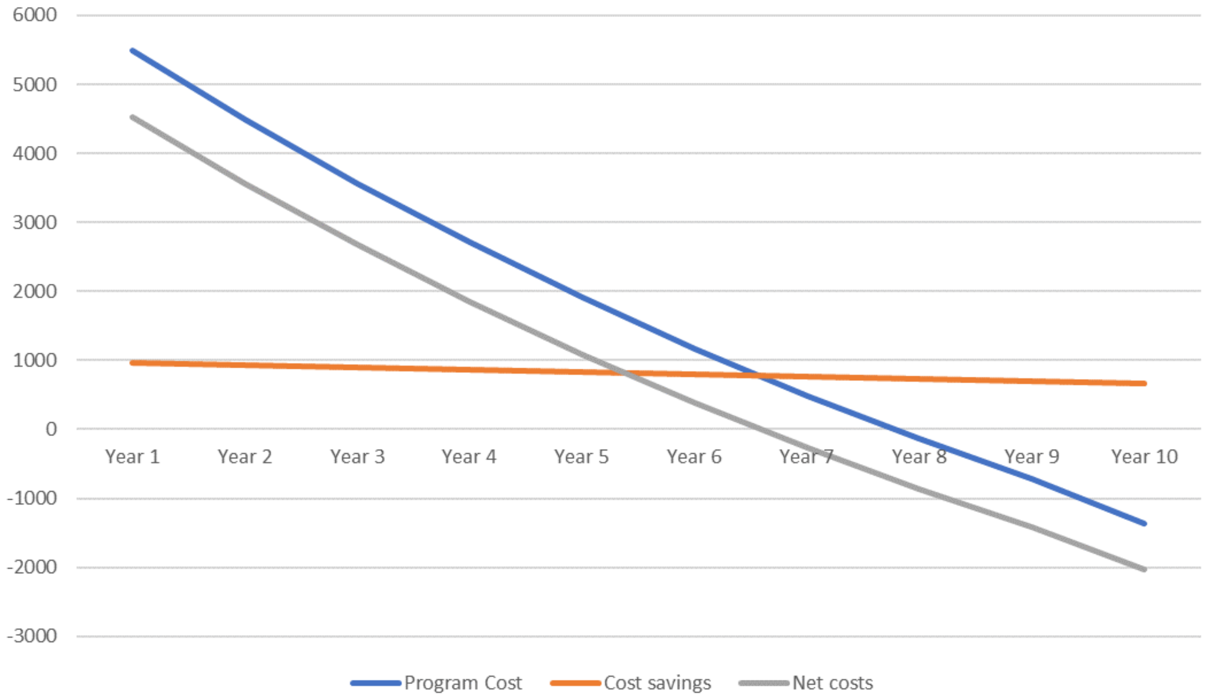
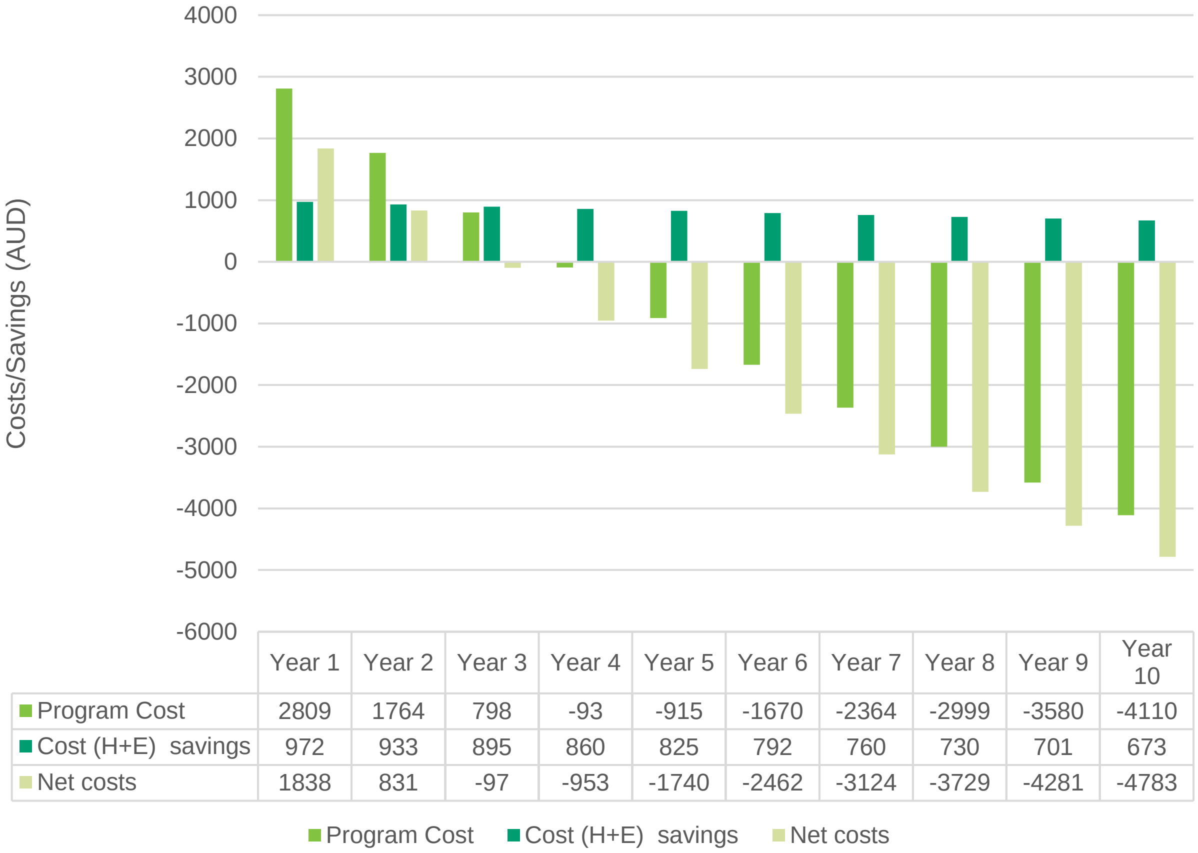


Figure 41. Projected program costs (per household) over 10 years (using health + energy savings).

From the whole-of-program perspective, it is appropriate to include both upgrade costs and administration costs in total cost. Note, however, that our average administration cost is high – a future upgrade delivery program with a more streamlined governance structure (i.e., no need for both a government agency and delivery partner) and a larger roll-out (with economies of scale) is likely to be substantially cheaper. We can also consider cost from the perspective of a householder who is considering upgrading their home. For this person, it is only the upgrade costs that are relevant. Figure 42 shows that, based on upgrade costs only, cost-saving is achieved within 3 years and is associated with a net saving of $4783 over 10 years.



	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Program Cost	2809	1764	798	-93	-915	-1670	-2364	-2999	-3580	-4110
Cost (H+E) savings	972	933	895	860	825	792	760	730	701	673
Net costs	1838	831	-97	-953	-1740	-2462	-3124	-3729	-4281	-4783

Figure 42. Program costs (upgrade only) over 10 years (using health + energy savings).

When only energy cost savings ($85 per winter) are included in the analysis, the upgrade is not cost-saving over 10 years; there is a net cost of $1357. Note that this is likely to be a conservative estimate of energy cost savings, as we only considered the 3 months of winter, and not the energy efficiency savings across the rest of the year. Nevertheless, it is a substantial payback period.

Table 13. Program cost (upgrade only), cost savings (energy only) and net costs over 10 years (per household).

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Program cost	2809	2615	2432	2260	2097	1944	1800	1664	1536	1416
Cost savings (energy)	85	82	78	75	72	69	67	64	61	59
Net costs	2724	2534	2354	2185	2025	1875	1733	1600	1475	1357

When only health cost savings ($887 per winter) are included in the analysis, the picture is similar to when health and energy savings are considered together. Instead of reaching the point of cost-saving within 3 years, that point is reached just after 3 years, and the net saving is $4197 over 10 years (Table 14). Note that these health benefits do not incorporate the difference in deaths and QALYs (which favoured the intervention) and thus these data may underestimate the true health savings achievable. In terms of where the health savings are made, $660 are saved in Victoria (hospital admissions and ED visits) and $227 are saved by the Commonwealth (MBS and PBS).

Table 14. Program cost (upgrade only), cost savings (health only) and net costs over 10 years (per household).

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Program cost	2809	1845	954	131	-628	-1326	-1967	-2555	-3092	-3583
Cost savings (health)	887	852	817	785	753	723	694	667	640	614
Net costs	1922	994	137	-654	-1381	-2049	-2661	-3221	-3732	-4197

Up to this point, we have assumed that there is only one householder obtaining the health cost savings. Yet there are many households that consist of two older people with a similar health profile. In these households, health cost savings can be expected to be doubled (2 x $887 = $1774), while upgrade cost remains fixed. In this scenario, the upgrade is cost-saving within 2 years and is associated with a net saving of $10,929 over 10 years.

Table 15. Program cost (upgrade only), cost savings (2 x health + 1 x energy) and net costs over 10 years (per 2-person household).

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Program cost	2809	912	-838	-2449	-3930	-5288	-6532	-7668	-8702	-9641
Cost savings (2 x health + energy)	1859	1785	1713	1645	1579	1516	1455	1397	1341	1287
Net costs	950	-873	-2551	-4094	-5509	-6804	-7987	-9065	-10043	-10929

Survival

A further indicative analysis was undertaken to estimate the potential impact of the intervention on survival given that the results, while not significant, suggest a trend towards intervention. Figure 43 shows the projected deaths over 5 winter periods, where W0 is the start of the first winter and W1 is the end of the first winter. These numbers are modelled on the control and treatment group in our sample with starting numbers of 648 (control) and 664 (intervention). The death rates during winter are modelled using the death rate calculated from the difference in deaths over the winter period (1.70% in control, 0.75% in intervention). Between each winter, the average death rate of the overall sample is used (we make the conservative assumption that the effect of the intervention on death rates can only be attributed in the winter period).

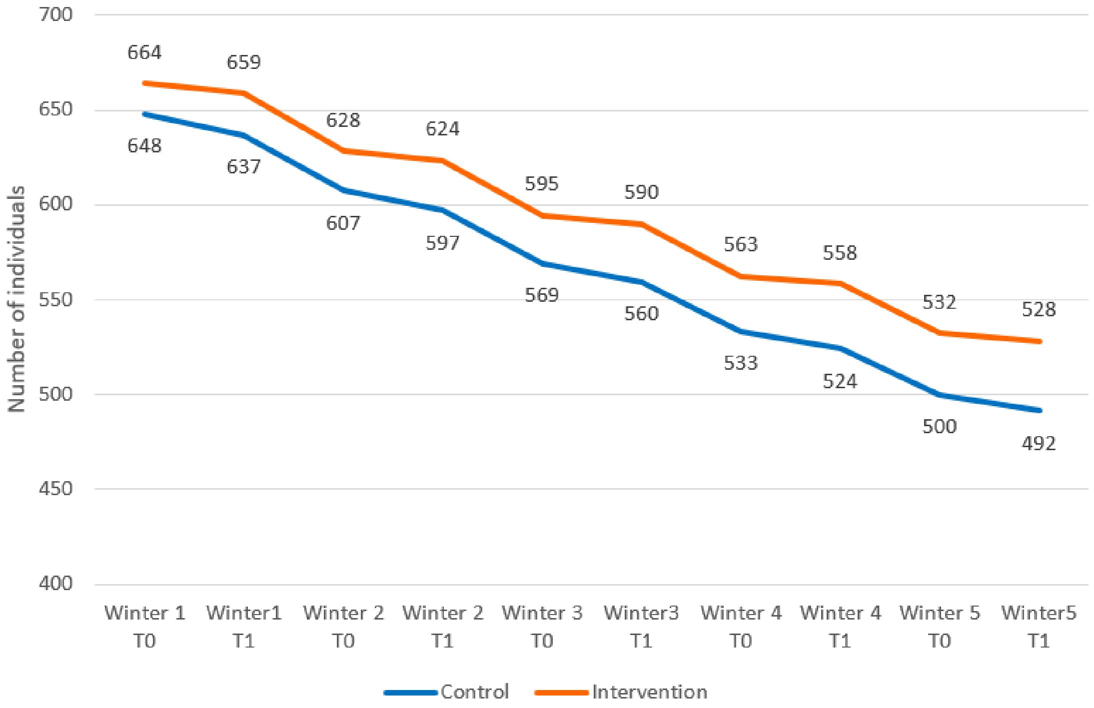


Figure 43. Death rates modelled over 5 winters using sample starting numbers and death rates.

This method was then applied to a hypothetical sample of 1000 in the control group and 1000 in the intervention group (see Figure 44). By the end of winter 5, there are 759 individuals in the control group and 796 individuals in the intervention group, a difference of 27 lives.

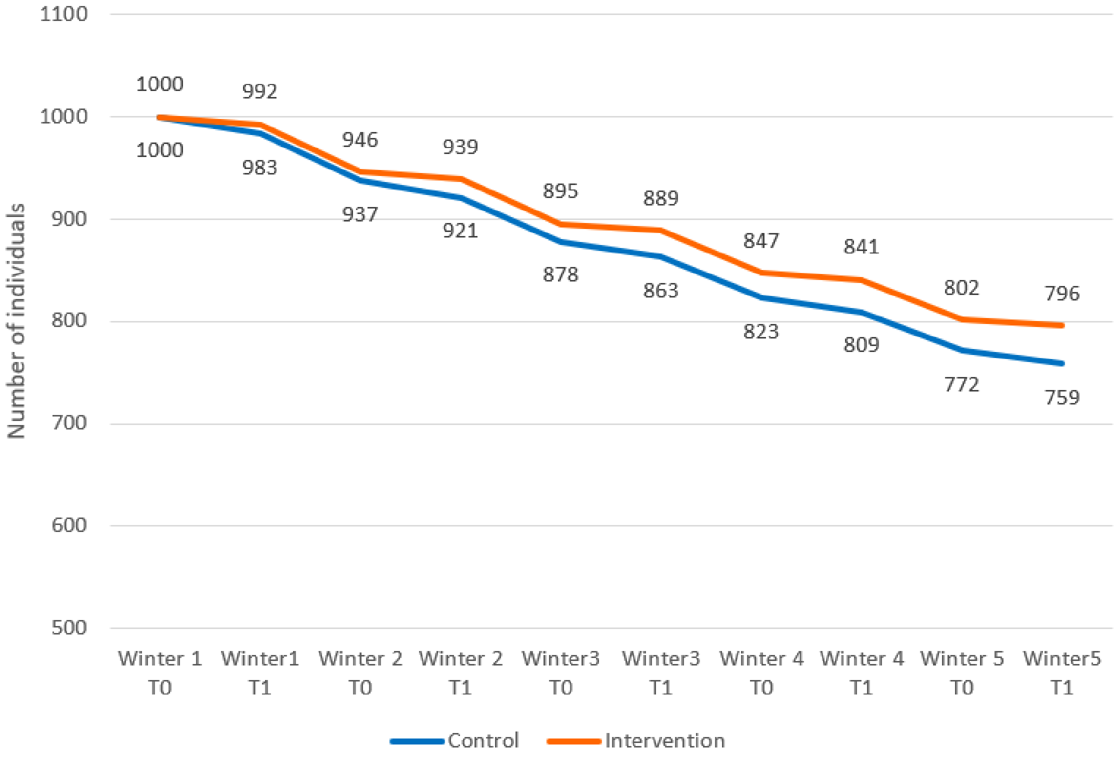


Figure 44. Death rates modelled over 5 winters using a starting sample of 1000 per group and sample death rates.

Conclusion

Victoria has a problem with its existing housing stock, with more than 1.3 million homes built before 1991 that average below 2 stars (NatHERS) for energy efficiency. For the people in these homes, this means that winter brings not only cold indoor temperatures and high energy bills, it brings risks to health. Using a randomised controlled trial design, the Victorian Healthy Homes Program provides evidence that a relatively minor thermal comfort and energy efficiency upgrade (average cost $2,809) has multiple benefits. Indoor temperature was significantly increased across the winter period, and this was matched by the subjective experience of householders, who reported greater warmth. Householders also noted a reduction in condensation. The upgrade resulted in significantly lower gas use, and therefore contributes to both lower energy bills and a reduction in greenhouse gas emissions. Better quality of life is likely to be related to the home’s improved comfort, and the increased social connectedness that comes from having a warm-enough house. Data on healthcare utilisation over winter revealed a consistent picture: people in upgraded homes used fewer services and had lower health costs. Healthcare cost savings over the single 3-month winter period were $887, dwarfing the $85 energy cost savings. Even with the most conservative assumptions, cost-benefit analysis indicates that the upgrade cost is paid back within 3 years. There is now ample evidence to show that improving winter warmth through thermal shell and energy efficiency upgrades provides multiple important benefits, both for householders and the broader community.