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Warmer Kiwis Study: Interim Report
An impact evaluation of the Warmer Kiwi Homes programme

Motu economic & public policy research

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EECA TE TARI TIAKI PŪNGAO ENERGY EFFICIENCY & CONSERVATION AUTHORITY

Warmer Kiwi Homes.

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Disclaimer

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Abstract

Over a fifth of New Zealanders find their homes to be too cold and damp. EECA's Warmer Kiwi Homes (WKH) programme aims to make New Zealand homes warmer, drier, and healthier, while improving their energy efficiency. The programme includes provision of clean heating devices (primarily heat pumps) to household living areas that do not have such heating. We examine impacts that WKH heat pump provision has on household outcomes including comfort and wellbeing, indoor environmental outcomes and electricity use. The evaluation covers 127 households in Auckland/Waikato, Wellington and Christchurch who applied for a heat pump through WKH in 2021. Evaluation methods include two qualitative household surveys, a house survey, indoor environmental quality readings from a monitor in the living area, and electricity use measured using smart meter data. Timing of heat pump installation was effectively randomised by the onset of COVID-19, so enhancing the study's statistical precision. The qualitative and quantitative data show that houses became more comfortable, warmer and less damp following heat pump installation relative to a house without a heat pump yet installed; CO2 levels also fell. These gains were achieved despite a likely fall in energy use.

JEL codes

I18, I31, I38, Q48

Keywords

Heat pumps; indoor temperature; electricity use; wellbeing; Warmer Kiwi Homes

Summary haiku

Winter through to spring

Houses keep warm with heat pumps

At no added cost

Contents

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Foreword

EECA is pleased to collaborate with Motu Economic and Public Policy Research (Motu) on this impact evaluation of EECA's Warmer Kiwi Homes programme. This interim report is the first report to be released as part of the Warmer Kiwis Study, which focusses on understanding the outcomes of heat pump installations in participating homes.

This two-year evaluation, which is being carried out by a consortium of experts led by Motu, provides up-to-date evidence about the impact and benefits of Warmer Kiwi Homes. The evaluation is looking at factors such as carbon and energy savings, as well as health and wellbeing. Energy use behaviours are also explored. The homes are being monitored for changes in temperature, humidity, air quality and comfort, with householders also completing quantitative and qualitative surveys. The study therefore brings together both the technical data on the impact of heat pump installations as well as the lived experience of the households.

EECA is grateful to the study participants for sharing their time and opening their homes to the researchers, and it is pleasing to hear positive feedback from participants that installation of a heat pump through the Warmer Kiwi Homes programme results in more comfortable homes that are materially warmer and drier. While these are only interim results, being shared at this halfway point of the study, they form part of an important ongoing body of work to ensure the Warmer Kiwi Homes programme is delivering real value to New Zealanders. We very much look forward to final, results in 2023.

Kate Kolich

Manager Evidence Insights and Innovation

EECA TE TARI TIAKI PŪNGAO
ENERGY EFFICIENCY & CONSERVATION AUTHORITY

Executive summary

Objectives

The Warmer Kiwi Homes (WKH) programme includes the provision of clean heating devices in living areas for eligible households that do not already have such heating. To be eligible, either the house must be situated in a disadvantaged neighbourhood or the homeowner holds a Community Services Card. We evaluate the effects of fitting heat pumps in the living areas of these homes in place of inefficient (or non-existent) heating.

This report provides an interim evaluation of the heat pump component of WKH. It analyses impacts of heat pump installation on outcomes for households that received a heat pump through the programme. Outcomes on which we focus include warmth and dryness of the living area, personal comfort and wellbeing, heating-related behaviours, and electricity consumption. The evaluation period covers winter and early spring 2021. A full evaluation in 2022 will cover summer 2021/22 and a second winter. It will incorporate the findings of this and subsequent analyses into a cost benefit analysis of the WKH heat pump component.

Evaluation components

The interim evaluation is based on 127 houses that applied to receive a heat pump under the programme through 2021. The study incorporates linked household survey data (both before and after heat pump installation), a house survey, data on indoor environmental outcomes (temperature, humidity and CO_2) and data on electricity consumption. The combination of these elements makes this evaluation more comprehensive than any prior evaluation of the impacts of heat pump use in New Zealand or elsewhere. COVID-19 and related supply chain issues effectively randomised whether and/or when a house within the study received a heat pump over the study period. This randomisation resulted in a natural experiment which we have leveraged in our statistical work.

Evaluation coverage

The evaluation covers three regions: Auckland and Waikato, greater Wellington, and Christchurch. While eligibility for the WKH programme is restricted (including being restricted to owner-occupiers), the houses included in the evaluation cover a diverse set of house types and households. The analysis of the indoor environmental and electricity data spans three winter months plus the first month of spring, so essentially relates to winter conditions. While the first set of qualitative data was collected in winter, the second set was collected in mid-late spring, and this timing may have affected findings that relate to households' indoor comfort and heating behaviours.

Key findings

Analysis across all components of the evaluation indicate a comprehensive set of benefits achieved through installation of heat pumps within the WKH programme. Key findings are as follows:

Indoor comfort and heating behaviours

- The proportion of households that reported ever having condensation on windows in their living room or bedroom fell from 95% to 30% after the heat pump was installed.
- The proportion of households that reported ever having damp in the living room or bedroom fell from 55% to 12% after having the heat pump installed.
- 82% of households said their house was much more comfortable or more comfortable after having received a heat pump.
- 79% of respondents said they were more satisfied with their home after having the heat pump installed.
- The proportion of households that reported ever having restricted heating due to cost fell from 80% to 21% after a heat pump was installed.

Indoor environmental quality

- Living area temperatures increased with heat pump installation by an average of 1.4^oC relative to a house without a heat pump fitted under WKH.
- The indoor temperature gains are highest when outdoor temperatures are low with an indoor temperature gain of 2.3^oC when the external temperature is 0^oC.
- Indoor temperature gains are greatest at 'breakfast' time (1.7^oC) and at 'dinner/evening' time (1.9^oC).
- Draughty houses experience lower gains in indoor temperature following heat pump installation.
- Installation of a heat pump reduces indoor humidity (by over one-third of a standard deviation of indoor relative humidity).
- Installation of a heat pump is associated with a reduction in CO_2 in the living area.

Electricity use

- Electricity use falls in a house fitted with a heat pump (or at least does not rise) relative to the counterfactual of not having a heat pump.
- The electricity savings are greatest when external temperatures are low.
- Electricity savings (of approximately 0.2kWH) are most pronounced in the evenings (6 pm – 9 pm) when indoor temperature gains are at their peak.

Conclusions

These interim findings indicate that installation of a heat pump through the WKH programme results in households that are more comfortable in their homes, with living areas that are materially warmer and drier. These benefits occur despite the treated households reducing (or at least not increasing) their electricity use. In addition, some households will have saved on gas use, a factor that is not incorporated into our study. Thus the comfort, temperature and dampness benefits have been achieved at the same time as energy use is likely to have been reduced.

1: Introduction and Background

Introduction*

This report presents interim results from the first winter of the Warmer Kiwis Study - an impact evaluation of the Warmer Kiwi Homes programme. This evaluation is specifically focused on the heat pump component of the programme, collecting and analysing new qualitative and quantitative data on the effects of heat pump installation in the New Zealand context. The Warmer Kiwis Study is the second of two phases of evaluation of the programme. Phase 1 reviewed prior studies on clean heating and insulation from New Zealand and international sources.[1] The current Phase 2 interim report will be followed by a full evaluation report (including a cost-benefit analysis) which will include results from data gathered from winter 2021 through to spring 2022 – data pertaining to two winters and a summer. Box 1 shows the full set of reports that comprise the WKH evaluation.

Box 1: An overview of the Warmer Kiwi Homes evaluation programme

Phase 1: Desk based review (2020)

Objectives

- Benefit: Cost Ratio estimated from similar programmes conducted in New Zealand and Internationally.
- Summary of evidence gaps and an outline of opportunities to use an evaluation of WKH to address these.

Phase 2: Warmer Kiwis Study (2021/22)

Objectives

- Measure impacts on health and wellbeing, indoor environment and change in electricity use.
- Updated Benefit: Cost ratio for Warmer Kiwi Homes

Interim Report (December 2021)

- Initial findings from monitoring of 127 homes in the first winter after having a heat pump installed.
- Covers the monitoring period June-September 2021.

Final Report (November 2022)

- Compete technical assessment of the effects of having a heat pump on a larger sample of homes over two winters.
- Cost benefit analysis of Warmer Kiwi Homes Programme.
- Covers the monitoring period June 2021- September 2022.

* All notes in the document are included as endnotes.

Background

The World Health Organization (WHO) recommends a minimum indoor temperature of 18°C,[2] a standard that most New Zealand houses fail to meet. In the 2018 New Zealand census, 21.2% of homes were described as "*too cold*" by occupants and 21.5% were described as "*damp*".[3] Cold houses are more prone to indoor dampness, with moisture condensing on cold surfaces such as walls and windows. A BRANZ study found that houses kept at temperatures of between 18°C and 20°C could avoid indoor dampness.[4] A potential cause of cold and damp prone housing is inadequate or ineffective heating. In addition to the low levels of insulation in older houses, New Zealanders traditionally only heat main living areas and approximately one tenth of homes have no heating source or rely on portable gas heaters for warmth.[3]

Warmer Kiwi Homes (WKH) is a government scheme run by EECA (Energy Efficiency Conservation Authority). It has the primary objective of making New Zealand homes warmer, drier, and healthier, with a secondary objective of improving the energy efficiency of homes. It seeks to do this by helping low-income owner-occupiers overcome financial barriers to energy efficiency by providing insulation and clean, effective and efficient heating to the main living area at low or no cost to the homeowner. Two core aspects of the programme are:

(i) Providing retrofitted insulation to older houses with insufficient existing insulation.

(ii) Providing clean heating devices to living areas in houses that do not have such heating already in place.

In practice, most clean heating devices fitted within the WKH programme are heat pumps. The scheme is available to homeowners in cases where the house is located in a more deprived area (NZDep = 8, 9 or 10) or in which the homeowner holds a Community Services Card (CSC).

The Phase 1 report to EECA on WKH identified that considerable evidence exists to support positive effects of retrofitted insulation in the New Zealand context.[5, 6, 7] Based primarily on benefits from retrofitted insulation, the Phase 1 report concluded that the WKH scheme had, as a central estimate, a benefit cost ratio (BCR) of 4.66; i.e. $4.66 worth of benefits for every $1 spent. This estimate excluded benefits relating to improved comfort and wellbeing following a retrofit. However, the report also concluded that there is less thorough evidence regarding the net benefits of installing heat pumps as part of a retrofit programme, and the evidence that is available is conflicting.[8, 9, 10, 11, 12, 13, 14, 15]

Benefits of a heating intervention are likely to be dependent on contextual factors relating to household type, house characteristics, the environment, and the scheme itself. For instance, a recent UK study[16] of a first-time central heating intervention for lower income households (most of whom were homeowners) found that the intervention group reported improvements in the indoor environment, finances, and mental well-being. However, the responses differed across participants, potentially reflecting diverse resident and housing characteristics. Similarly, an assessment of a retrofit scheme in Ireland[17] found persistence of energy-intensive domestic activities following a retrofit which had the potential to cancel out some of the savings made through retrofitting. The authors of that study argued for an integrated approach that combines a retrofit with a programme to re-shape householders' energy use practices.

Health impacts of poor quality (cold, damp and mouldy) housing arise from exposure to lower indoor temperatures that contribute to increased dampness and mould. The health impacts include increased risk of respiratory infection, asthma exacerbation and potentially also asthma development.[18] A 2007 economic analysis calculated a 21% (95%CI: 12-29%) attributable fraction of asthma cases resulting from dampness and mould.[19] Together, this body of results implies that policy initiatives which encourage more efficient heating with improved thermal comfort are likely to represent an overall societal benefit from reduced use of health services.

Existing poor quality heaters may also contribute to raised levels of nitrogen dioxide and other harmful particulates. At a macro level, inefficient heaters contribute to avoidable greenhouse gas emissions.

Given these factors, it is important to evaluate what the effects are of fitting heat pumps in place of inefficient (or non-existent) heating. Our focus, in this evaluation of the heat pump component of the WKH programme, is to understand how heat pumps have contributed to occupants' heating behaviours, wellbeing and comfort, their electricity use, and to indoor environmental outcomes including temperature, relative humidity and CO_2.

Report structure

This report includes 6 further sections: Section 2 outlines the nature and methods used in the evaluation. It also outlines practical issues which arose through 2021 that provided logistical challenges to the evaluation. The methods used to address these challenges are outlined. Section 3 details the characteristics of houses and households that are included in the evaluation. This information was gathered through two household surveys and a house inspection that were conducted with WKH participants. Section 4 presents survey results relating to 106 households obtained through the two surveys and the house inspection. Results relating directly to the self-reported impacts of the heat pump were based on 91 households that had their heat pump installed prior to the second survey being conducted. Section 5 presents analysis of information gained from internal environmental quality monitors placed in the living areas of WKH participants. The information covers indoor temperature, relative humidity, and carbon dioxide (CO_2) levels. Section 6 presents analysis of information gained from electricity records of WKH participants for household electricity use. Finally, section 7 synthesises the results and provides interim conclusions on the effects of heat pumps installed through the WKH programme.

2: Evaluation Methods

The aim of this evaluation is to determine the effectiveness of the WKH heat pump intervention in improving household energy efficiency, comfort, health, and wellbeing.

A before and after study design using an opportunistic sample of Warmer Kiwi Homes subsidy applicants was adopted. The (ongoing) study began on 4th June 2021 in four locations across New Zealand: Auckland City, Waikato, Greater Wellington and Christchurch City. Due to low numbers of study participants recruited in the Waikato, it is grouped with Auckland for the analysis.

2.1 Study Components

The evaluation includes a number of components to provide a comprehensive assessment of the impacts of adding a heat pump to the living area of the home. These components comprise:

- An assessment of the change in energy use of the household consequent on having the heat pump fitted by collecting Smart Meter electricity data from participating households and from matched control households.
- An assessment of the physical impacts of the heat pump on temperature, relative humidity, and CO_2 levels in the living area of the house through data gathered by installation of monitoring equipment in the main living area.

- An assessment of the energy use of the heat pump across different climate zones by installing an energy monitoring device connected to the heat pump.
- An assessment of occupant wellbeing, and behaviours which influence energy consumption and indoor environmental quality, through data gathered via household questionnaires administered before and after heat pump installation. The questionnaires are also used to understand heating and ventilation practices and occupant reported indicators of dampness and mould.
- An assessment of house condition through an inspection of the exterior of the house.

The components will be brought together in a comprehensive cost-benefit analysis (CBA) at the conclusion of the study in late 2022. The CBA will use the Treasury's CBAx tool and align its results to the Treasury's Living Standards Framework (LSF). These interim results of the evaluation will inform the final CBA; no CBA has been conducted for this interim report.

2.2 Study Population

In designing the study, we first conducted a power calculation to determine the number of households required to provide reliable results. The power calculation used data from a 2008 New Zealand intervention study examining the effects of installing effective heating on children's health.[20] To obtain >80% statistical power, we estimated that a sample of 200 houses (acting as their own controls) would be needed to determine significant changes in respiratory symptoms and a sample of 100 houses (acting as their own controls) to determine significant changes in self-reported health.

The study population was recruited opportunistically through five Warmer Kiwi Homes approved heat pump providers: Energy Smart, Enviro Masters, Greenside, Mint and Sustainability Trust. Details of working with heat pump providers are given below.

2.3 Data Collection

Data was collected by Motu Research and study partners: Allen & Clarke, and University of Canterbury. Advice was also received from colleagues at University of Otago, Victoria University of Wellington and Massey University. Verbal consent to collect data for the evaluation was obtained over the telephone when study participants were recruited.

Data collection was conducted by field workers based in Auckland, Wellington, and Christchurch. Written consent, including consent to contact electricity providers for data was collected by the field workers when they visited participating households. Details of field work conducted are given below.

2.4 Working with Heat Pump Providers

The WKH subsidy is managed via service providers (New Zealand businesses) who fit insulation and clean heating systems. The service providers visit applicants' homes to assess eligibility for the subsidy, and then claim the subsidy for the applicant in return for work done. In order to recruit participants who were assured to be eligible for the scheme, our method involved working with five of these service provision companies; two in Auckland, one each in Wellington and Christchurch, and one which operates nation-wide.

The original study design involved the service providers supplying our recruitment materials to applicants during their initial visit to assess eligibility, and passing on to us the contact details for those who expressed interest in participating in the evaluation.

Difficulties in recruiting households and in accessing materials (heat pumps and monitoring equipment) were encountered as a result of supply-chain problems, related to the COVID-19 pandemic and the Suez Canal closure. These issues led to significant delays in heat pump installation. Consequently, the methodology was revised so that service providers supplied us with lists of applicants who had already been approved for eligibility in order for us to make contact with the household. In these cases, we explained the nature of the study to the household after making contact. These changes led to unavoidable variability in the amount of time available to conduct baseline monitoring of the indoor environment conditions; however, we endeavoured to avoid very short baseline sampling periods (less than one week).

In addition to helping us in recruiting participants into the evaluation, service providers helped us by fitting energy monitoring devices on the heat pump during installation. This is described in greater detail below in the section on "Heat Pump Energy Use Monitoring".

The researchers wish to acknowledge the significant contribution to our study from the five businesses who collaborated with us on this project, and express our sincere thanks.

2.5 Fieldwork

Fieldworkers with experience conducting research were identified in the three regions where data was being collected (Auckland, Wellington, and Christchurch). In total there were six fieldworkers who undertook field work: two in each region. Fieldworkers all received training both in a seminar and by conducting their first visit with the fieldwork coordinator in order to ensure consistency of assessments.

Two field visits were planned for each house, based on a before and after (heat pump installation) data collection process. During the initial visit, as well as conducting the baseline survey, data was collected on the physical characteristics of the houses. This included measuring the living area volume and window area and collecting data on house age, double glazing, and insulation.

Floor plans of the living area were drawn for each house, including any open-plan areas which were open to the space where the heat pump was to be installed.

Additionally, information was collected on foundation type, number of storeys, whether the house was detached or conjoined to others, and each house was rated on the condition of the exterior. Houses were assigned a condition rating for each of: the roof, spouting and guttering system, windows, wall claddings, and if painted, the condition of paint on exterior walls. For houses with a subfloor, information was gathered on how well the subfloor space was ventilated and whether downspouts opened to a drain, or to the ground.

2.6 The Questionnaires

Information on the demographic composition of the household, heating, ventilation and energy use habits, thermal comfort, health, and wellbeing was collected through two web-based questionnaires, one scheduled to be before and one scheduled to be after the heat pump was installed.

The baseline survey was completed by participants on a tablet provided by a field worker that visited the house. A second home visit was planned to conduct the follow-up survey and collect monitoring equipment. However due to the community outbreak of COVID-19 Delta variant in August 2021, the second visit became problematic so the follow-up survey was conducted over the telephone with field workers typing answers into the online survey tool. In addition, not all participants had had their heat pump installed by the time of the second survey. A modified follow-up questionnaire was completed by the group which did not yet have heat pumps installed.

2.7 Indoor Environmental Monitoring

Monitoring devices supplied by Tether, a New Zealand owned and operated company were used to measure indoor air quality. An EnviroQ device collected data at half-hourly intervals on temperature, relative humidity, carbon dioxide, and light. A built-in capacity for collecting sound pressure level (noise) information was not utilised for this study.

In houses that did not have the network coverage required for the EnviroQ, a Hobo device was installed. Hobos are data loggers that record temperature and relative humidity also at half hourly intervals. The Hobos need to be removed from the house in order for data to be downloaded.

In order to maximise the consistency of the monitoring data, the devices were placed using a consistent protocol which involved first asking the participant where the heat pump was to be installed, then placing the device on a perpendicular, internal wall at a distance between three and four metres from the heat pump wall. The devices were placed at 1.5m high as a compromise between measuring the lower room air space, while keeping the devices out of the way of people and furniture.

2.8 Heat Pump Electricity Flow Monitoring

During the fieldworker's initial visit, an energy monitoring device (also supplied by Tether) was left for the heat pump installer. The heat pump installers then installed these devices to the live wire of the external heat pump unit during installation of the heat pump. Unfortunately the collection of data from these monitors was found to be unreliable due to network coverage issues. Data for this component of the study could not be collected as a result. It is intended that a different energy monitoring device will be installed for newly recruited houses to the evaluation through 2022.

2.9 Electricity Record Procurement

Consent to collect electricity data and details of participants' electricity supply over the previous two years were collected during the first fieldwork visit. Houses were checked to determine whether they had a Smart Meter using the "*My Meter*" tool on the Electricity Authority's website.[21] Data from participating households that had a Smart Meter was requested from electricity companies through the Electricity Authority (EA) Transfer Hub. Half-hourly data was requested for up to two years prior to the date of the request.

Data supplied depended on what was available. In some cases, companies were unable to provide any electricity consumption information for a study participant, or could only provide limited records. Data quality varied between energy companies and some could only provide daily or monthly breakdowns.

It was intended that energy data would be collected from up to 10 matched control houses that had received a heat pump in 2020. Data was to be matched by StatsNZ Statistical Area 2[22] and by energy use in March 2021 (as a shoulder month where energy was least likely to be used for heating or cooling). However, time constraints resulted in the match not being able to be completed in time for this report. Houses in the first cohort of the evaluation therefore act as their own (before vs after) controls.

2.10 Weather Data Procurement

Weather data was collected from the weather station closest to participating households that had a full set of records for June to September 2021. Minimum, maximum, and mean temperature were downloaded from the NIWA Cliflo website.[23] These data were used as a control for the analysis of indoor temperature, CO_2, and electricity use. Relative humidity data were also downloaded from the same weather stations to act as a control in the analysis of indoor relative humidity and CO_2 in the living area.

3: Demographic Profile of Study Participants and House Condition at Baseline

The Study recruited 127 households (337 people): 65 (51.2%) in Auckland and the Waikato, 37 (29.1%) in Wellington and 25 (19.7%) in Christchurch. *Tables detailing demographic characteristics are provided in Appendix 1*.

The study population comprised 28 (22.0%) single person households, 40 (31.5%) two person households and 45 (35.8%) three to four person households, with the remaining 14 (10.7%) households ranging from five to eight people. Most had lived in their home for over two years (72.4%), with the second highest proportion having lived in their home for under six months (14.2%). The majority of participants lived in houses that were less than 100m² (58.7%); however this varied between regions with Christchurch having a greater number of larger houses, including 24% that were over 200m².

Table 3.1 Socio-demographic characteristics of Study households at baseline

Socio Demographic Characteristic	**Number of people**	**Percentage of each category**
Age		
Pre-school (<5 years)	55	16.3
School age (5-17 years)	40	11.9
Adult (18-64 years)	170	50.4
Older adult (≥65 years)	63	18.7
Did not state	9	2.7
Ethnicity*		
New Zealand European	154	45.7
Māori	40	11.9
Pacific peoples	112	33.2
Asian	38	11.3
Middle Eastern	4	1.2
Did not state	1	0.3
Gender		
Female	171	50.7
Gender neutral	3	0.9
Male	163	48.4
Work Status		
Homemaker	9	2.7
Unable to work (medical)	6	1.8
Seeking work	11	3.3
Pre-schooler	17	5.0
Student	70	20.8
Working	148	43.9
Retired	65	19.3
Did not state	11	3.3

*Notes: *A respondent can report multiple ethnicities; ethnicities are not prioritised in the table. See Appendix for full table (Table A.1.1).*

Most primary respondents (65.0%) were of working age (18-64 years) and working full or part-time (57.3%). These demographics were also true for all household members with 50.5% of working age and 44.7% working full or part time. The second largest group were older adults (18.7%) who were retired (19.6%) followed by school-aged children and pre-schoolers. There is an over-representation of young people (under 18 years) (28.2%) compared to the New Zealand population, based on the 2018 Census – where 19.7% of the population was under 15 years whilst population of working age (18-64 years) was under-represented (52.0% compared to 65.1% for the New Zealand population). Reflecting the differences in age, fewer of the study population worked full or part time (44.7%) when compared to the 2018 census population (64.7%).

Ethnicity was not prioritised with participants able to indicate as many ethnicities as were applicable. Just under half of those who stated an ethnicity included NZ European or European (47.5%) with the second largest group being Pacific Peoples (33.2%) - comprising Samoan, Cook Island Māori, Tongan, Niuean, Tokelau and Fijian peoples, followed by Māori (11.9%) then Asian (4.5%) - comprising Indian, Korean and South-East Asian peoples, then Middle Eastern (1.2%). Ethnicity varied widely between the three centres in the study (Appendix A.1.1). The use of total response rather than prioritised ethnicity meant that a comparison of ethnicity to the New Zealand population could not be made.

3.1 Health and Wellbeing

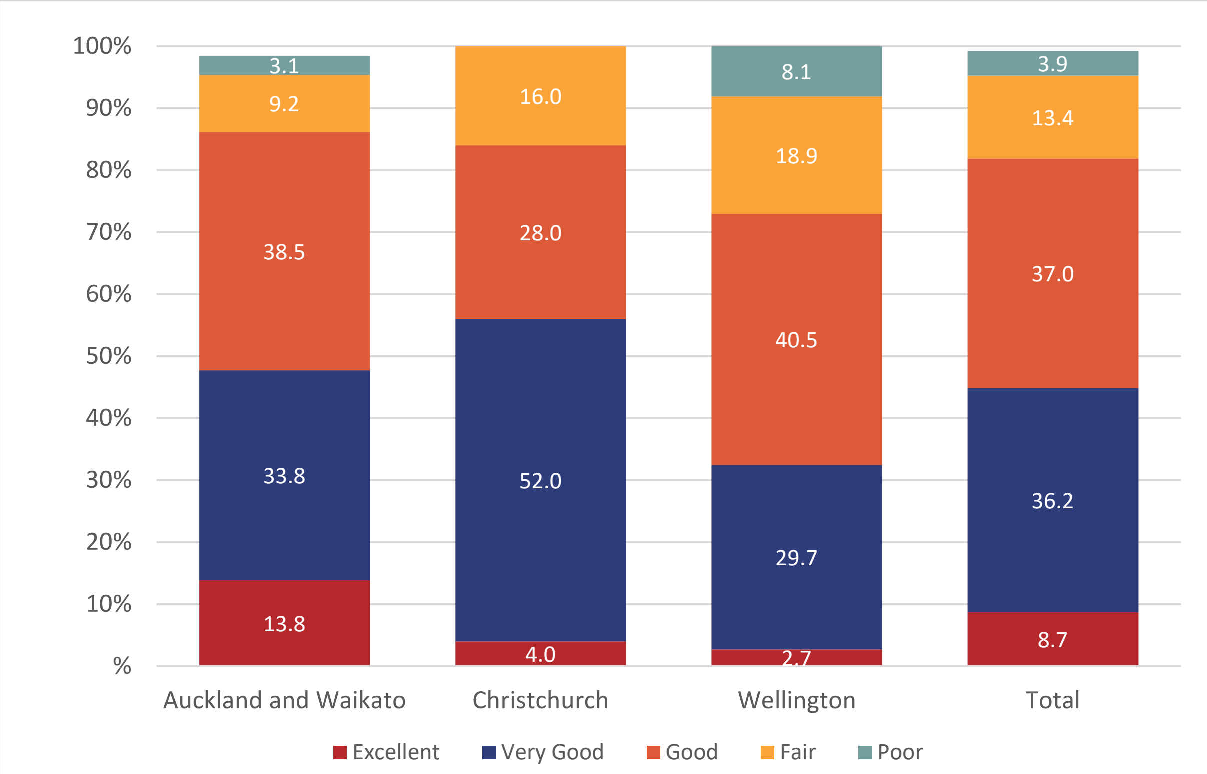
Self-reported health of primary respondents from Study households in the baseline survey was positive with just under half (44.9%) rating their health as either excellent or very good and a further 37.0% considering themselves to be in good health (Figure 3.1).

The majority of households reported having sufficient income to meet their needs, with 65 (51.2%) reporting they had enough or more than enough income and 46 (36.2%) reporting they had just enough income.

Responses to overall life satisfaction were positive with 105 respondents (82.7%) rating it at seven or above. Aucklanders had the greatest level of life satisfaction, with over 40% giving their life a score of nine or ten out of ten, compared to 25.9% of people living in Christchurch and 16.7% of Wellingtonians.

When asked about specific areas of wellbeing at baseline, the response was again overwhelmingly positive, with most providing ratings at the higher end of the scale. Questions that received a lower score centred on energy levels: (*How often have you felt active and vigorous?*) and sleep: (*How often have you woken up feeling fresh and rested*?).

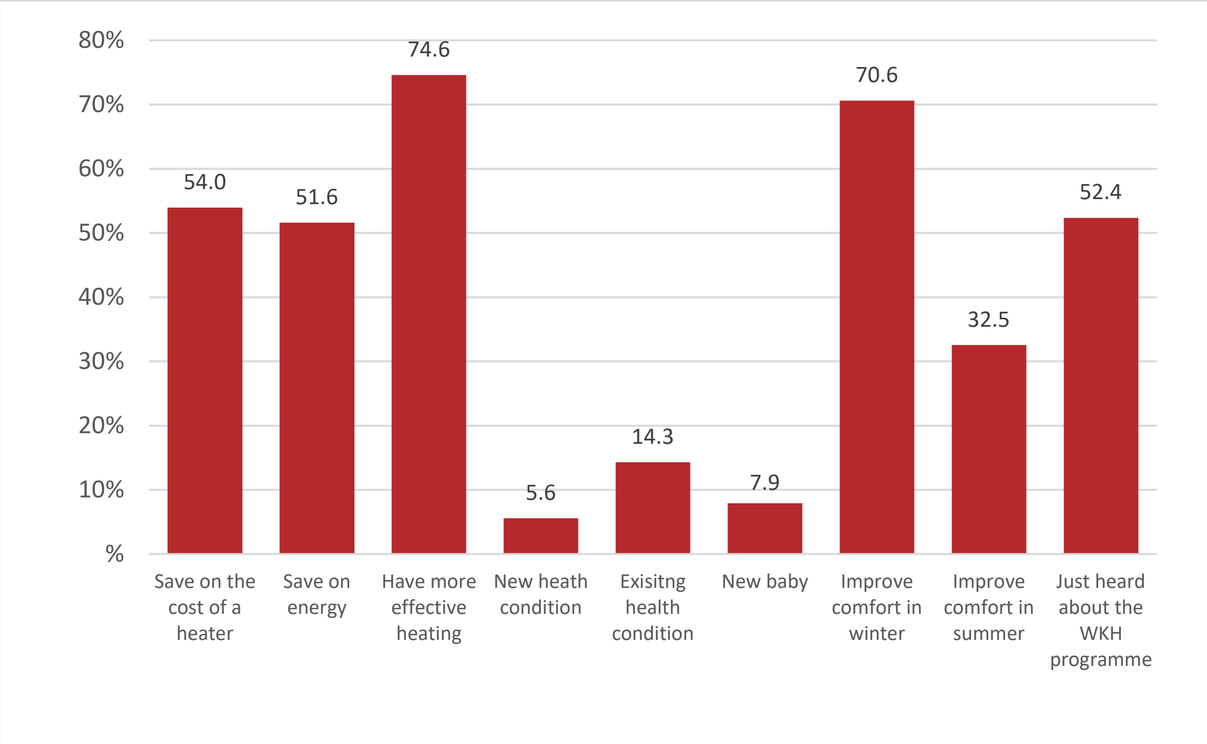
Figure 3.1: Self-rated health of primary respondent in household by area (percent)



3.2 Motivation for Applying for the Warmer Kiwi Homes Heat Pump Subsidy Programme

When asked why they applied for a heat pump through the Warmer Kiwi Homes subsidy programme, households were encouraged to indicate as many reasons as they felt were relevant; percentages therefore do not add up to 100. The majority of answers centred on warmth, by either having more effective heating (74.6%) or improving comfort in winter (70.6%) (Figure 3.2). Improving comfort in summer - through use of the heat pump as an air conditioner - was identified by around a third of respondents (32.5%). A second motivator was to save on costs, either of the heat pump itself (54.0%) or on energy (51.6%).

Figure 3.2: Reasons for applying to the Warmer Kiwi Homes subsidy programme (percent)



Just over half of households (52.4%) had only recently heard about the Warmer Kiwi Homes subsidy programme, with information coming from a variety of sources including: service providers who had installed insulation, the local paper, on Facebook or word of mouth (e.g. from a hairdresser who visited the house and noticed it was cold). Other reasons included: becoming eligible for the subsidy, having recently bought a new house, having previously had a heat pump that had stopped working, to avoid wires from portable electric heaters, children getting cold, because "*old people need it for their health" and "because of the winter energy payment, I feel I can afford a heat pump".*

3.3 House Condition: Internal

Table 3.2 provides baseline survey information on the internal condition of houses in the Study. Regional breakdowns are provided in the Appendix (Table A.1.2).

Table 3.2 Internal condition of houses in the Warmer Kiwis Study

House Condition	**Number of households**	**Percentage of households**
Too cold in winter		
Always	30	23.6
Often	42	33.1
Sometimes	37	29.1
Never	8	6.3
Don't know	8	6.3
Didn't answer	2	1.6
Limit heating due to cost		
Always	22	17.3
Often	18	14.2
Sometimes	51	40.2
Rarely	8	6.3
Never	23	18.1
Don't know	5	3.9
Condensation on living room windows		
Always	44	34.6
Often	33	26.0
Sometimes	43	33.9
Never	7	5.5
House dampness		
Always	9	7.1
Often	17	13.4
Sometimes	46	36.2
Never	52	40.9
Don't know	3	2.4
Mould in living or bedroom		
Always	5	3.9
Often	15	11.8
Sometimes	49	38.6
Never	53	41.7
Don't know	5	3.9

Note: See Appendix for full table (Table A.1.2)

Figure 3.3: House too cold in winter (percent)

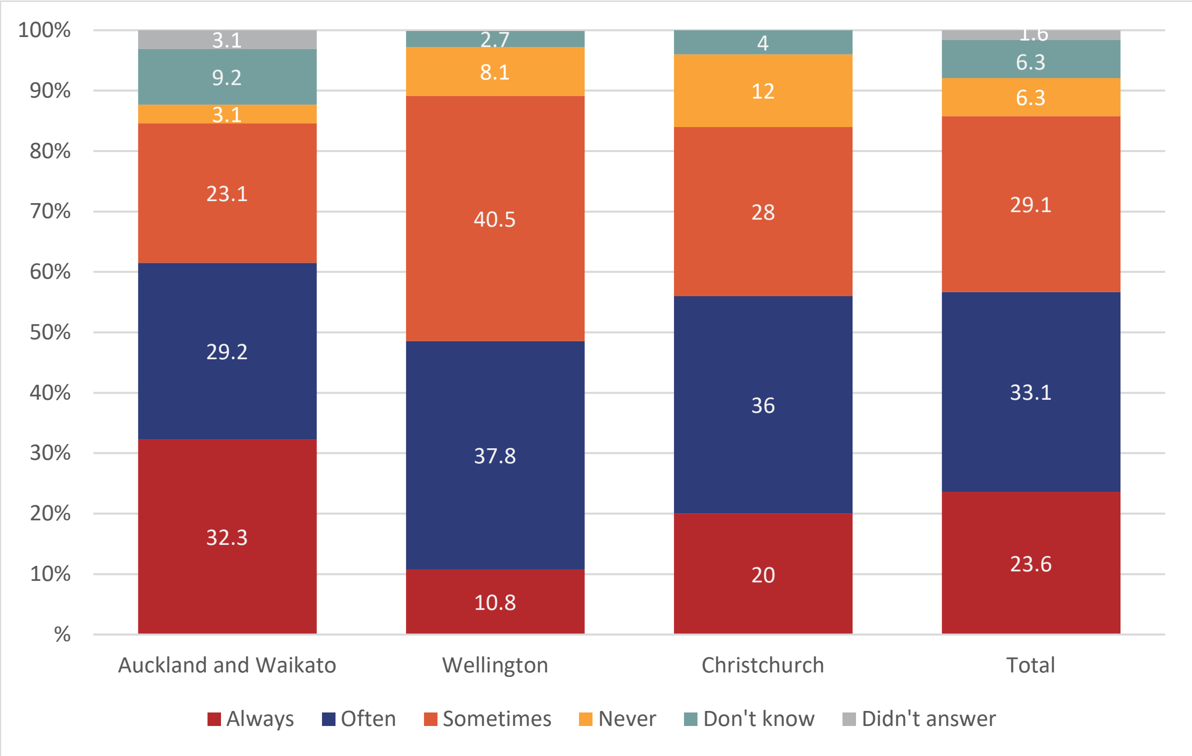
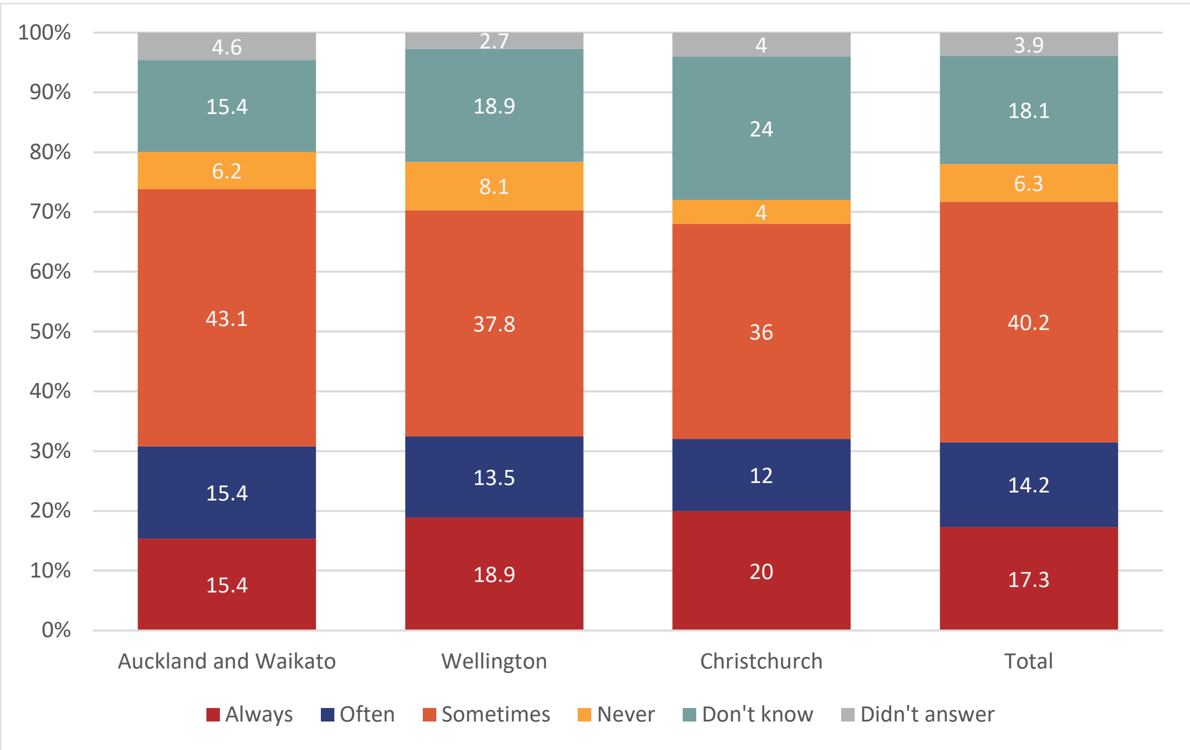


Figure 3.4: Limit heating due to cost (percent)



Prior to heat pump installation over half the respondents (56.7%) said their house was always or often too cold in winter (Figure 3.3) with just under a third (31.5%) reporting that they always or often limited their heating due to cost (Figure 3.4). When asked for other reasons for limiting the heating of rooms, three respondents cited power costs specifically.

Moisture was also identified as an issue with 60.6% of households reporting that there was always or often condensation on the living room windows during winter. Very few houses, less than 15%, had any double glazing. Householder-assessed dampness - defined as "*a damp feeling, visible damp patches or a musty or mouldy odour in the living room or any of the bedrooms*" - was always or often present in winter in 20.5% of houses. Visible mould in the living area or bedroom was always or often present during winter in 15.7% of houses. Self-reported mould in these areas was lower than that reported by the BRANZ Pilot Housing Survey (PHS) 2018-19 where visible mould was reported in 54% of bedrooms and 37% of living spaces.[24]

3.4 Housing Characteristics

There were few multi-storey houses in our sample, and of those that were higher than a single storey, most were nevertheless small (less than $100m^2$, Figure 3.5).

Figure 3.5: House size and number of stories for surveyed houses (percent)

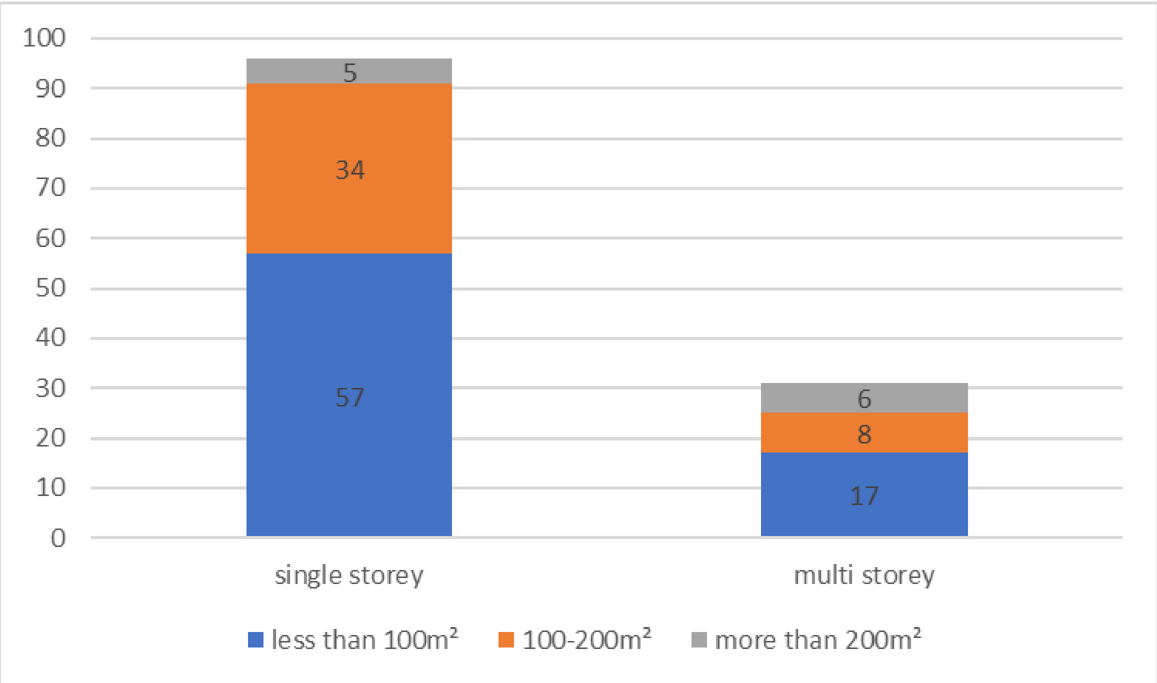
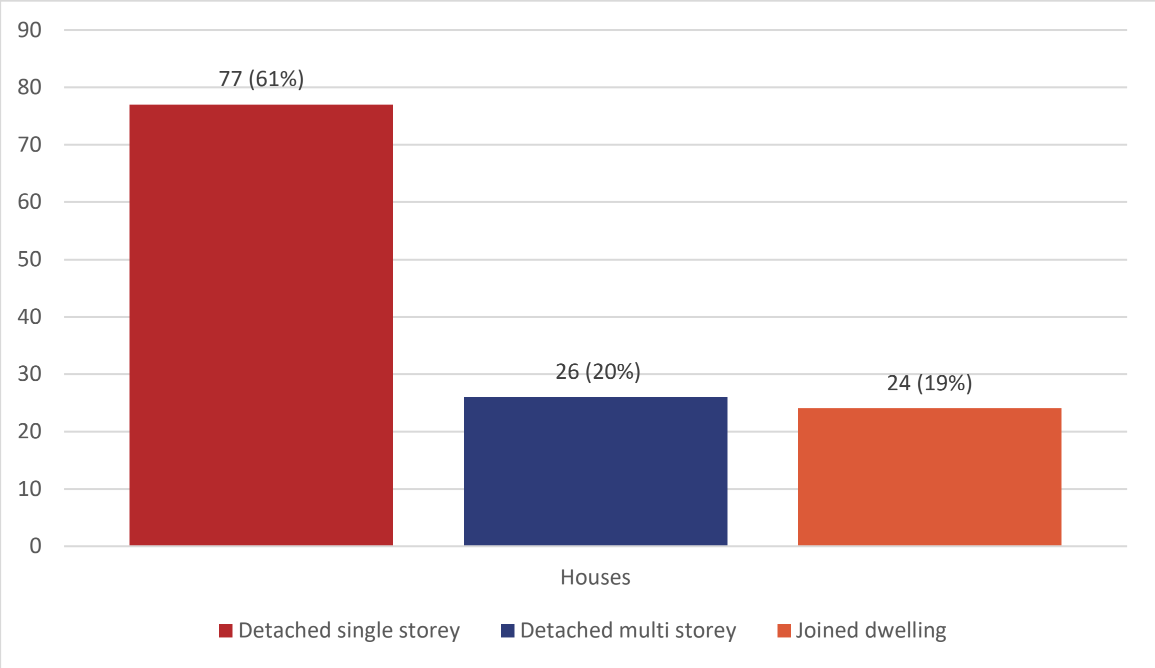


Figure 3.6: Building type for surveyed houses (number)



Our sample bears strong similarities to the total sample of the Pilot Housing Survey (PHS) collected by BRANZ and Stats NZ in 2018 which included owner occupied and rental houses.[25] The similarities are in terms of building type (61% detached single storey, compared to PHS 62%, Figure. 3.6), window type (aluminium 64% vs PHS 68%, Figure. 3.7), and the proportion of homes with a concrete slab foundation (31% vs PHS 36%, Figure. 3.7) compared to piles.

Only 25% of houses in the sample were never draughty, and 14% of participants reported that their house was always draughty. Although our measure is not directly comparable to that used in the PHS, our sample would appear to be significantly draughtier, with the PHS reporting approximately half the sample was not draughty while 22% were “draughty or very draughty”.

Figure 3.7: House characteristics (number of houses)

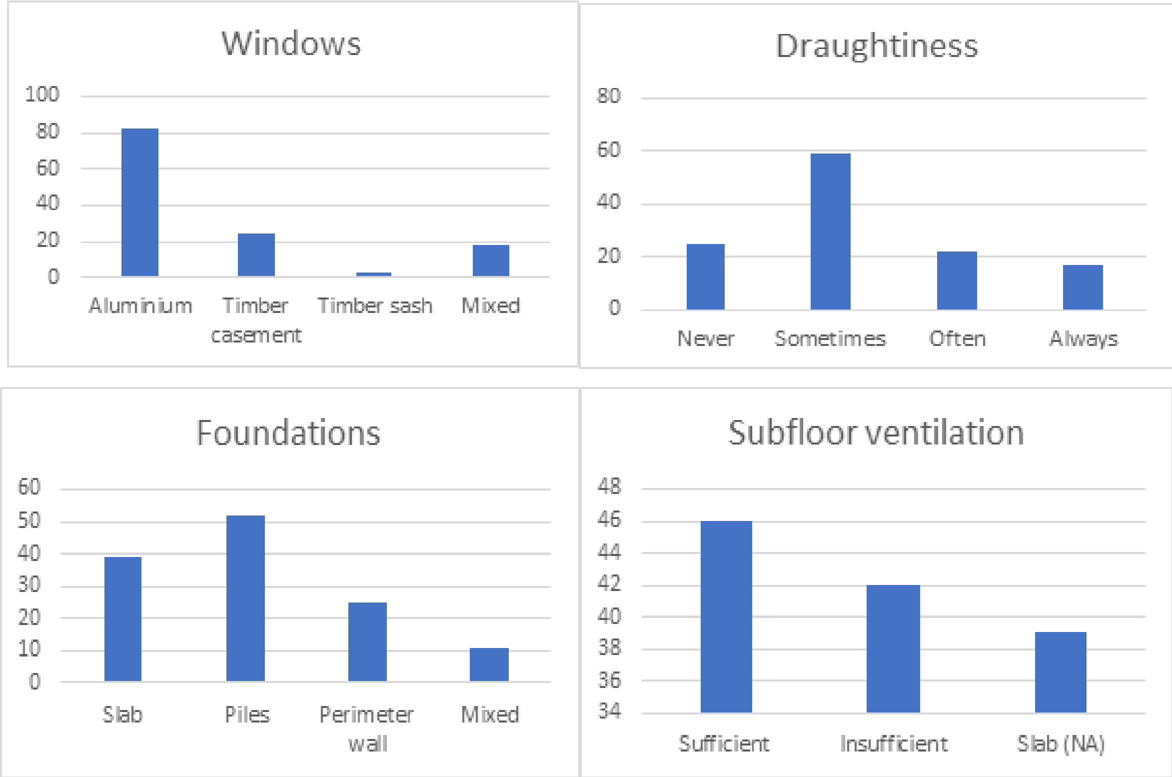
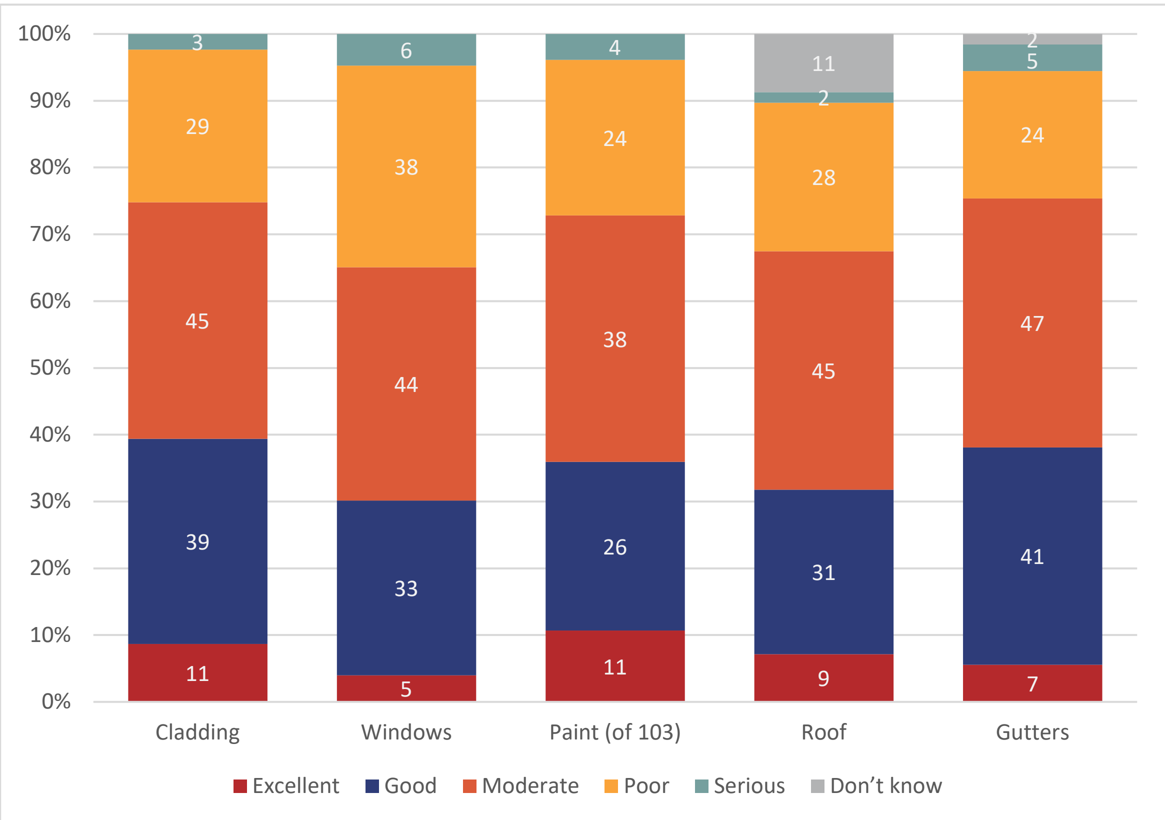


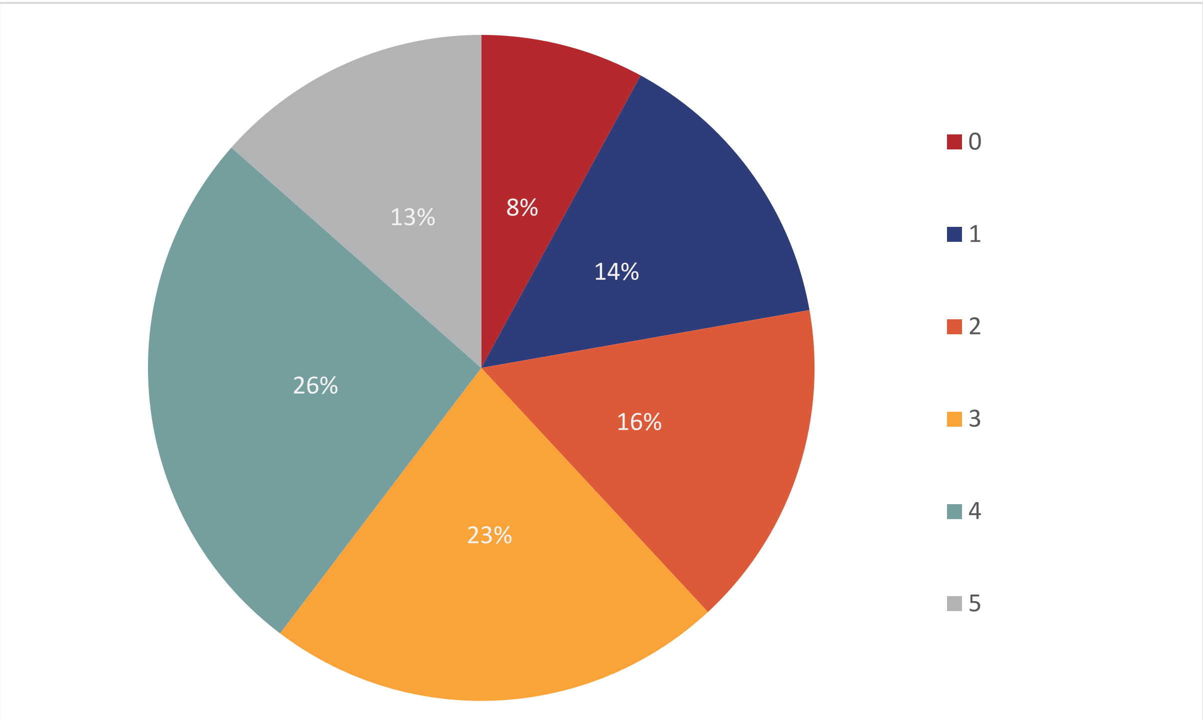
Figure 3.8: Building envelope component condition (percent)



In terms of roof, window and wall cladding condition, our sample is similar to the rental houses in the PHS with 39% of cladding in excellent or good condition compared to 40% in the rental houses in the PHS and almost 50% for their owner-occupied homes. For roof condition 31% of our sample had roofs in excellent or good condition, compared to 35% for PHS rental houses and 52% for PHS owner-occupied houses. In our sample only 30% of houses had windows which were in excellent or good condition, compared to 38% of rental houses in the PHS and 58% of owner-occupied houses. The PHS did not report on condition of the gutters or paint on the exterior walls. In our survey, these characteristics were generally similar in terms of condition to the other exterior components, with 35% of houses with painted claddings having paint in excellent or good condition and a similar proportion for spouting and guttering systems (Figure 3.8).

Approximately 40% of the sample had four or more components in poor condition (roof condition moderate to serious, cladding condition moderate to serious, window condition moderate to serious, subfloor ventilation insufficient, some downspouts not linked to stormwater drains) (Figure. 3.9). This suggests that many houses in the sample are in a state of disrepair, and potentially dilapidation.

Figure 3.9: Number of house components in moderate to poor condition

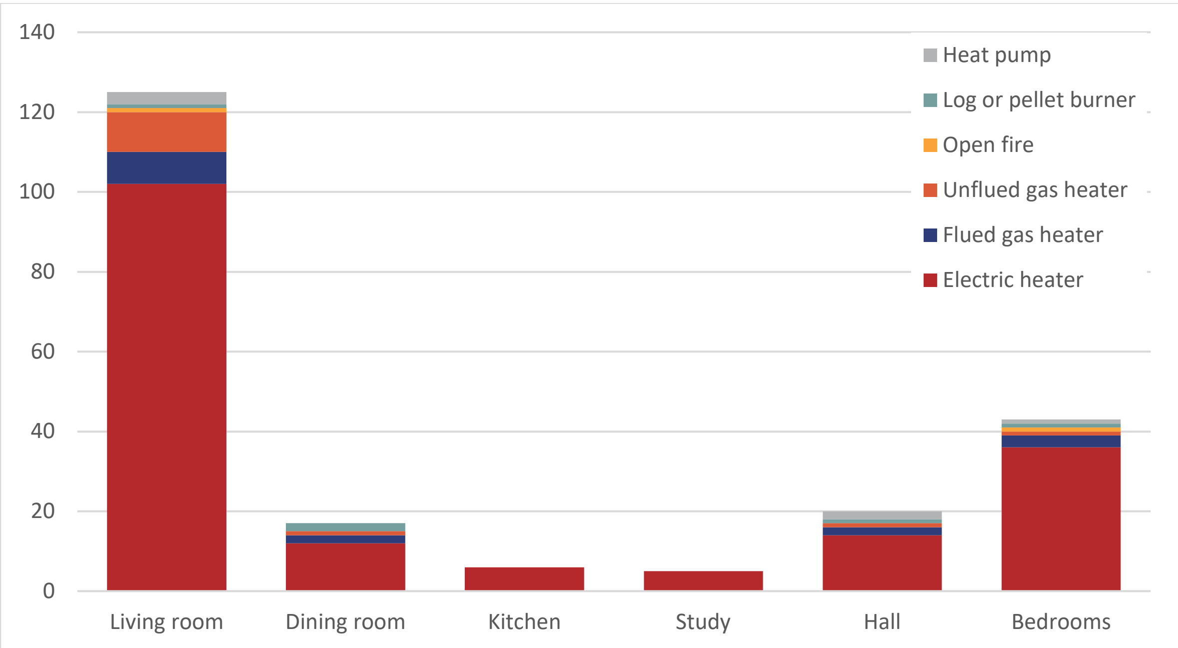


In summary, compared to the most recent, nation-wide survey of housing condition in New Zealand homes, our sample was found to be similar in terms of size and construction style to the national sample, and in somewhat worse condition than typical owner-occupied houses, being more similar in terms of condition to rental houses.

3.5 Heating Behaviour

At baseline, almost all (93.7%) of the study households heated their living room in winter, with over half (58.7%) also heating at least one bedroom (Figure 3.10). Other rooms heated included the dining room (13.1% of households), kitchen (9.5%), hallway (15.9% and study (4.5%). Where the kitchen, hall, or dining room were part of an open plan space, these were recorded as part of the living area. The heating calculator, used by the service provider to determine the size of heat pump required, measured all spaces within the living area that were not closed off by a door. Therefore, the kitchen, dining room, and hallway were only counted as separate spaces from the living area in the survey if they could be shut off by a door. In some instances, these rooms were heated using the heating source from the living area by leaving doors open once the living room was warm.

Figure 3.10 Number of study houses heated in winter, by heating method



Note: Y axis shows number of houses in the study heated over winter. Bedrooms refers to at least one bedroom being heated.

The majority of households (between 70% and 100% depending on the room) used some form of electric heater for all rooms that were heated in winter. Eight percent of households used an unflued gas heater to heat the living area, greater than the approximately 6% who reported using this form of heating by the 2018 New Zealand Census.[26] Those that used a heat pump in the living area were using a heat pump that had been installed in another part of the house and were keeping doors to the living area open. Those who listed open fires or log/ pellet burners as a means of heating hallways or bedrooms were likely to also have done so by opening doors from living areas to allow heat to spread to other parts of the house.

Just under a quarter of households (22.8%) were aware of times of day when energy prices were lower (for example the *hour of power*) and took advantage of these opportunities, including to heat more rooms in the house. Over two-fifths of households (41.8%) received a winter energy payment.

When asked about reasons for not heating rooms that were used regularly (other than cost), the most common reason was households did not have enough heaters or that the heaters were ineffective. In addition, a number of responses raised concerns about the safety of leaving heaters switched on in unoccupied rooms (for example bedrooms during the evening), some adding that the heaters were "*quite old and a bit broken*". Only one response cited environmental reasons for limiting their use of heating, however another put the coldness of the living area down to *"a lifetime habit of only heating the room to 16 degrees"*. This sentiment was echoed by another response that complained the children would leave the heater on too high a setting, resulting in the parents waking up dehydrated and with headaches.

A number of alternative methods of keeping warm indoors during winter were employed by households, the most common of which were: to use more blankets (78.6%) on the bed and in the living area and to wear more clothes (69.8%). Many households mentioned closing off rooms (40.5%) or going to bed early in order to keep warm (32.5%), whilst a few said that they slept in the living room (7.9%) or that the family slept in a single room (4.8%).

3.6 Interactions between Occupants and their Houses

Houses with more occupants were more likely to have dampness reported in the baseline survey (Figure 3.11). As shown in previous work,[27] there was little correlation between number of occupants and house size, demonstrating a wide distribution in occupant-to-floor-area ratio

(Figure 3.12). The relationship between dampness and occupancy is expected due to each additional occupant increasing the moisture produced from breathing, cooking, and washing.[28]

Figure 3.11: House dampness by number of occupants (percent)

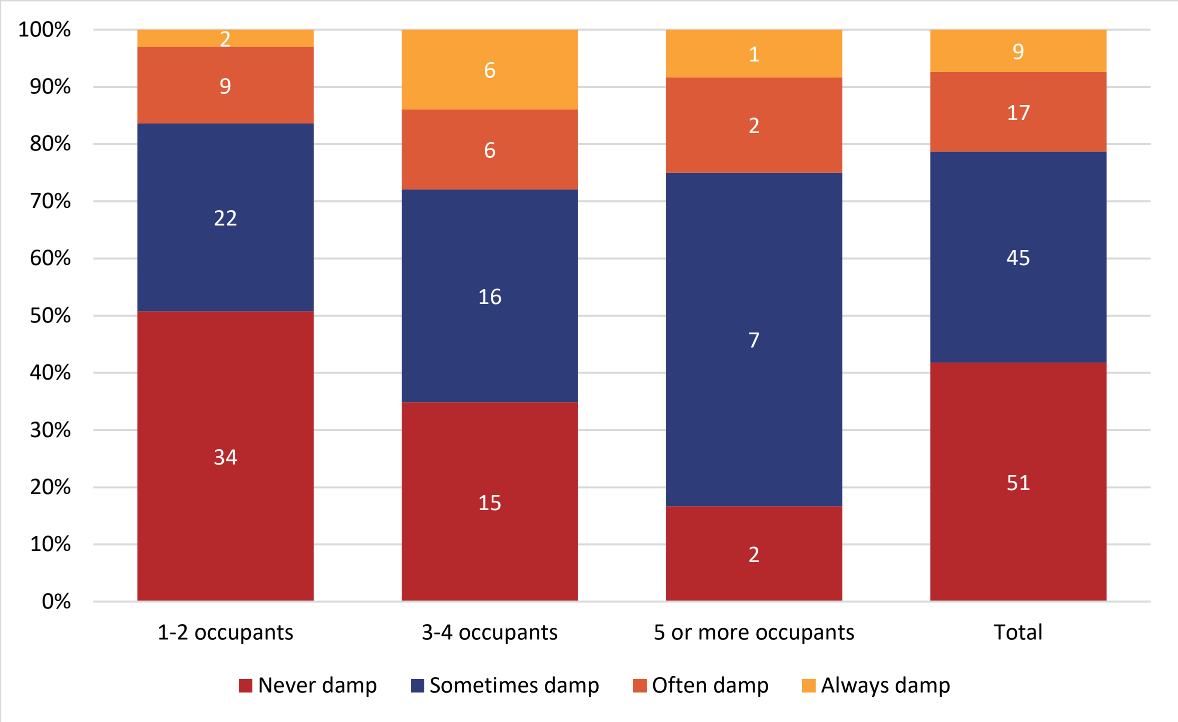


Figure 3.12: Number of occupants by house size (percent)

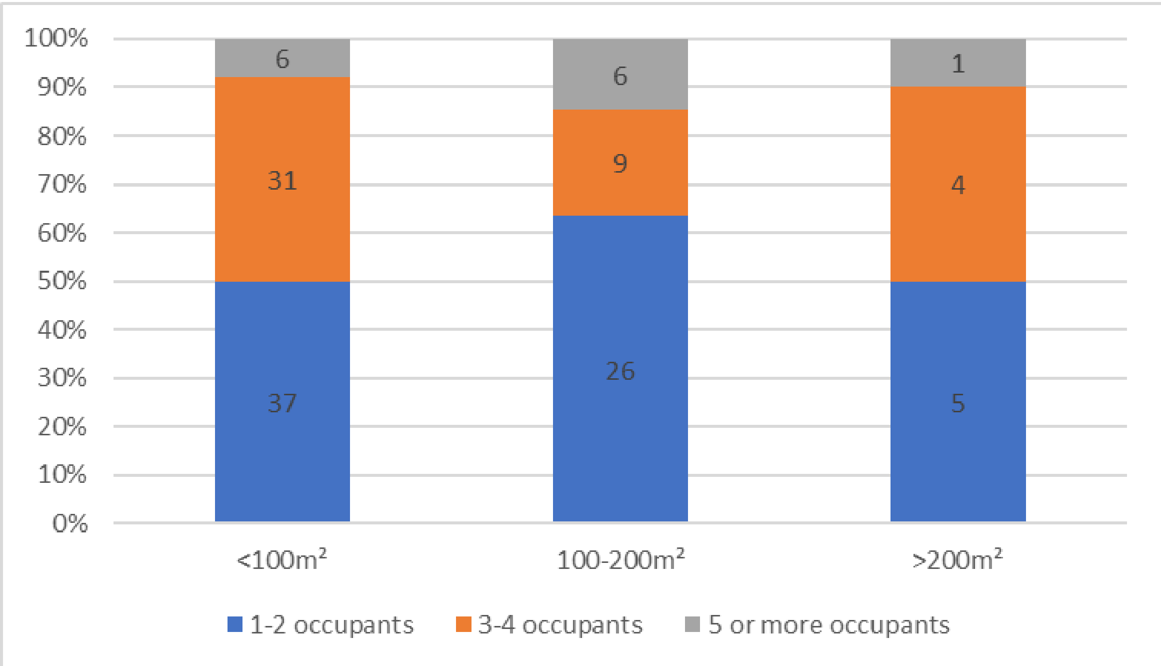
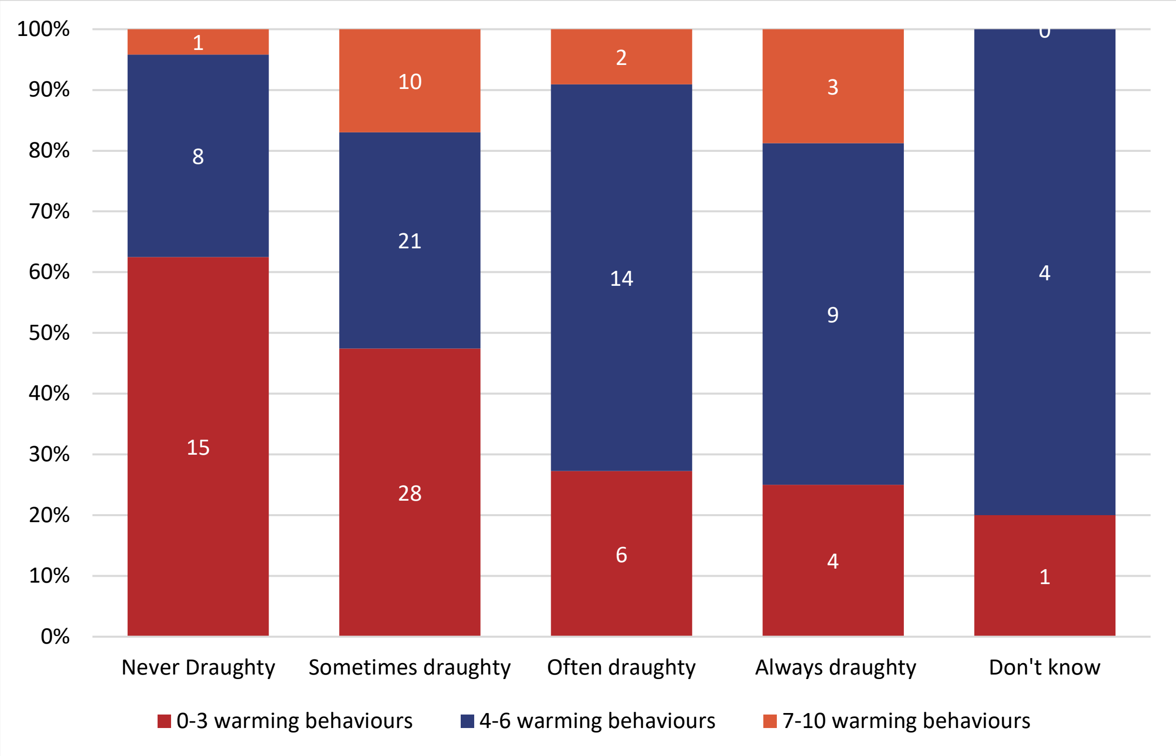


Figure 3.13: House draughtiness and cumulative warming behaviours (percent)



Questions about whether occupants used certain behaviours to keep warm in their homes, including having hot drinks, exercising, going out somewhere warmer or wearing additional clothes and blankets, were summed and the cumulative count was compared to reported draughtiness. This showed a clear relationship between increased draughtiness and more warming behaviours undertaken by occupants (Figure 3.13). This demonstrates that draughtiness is a significant issue for participants in this research.

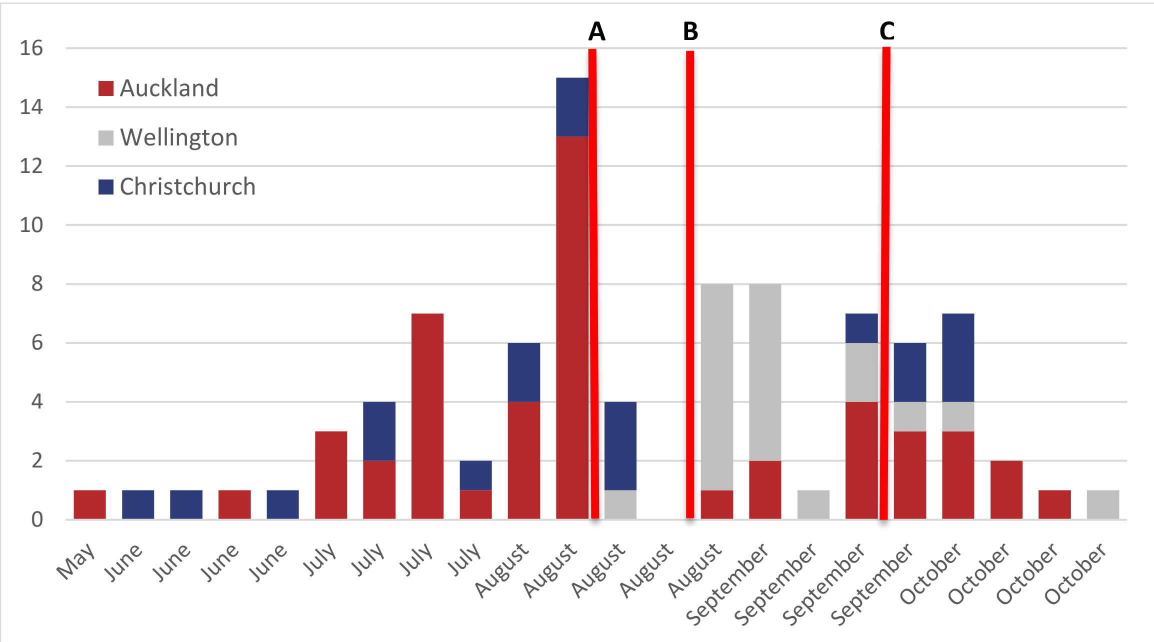
4: Impact of the Heat Pump: Results from the Household Survey

Responses from 106 households (274 people) are included in analysis of the household surveys: 48 (45.3%) in Auckland and the Waikato, 33 (31.1%) in Wellington and 24 (22.6%) in Christchurch. Of the 21 households from the baseline survey not included: three had withdrawn from the study, nine had a different primary respondent from the first survey and interviews for nine were unable to be arranged before analysis of the follow-up survey took place. When comparing size of the 106 households between baseline and follow-up, 14 households had changed size: six had one less person, one had two less people, two had three less people and five had one extra person. Tables comparing responses to the baseline and follow up surveys are provided in Appendix 2.

Due to a combination of supply chain issues and lockdowns to control the community spread of the COVID-19 Delta variant, not all households recruited to the Warmer Kiwis Study had their heat pump installed by the end of the winter. When initial monitoring was completed on 26th September 2021, 68 (63.8%) of the 106 households had had their heat pump installed (Figure 4.1). Follow-up interviews were conducted between 18th October and 14th November. By the time of their follow-up interview 91 (85.8%) households had had their heat pumps installed. Installations were not evenly distributed across the follow-up cohort, with Wellington lagging behind Auckland and Christchurch.

Figure 4.1 provides a weekly breakdown of heat pump installations by area. Line A on the graph represents the week of the beginning of the COVID-19 Delta variant lockdown when all of New Zealand moved to Level 4. Line B represents the move from Level 4 to Level 3 for all of New Zealand south of Auckland. Line C represents the end of the monitoring period for indoor air quality and electricity data.

Figure 4.1: Heat pumps installed weekly (number)



Note: Sample starts week beginning May 31st 2021. The heat pumps installed after line A were installed in the days immediately prior to lockdown (the chart weeks start on a Monday and lockdown started on a Thursday).

When interpreting the survey results that follow, their respective timings must be borne in mind. The first survey was conducted at the outset of the study in winter, whereas the second survey was conducted in spring from mid-October to mid-November. It is possible that the responses to certain questions may reflect recent weather in the respondent's location with warmer weather generally being experienced in the second, relative to the first, survey.

4.1 Impact of the Heat Pump on House Condition

Limiting heating due to cost, condensation on living room windows and damp, mouldy or musty odour in the living room or bedroom were reported less frequently at follow-up (compared to baseline) by the 91 households that had their heat pump installed (Figures 4.2-4.4).

At follow-up, 7.7% of households that had had their heat pump installed said they always or often limited heating in the living area due to cost compared to 31.9% at baseline. Those that sometimes limited heating in the living area also fell from 37.4% to 8.8% (Figure 4.2). In the baseline survey, it was common amongst respondents to describe putting off turning on heaters until as late as possible in the evening to avoid high power bills and that this would "*just take the edge off the cold*" before they went to bed. They were more comfortable using the heat pump, many describing it as "*instant heating*".

The number of people reporting always or often having condensation on windows in the living area also fell from 59.4% of households at baseline to 2.2% for those that had a heat pump at follow-up. Households that sometimes had condensation on living area windows also fell between baseline (34.1%) and follow-up (26.4%) (Figure 4.3).

Households that had reported always or often noticing damp in their living room or bedroom fell from 20.9% at baseline to 2.2% at follow-up where a heat pump was installed (Figure 4.4). There was also a decrease in households that reported sometimes noticing damp from 29.7% at baseline to 9.9% at follow-up.

Figure 4.2: Households restricting heating due to cost after a heat pump is installed compared to baseline (percent)

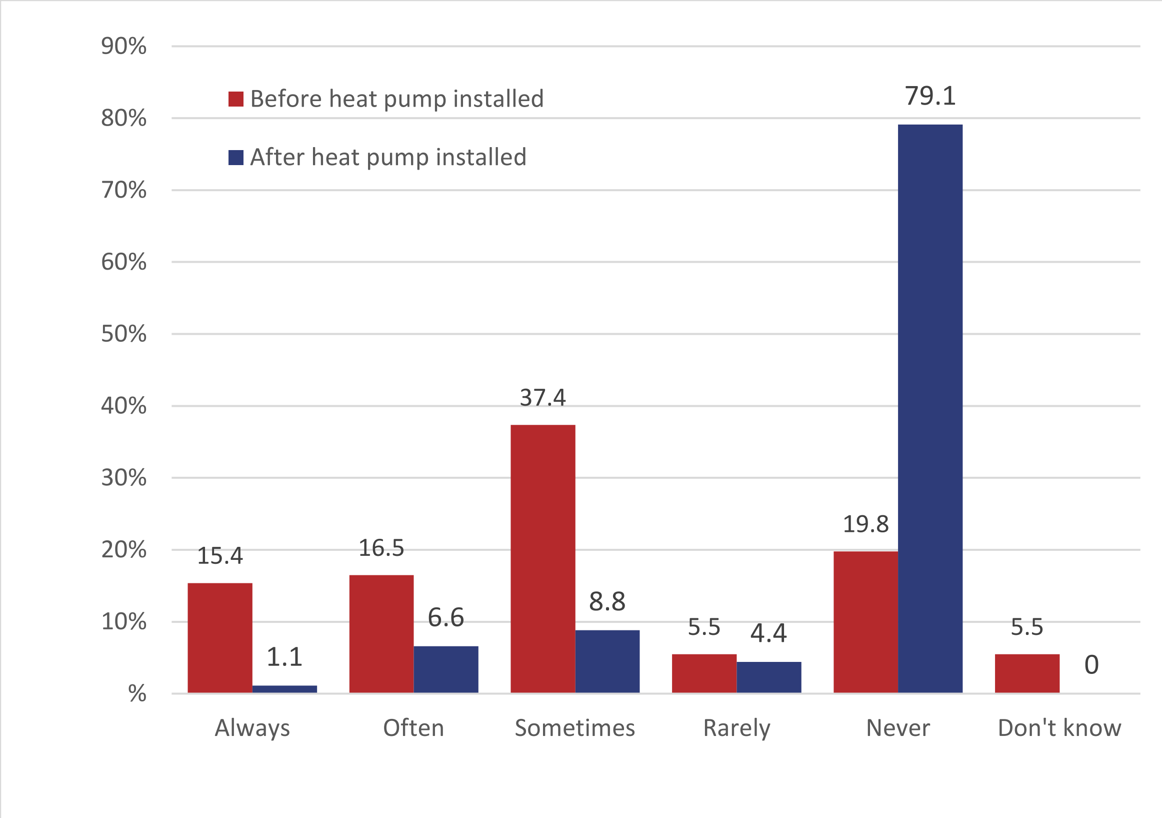


Figure 4.3: Households with condensation on windows in the living room or bedroom after a heat pump is installed compared to baseline (percent)

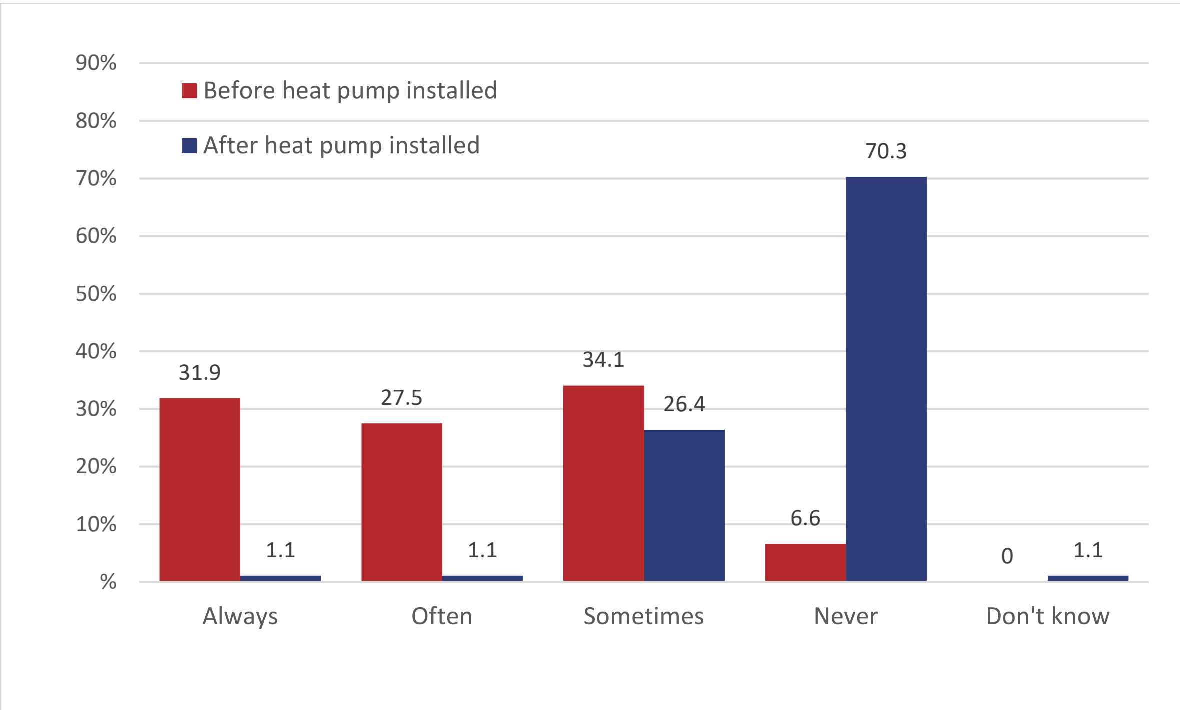
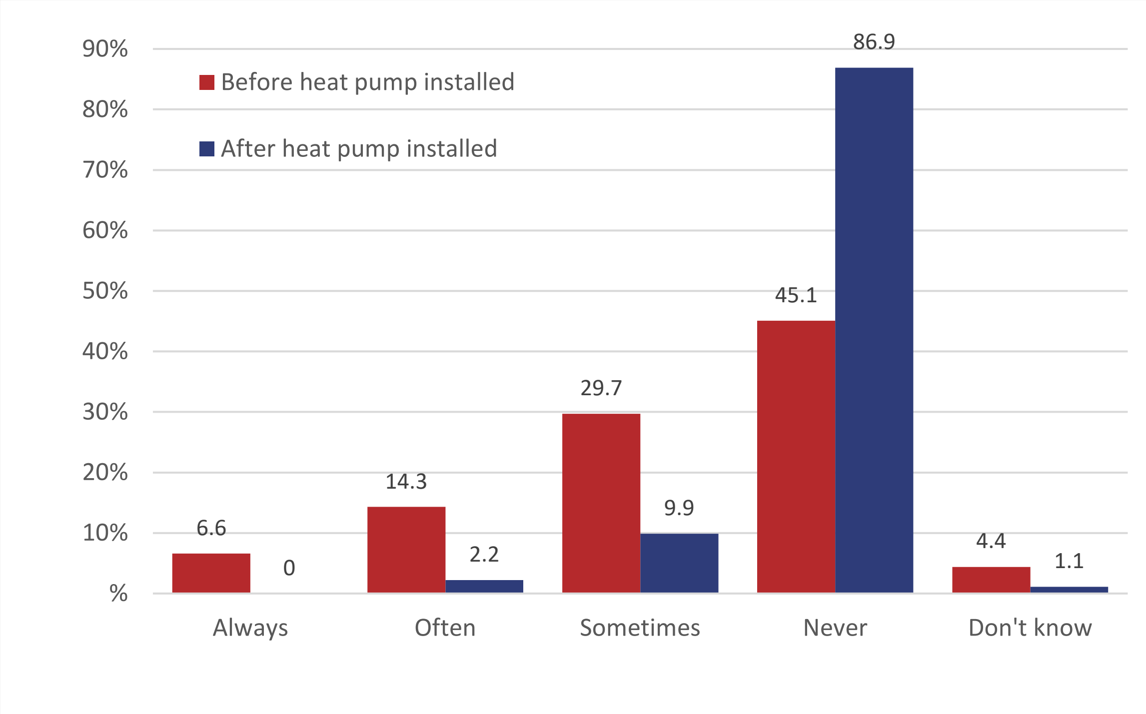


Figure 4.4: Households with dampness in the living room or bedroom after a heat pump is installed compared to baseline (percent)



4.2 Heating Behaviour Using the Heat Pump

At follow-up, when asked about the rooms they heated, many households that had a heat pump installed said that once the living area was heated, they opened doors to allow the warmth to spread to other areas of the house. This included the hallway (25.0%), kitchen (27.2%), bedroom(s) (27.2%) and bathroom (2.2%). Some responses (6.6%) indicated that the heat pump could warm up the whole house. At least one response described using the *hour of power* to maximise the fan settings and spread the heat through as much of the house as possible. Most households found the heat pump was simple or very simple to use (86.8%) and that service providers had shown them how to use the heat pump (56.2%) - in at least one case setting it up for them - and /or left an instruction manual (89.1%).

In terms of how they use the heat pump on a daily basis, most households switch it on when they feel cold (Figure 4.5). Once switched on, most keep the temperature at a set level - usually around 20°C, however settings varied between 15°C to 24°C, (Figure 4.6). Many responses mentioned initially setting the temperature at the higher end of the range, then turning it down once people were warm. Only about a third (30.4%) used the fan settings to moderate and direct the heat. These behaviours may reflect the heat pumps being newly installed and householders still learning how to use them to the greatest effect.

Figure 4.5: Study households that had a heat pump installed before follow-up by how they use their heat pump to keep warm (percent)

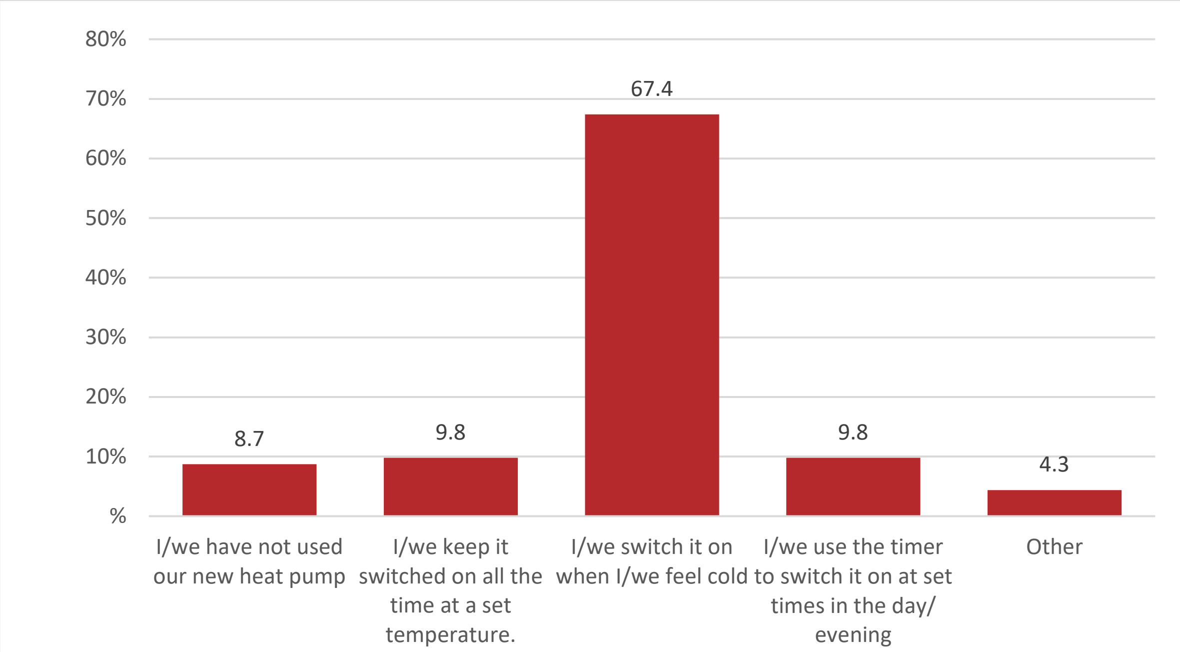
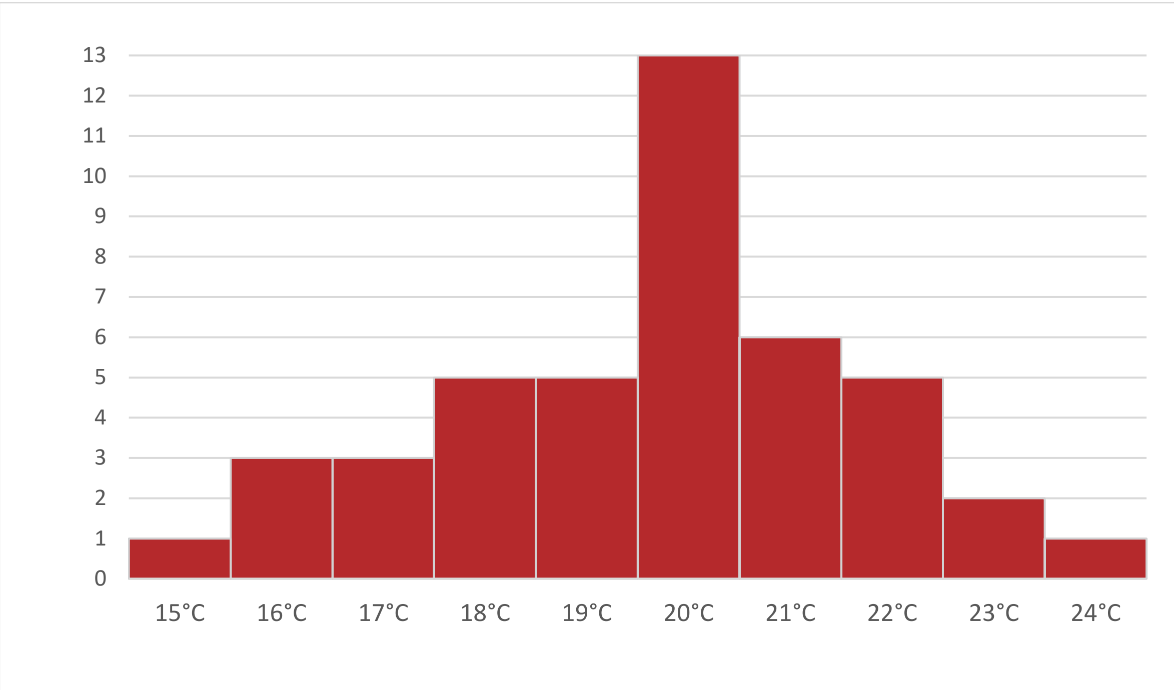


Figure 4.6: Self-reported temperature range that the heat pump is operated at by Study households that had a heat pump installed (number of houses)

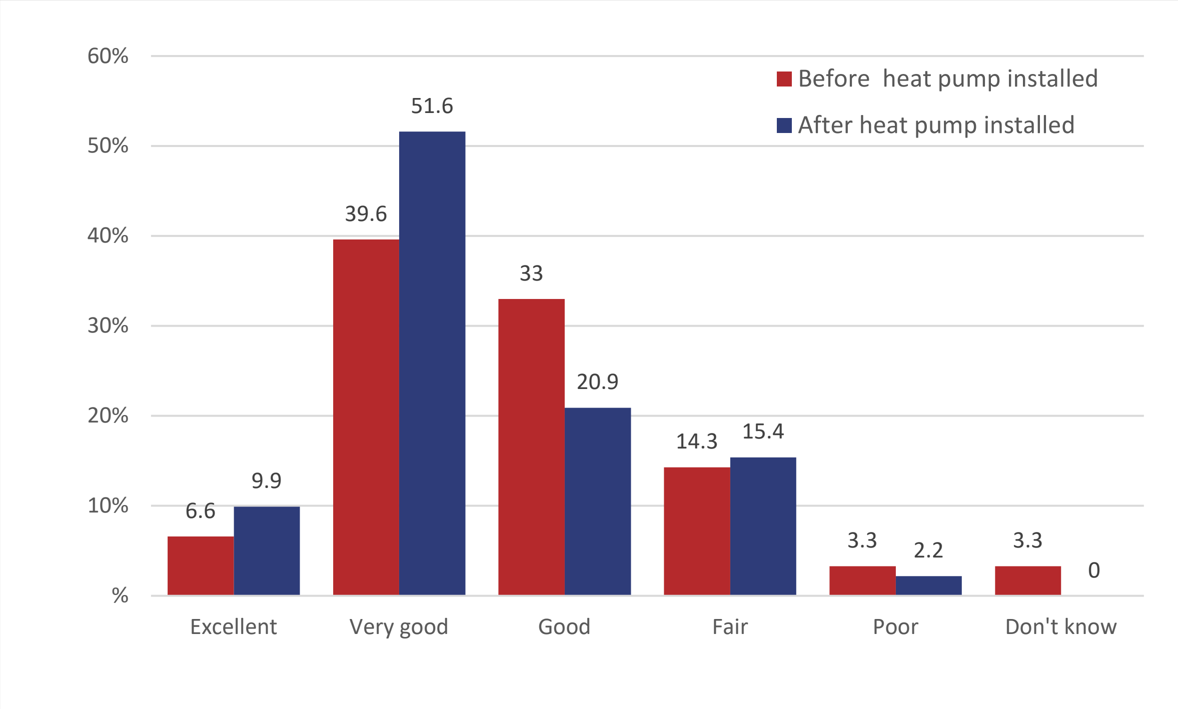


Note: Participants could choose a range of temperatures. Each temperature within the range indicted is included in the figure. Only includes participants that stated a temperature.

4.3 Impact of the Heat Pump on Health and Wellbeing

There was an overall improvement in self-reported health amongst primary respondents in households that had received a heat pump with the proportion of responses stating that they were in excellent or very good health rising from 46.2% before heat pump installation to 61.5% after installation (Figure 4.7).

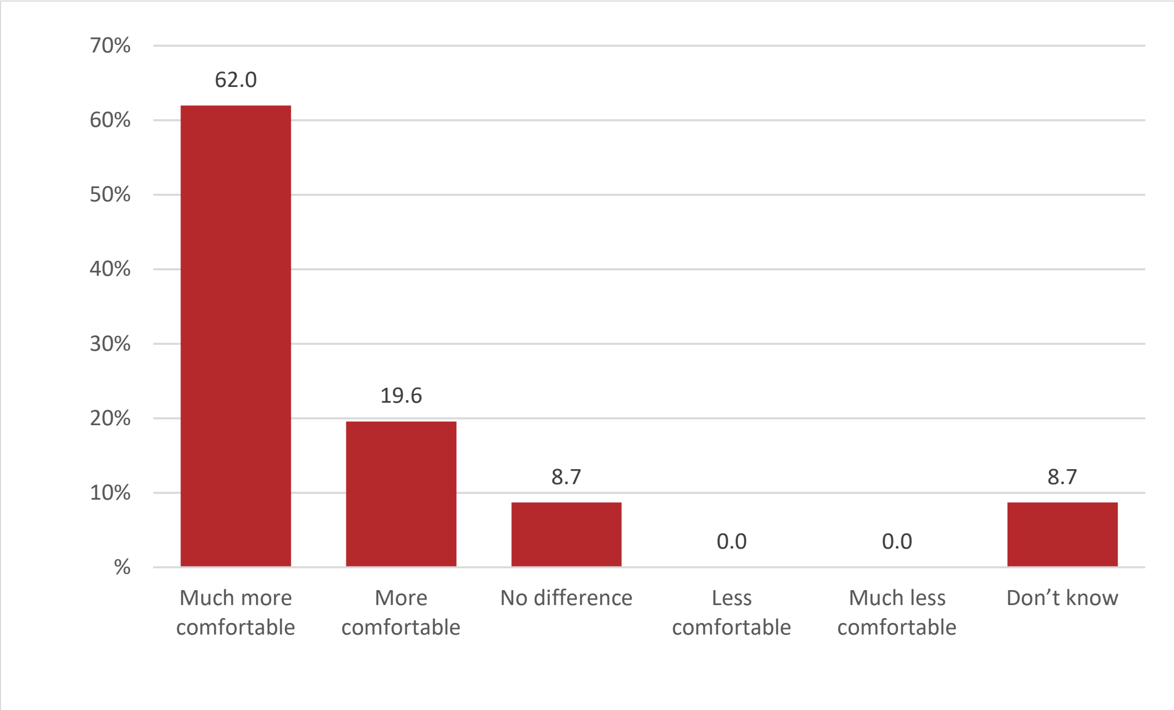
Figure 4.7 Self-reported health of primary respondents after their heat pump was installed compared to baseline (percent)



Of primary respondents that had a heat pump and answered the life satisfaction question in both surveys (89), 23 (25.3%) did not change their rating of life satisfaction between the baseline and follow-up surveys; 37 (40.7%) of primary respondents scored their life satisfaction greater at follow-up whilst 29 (31.9%) gave a lower life satisfaction score. It should be borne in mind that the period between the two surveys was greatly affected by the COVID-19 Delta outbreak (and accompanying lockdown and other policy responses) which will have influenced responses to overall life satisfaction.

The overwhelming majority of study participants that had received a heat pump (81.6%) said that their home was either much more comfortable or more comfortable as a result (Figure 4.8). Nobody said the heat pump had made their home less comfortable. However one response – that stated the heat pump had made no difference to the comfort of their home – complained of dry eyes. Of the remainder of "*no difference*" responses, half had not used the heat pump yet and one said it was similar to their old (electric) heater. None of the "*don't know*" responses had used their heat pump. Often this was due to it having been installed very recently (since the beginning of October 2021).

Figure 4.8: Difference the heat pump made to home comfort amongst Study participants that had their heat pump installed by follow-up (percent)

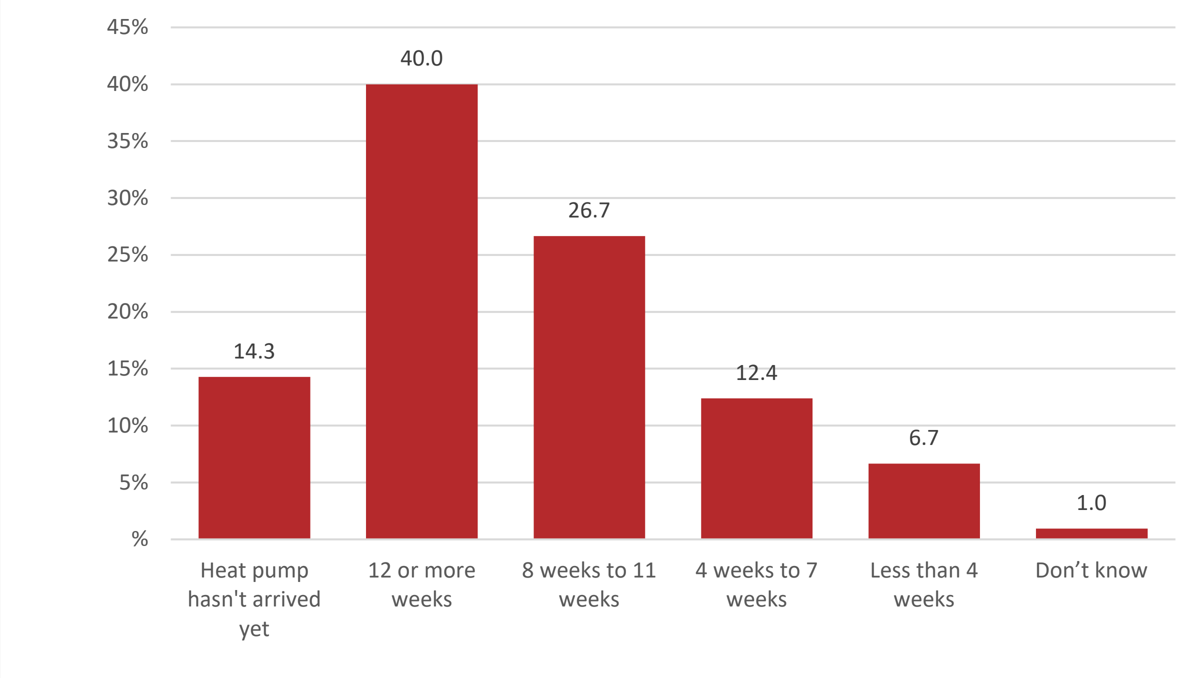


In addition to feeling more comfortable in their home, 79.1% of households that had their heat pump installed said they felt more satisfied with their home. When asked to elaborate, answers about how the house was more comfortable and why people felt more satisfied with their home were similar. Many responses centred on the added value of having the heat pump and the additional warmth it provided. The convenience of being able to regulate temperature, instant heat and fewer problems with condensation and damp were also cited as reasons the house felt more comfortable. Responses included how the heat pump had allowed the living area to be used more effectively and for longer. The improvement of the heat pump over prior forms of heating was also cited, particularly around concerns about the safety of the heater. A number of responses noted an improvement in health since the heat pump had been installed, while others reflected on the reduction in stress that an effective source of heating had given them. Increased pride in the house was also identified, especially feeling more comfortable hosting family and friends. A full list of responses is included in Appendix 3.

4.4 Overall Satisfaction with the Warmer Kiwi Homes Subsidy Programme

Households most commonly had to wait over three months for their heat pump to arrive (Figure 4.9). There were wide variations in the time taken for installation beyond three months. Delays included decommissioning older heating sources and having insulation installed, as well as supply chain issues and installations being stalled by the COVID-19 Delta variant related lockdowns.

Figure 4.9: Amount of time it took for the heat pump to arrive from first applying to the WKH programme (percent)



Despite the delays, 91.3% of households that received a heat pump said they were very happy or happy with the whole experience of the Warmer Kiwi Homes subsidy programme. Almost all (95.6%) felt that the heat pump had been the right choice for their home and 88% said that the heat pump had met or exceeded their expectations.

Overall, households were very grateful to receive their heat pumps and said that the service providers had been helpful, and communication was good. Many households said they would have liked the heat pump sooner but understood the delays due to COVID-19 and supply chain problems. In addition to managing expectations over the time between applying for and receiving a heat pump, being able to order the heat pump whilst waiting for insulation to be installed and/or an older heating source being decommissioned, were suggested as ways to help speed up the process.

5: Quantifying the Impact of Heat Pumps on Indoor Environmental Quality

5.1 Data Analysis

Each house in the programme received either a Tether EnviroQ or a Hobo indoor environmental monitor at the time of the first fieldworker visit. The EnviroQ monitors relay data half-hourly to a central server, while the Hobo monitors store the data on the device. This interim report only includes data from the EnviroQ monitors.

The EnviroQ data include indoor temperature (measured as degrees C), indoor relative humidity (measured as %RH), CO_2 (measured as parts per million, ppm) and light (measured by lux, a measure of luminous intensity). (The EnviroQ monitors can also measure sound pressure level, but this function was disabled.) We model the effect of heat pump installation on the first three of these variables and use the fourth as a control variable; a discussion of the modelling approach follows below. Our dataset includes all available data prior to heat pump installation and all available data post installation; data for the day of installation is dropped from the analysis since the hour of installation is not known.

Our modelling draws on two further data sources. The first is the data sourced at the time of the first visit via the household survey and concurrent house inspection survey. The variables on which we draw for this interim report include perceived draughtiness, a composite measure of house condition, and the number of occupants of the house. The subsequent final report will draw on further house and household characteristics derived from these surveys.

The second data source on which we draw is the Cliflo weather data compiled by NIWA described earlier in this report. The Cliflo data is recorded hourly at the start of each hour. We use the Cliflo data for our measures of external temperature and external relative humidity.

The timing of each EnviroQ's half-hour reading depends on the exact time at which the monitor was activated so differs for each house. Our hourly readings correspond to the reading that is closest to the start of each hour (so is within 15 minutes of the hour start). We use data at hourly intervals for the modelling given that that the external (Cliflo) environmental data is hourly. This choice also avoids unnecessary clutter when presenting the results.

5.2 Modelling Approach

Our modelling approach is based on a 'difference-in-difference' (DiD) analysis assessing the impact that installation of a heat pump has on the indoor (living area) environment. Typically, in a DiD equation, we have a treatment variable – which in our case is the installation of a heat pump under WKH – that modifies the relationship between another variable and the outcome of interest.

Our initial outcome of interest is temperature in the living area. The relationship that the heat pump may modify is that between this indoor temperature and the outdoor temperature in that location. A simple DiD specification controls for the outdoor temperature and also includes a dummy variable for the post-treatment period; it then focuses on the interaction between these two variables (i.e., the difference-in-difference).

In our case, we leverage the fact that heat pumps were installed on different days throughout the programme, with some properties not receiving a heat pump at all during the sample period. The timing of heat pump installation was essentially random from the perspective of the household, being affected *inter alia* by delays related to the COVID-19 pandemic. Thus we have a natural experiment in which the timing of treatment can be regarded as random. In our analysis, we leverage the random timing of this treatment. Note that all houses in the study applied to have a heat pump under WKH, so the results should be interpreted as being applicable to households eligible for the scheme and who wish to have a heat pump installed; i.e. the randomisation occurred within the set of households meeting these criteria.

Our estimates include controls for each separate day of the study to account for national factors – such as weekends and public holidays – that affect heat pump use. Since the timing of treatment differed for each house, we are able to include this set of day control variables alongside a variable, *HP*, that takes a value of 0 prior to heat pump installation and a value of 1 post installation. (The controls for each day do not control for region-specific factors such as a regional lockdown. In the final report for this study, we will examine alternative ways to account for such regional effects.)

The richness of our data also enables two further sets of control variables. First, we control for a set of hour variables (i.e., 23 separate variables with one hour omitted as a reference category), where each hour variable equals 1 on that hour and 0 otherwise. This set of variables controls for different heating and living behaviours at particular times through the day (e.g., sleeping at

3.00 a.m. and having breakfast at 7.00 a.m.). The second set of control variables is a 'fixed effect' for each house in the study, i.e., a separate variable for each house that is equal to 1 for that house and 0 otherwise. This set of variables controls both for unchanging features of the house (e.g., sunny, windy, draughty, house condition, etc) and for unchanging features of the household (e.g., number of occupants, ages, health, etc). The house fixed effect does not control for features that change over the (short) sample period, such as the number of occupants.

Thus our full set of controls take account of effects relating to each day of the sample, each hour of the day, and each house (and household) in the study. Controlling for each of these aspects enables us to estimate the effect of heat pump installation without the presence of noise caused by any of these aspects.

The simplest form of equation for indoor temperature that we estimate is:

$$Temp^{I}_{iht} = \beta_0 + \beta_1 Temp^{O}_{iht} + \beta_2 HP_{iht} + \mu_t + \mu_h + \mu_i + \varepsilon_{iht} \qquad (1)$$

where: $Temp^{I}_{iht}$ is indoor (living area) temperature of house *i* at hour *h* on day *t*;

$Temp^{O}_{iht}$ is outdoor temperature at house *i*'s location at hour *h* on day *t*;

HP_{iht} is a dummy variable for heat pump installation (=0 pre installation; =1 post);

β_0, β_1, β_2 are coefficients to be estimated;

μ_t is a set of day fixed effects to be estimated;

μ_h is a set of hour-of-day fixed effects to be estimated;

μ_i is a set of house fixed effects to be estimated;

ε_{iht} is the residual.

Specification (1) and subsequent specifications are estimated as an unbalanced panel equation using ordinary least squares regression; ε_{iht} will likely be correlated within each household, so standard errors are in each case clustered by house. The sample period (for this and subsequent specifications) is the period 1 June 2021 to 26 September 2021, being the three official winter months plus the first month of spring. The end-date is chosen to be consistent with the availability of all other data used in the modelling.

In specification (1), our focus is on the heat pump parameter, β_2, which indicates the average difference in indoor temperature of the house (in degrees Celsius) following heat pump installation (relative to having no heat pump installed under WKH) after controlling for external temperature.

We extend specification (1) by including the interaction effect of a heat pump with external temperature, as shown in specification (2):

$$Temp^{I}_{iht} = \beta_0 + \beta_1 Temp^{O}_{iht} + \beta_2 HP_{iht} + \beta_3 HP_{iht} Temp^{O}_{iht} + \mu_t + \mu_h + \mu_i + \varepsilon_{iht} \quad (2)$$

In specification (2), our focus is both on the heat pump parameter, β_2, and on the interaction parameter, β_3. The latter coefficient indicates whether the installation of the heat pump changed the relationship between indoor and outdoor temperature after controlling for other factors. If β_3 is significant, then the effect of a heat pump on indoor temperature (relative to external temperature) will differ according to the external temperature. At a given external temperature, having a WKH heat pump installed is estimated to raise the indoor temperature (in degrees Celsius) relative to the counterfactual of having no heat pump by: $\beta_2 + \beta_3 Temp^{O}_{iht}$. We hypothesise that $\beta_3 < 0$ so that the impact on indoor temperature of having a heat pump will increase as external temperature decreases.

The impact of the heat pump may also depend on certain house-specific factors. One of these factors for which we gather hourly data is light in the living area. The amount of light received in the room may directly affect temperature through solar gain. We can include this effect by adding a variable, *Light*, to equation (2). In further work, we tested whether the interaction of *HP* with *Light* is significant when added to the equation; the interaction term is never significant, so this extension is not further reported.

Other factors that may affect the impact of the heat pump include draughtiness, house condition, and number of occupants. It is likely that a heat pump will be less effective in a house that is draughty as heat will be lost from the living area. A house that is in poor condition may also lose more heat than a house which is in good condition. The number of occupants may have a direct effect on temperatures and may also affect behavioural use of the heat pump (e.g., a household with four occupants may feel it more worthwhile to use the heat pump than a household with a sole occupant).

Data on each of these aspects is sourced from the first survey of each house. The *Draughty* variable is set equal to 0 if the house is regarded by the occupant as not being draughty and equal to 1 otherwise (i.e., if it is draughty). *Condition* is set equal to 0 if the house is regarded as in good condition (via the fieldworker's inspection) and equal to 1 otherwise (i.e., if it is not in good condition). The *Occupants* variable is split into three categories: 1-2 occupants, 3-4 occupants, and 5+ occupants (with 1-2 occupants omitted as the reference category).

Each of the *Draughty*, *Condition* and *Occupants* variables is unchanging for each house across the sample period (since they refer to the initial survey and inspection). For this reason, we are unable to include these variables as separate explanatory variables in the specification since the house fixed effect (which is also unchanging for each house) already captures these (and all other unchanging) effects. However, we can interact *HP* with each of the *Draughty*, *Condition* and *Occupants* variables to test whether the impact of installing the heat pump differs according to whether a house is draughty, or in poor condition, or by the number of occupants of the house.

Extra regression results are therefore presented in which we supplement specification (2) with the addition (separately) of each of:

(a) $Light_{iht}$,
(b) $HP_{iht}Draughty_i$,
(c) $HP_{iht}Condition_i$,
(d) $HP_{iht}Occupants(3-4)_i$ and $HP_{iht}Occupants(5+)_i$

where: $Light_{iht}$ is (living area) light in house *i* at hour *h* on day *t,*
$Draughty_i$ is a variable indicating if house *i* is draughty (=1) or not (=0),
$Condition_i$ is a variable indicating if house *i* is in good condition (=1) or not (=0),
$Occupants(3-4)_i$ indicates that house *i* has 3 to 4 occupants,
$Occupants(5+)_i$ indicates that house *i* has 5 or more occupants.

These supplementary equations are shown in specification (3), in which $AddedVariable$ is in each case one of the four variables (a) – (d) listed above:

$$Temp^I_{iht} = \beta_0 + \beta_1 Temp^O_{iht} + \beta_2 HP_{iht} + \beta_3 HP_{iht} Temp^O_{iht} + \beta_4 AddedVariable_{iht}$$

$$+\mu_t + \mu_h + \mu_i + \varepsilon_{iht} \qquad (3)$$

The added variables are entered separately into specification (3) to ascertain whether any of these variables causes a change in interpretation of the estimated relationships for the effect of a heat pump. (We note that some of the added variables may be collinear with one another – for example, a draughty house may also be in poor condition – so care must be taken in interpreting the results from these additional variables.)

We estimate all regressions on the 95 houses for which we have complete data, comprising 161,241 observations. We note here a number of limitations and potential extensions of specification (2), beyond inclusion of the added variables shown in specification (3).

One limitation is that both the direct effect of outdoor temperature on internal temperature and its interacted effect with the heat pump is specified as a linear relationship. It is possible that the relationship is non-linear, and several non-linear specifications can be explored. One extension that we implement is to restrict the sample to include only observations for which the external temperature is less than 18°C (which corresponds to the WHO guidelines for minimum recommended indoor temperature). This restriction (which removes approximately 1% of observations) accounts for situations in which households may not have used the heat pump owing to a perception that the external environment was already warm enough to obviate the need for heating. The exclusion of the small number of observations with external temperatures above 18°C makes virtually no difference to any of the estimates and so these results are not presented or discussed further.

A second way to incorporate non-linearities is to extend the hour-of-day effects from simply a shift in the constant term (implemented in specifications (1) and (2) via the inclusion of hour fixed effects) to different hour-of-day coefficients for each variable. We implement this alternative by presenting a set of 24 separate estimates in which each equation subsets on a specific hour of the day. For clarity, we estimate these relationships based on specification (1), so the results show how much warmer, on average, a house is with a WKH heat pump (relative to the counterfactual) at each hour of the day. Other methods of implementing non-linearities, that we have yet to investigate, include entering the external temperature variable in alternative (non-linear) functional forms.

Relative to each of the specifications shown above, tighter control over region-specific factors may be warranted, especially given the regional lockdowns that occurred through the sample period. Subsequent modelling will investigate alternative modelling strategies (potentially including the addition of a lockdown dummy variable) to take these effects into account.

Finally, specification (3) can be extended by including additional interaction effects of the heat pump with features of either the house or the household, using further data from the first household survey and house inspection. Particular aspects that may merit attention include interactions of heat pump installation with household income adequacy, receipt of the Winter Energy Payment, age of occupants, regular times for house occupancy, prior heating behaviours, prior heating appliances, and health status. These potential extensions are left for the final report at the end of the study.

Specifications (1) and (2) have each been outlined with respect to internal temperature as the dependent variable. We estimate similar equations for each of humidity and CO_2. For humidity, we replace internal temperature by internal relative humidity ($Humidity_{iht}^{I}$) and replace outdoor temperature by outdoor relative humidity ($Humidity_{iht}^{O}$). This approach reflects a hypothesis that external relative humidity, rather than external temperature, is the main external determinant of internal relative humidity. In subsequent modelling, we will test whether external temperature affects indoor relative humidity in addition to the impact of external relative humidity. We are agnostic on external determinants of CO_2, so we extend specifications (1) and (2) to include both outdoor temperature and outdoor relative humidity. For both relative humidity and CO_2, we present the specifications estimated across all hours and omit the hour-by-day specifications which provide little additional understanding of the heat pump impacts with respect to these outcomes.

5.3 Results

5.3.1 Indoor Temperature

Table 5.1 presents estimates for the indoor temperature impacts (over winter and early spring months) of installing a WKH heat pump using specifications (1) and (2) for the full sample (i.e. across all hours of the day).

The estimates derived from specification (1) shows that, on average, indoor (living area) temperature rises by 0.2°C for each 1°C rise in outdoor temperature (irrespective of any effect of a heat pump). After controlling for external temperature, the impact of heat pump installation is to raise indoor temperature by an estimated 1.4°C. This estimate can be taken as a summary statistic for the effect on living area temperature of installing a WKH heat pump relative to the temperature that would have existed without the installed heat pump. Note that the temperature in the counterfactual (i.e. in the situation without the WKH heat pump) includes the effect of any prior heating devices used in the house, so the estimated impact of the heat pump on living area temperature is additional to what would previously have been experienced by the household.

Table 5.1: Modelling indoor temperature impacts of heat pump installation

	(1)	(2)
Outdoor temperature ($Temp^{O}_{iht}$)	0.198***	0.227***
	(0.0154)	(0.0204)
Heat pump (HP_{iht})	1.422***	2.258***
	(0.254)	(0.574)
Interaction (HP_{iht}*$Temp^{O}_{iht}$)		-0.0779**
		(0.0378)
Day fixed effects	YES	YES
Hour fixed effects	YES	YES
House fixed effects	YES	YES
R^2	0.632	0.634
Number of houses	95	95
Observations	161,237	161,237

Notes: Constant included but not reported.
*Standard errors (clustered on households) in parentheses; *** p<0.01, ** p<0.05, * p<0.1.*

The results of specification (2) show that, while 1.4°C is the estimated average effect across the sample, the impact differs according to outdoor temperature. If outdoor temperature were 0°C, specification (2) indicates that the heat pump is estimated to add 2.3°C to the indoor temperature (relative to the counterfactual). For each additional degree of external temperature, the heat pump contribution falls by almost 0.08°C. For instance, at the average external temperature throughout the sample (which was 10.86°C), heat pump installation is estimated to raise indoor temperature by 1.4°C (≈2.258 – 10.86*0.0779), while if external temperature were 20°C indoor temperature is estimated to be raised by 0.7°C (≈2.258 – 20*0.0779). In each case, these increases are relative to the counterfactual of not installing a WKH heat pump.

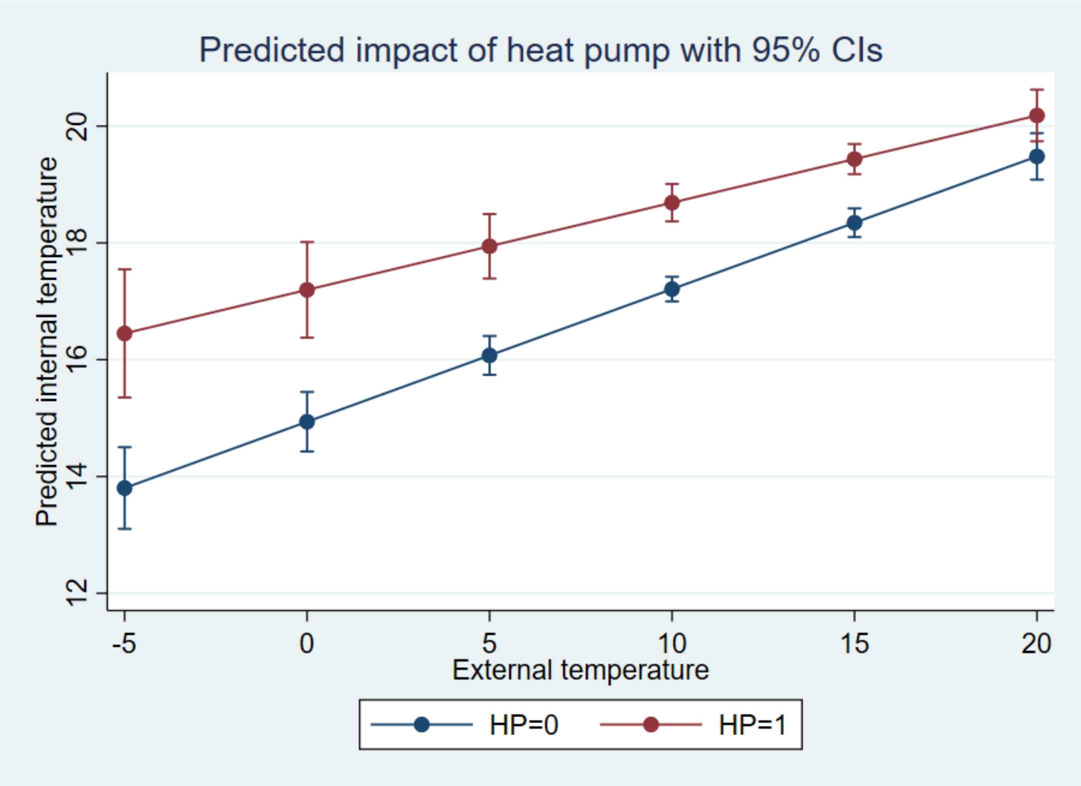
Figure 5.1 depicts the estimated living area temperatures across outdoor temperatures ranging from -5°C to 20°C for a house with a WKH heat pump installed (HP=1) relative to the same house without the heat pump (HP=0). In each case, the 95% confidence interval (CI) is shown. To interpret the graph, take the case of an external temperature of 5°C. In that case, the internal temperature is estimated to reach the WHO recommended indoor minimum temperature of

18°C with a heat pump, whereas without a heat pump the indoor temperature would only be 16°C. In a house without a heat pump the internal temperature is estimated to reach 18°C only once external temperature reaches approximately 14°C. The figure shows that the difference in internal temperatures with a WKH heat pump relative to without is statistically significant except at the very top end of the external temperature range where the confidence intervals overlap (i.e., at 20°C).

Table 5.2 presents results in which we estimate specification (3) to test for additional effects from each of light, draughtiness, house condition and number of occupants. These extensions provide us with robustness checks on the estimated magnitudes of the estimated responses from specification (2) once we control for other potential influences on indoor temperature and heat pump use. As shown in the table, estimates of the heat pump's impact on indoor temperatures remain consistently strong in the presence of these added influences. Nevertheless, several results are of interest.

First, as hypothesised, a living area which receives greater light has a higher temperature than one that receives less light, after controlling for outdoor temperatures and the presence of a heat pump. As noted earlier, further tests showed that there is no additional impact of light on the effectiveness of the heat pump itself. Thus houses which receive more light are consistently warmer than those which receive less light, both before and after the installation of a heat pump.

Figure 5.1: Modelled temperature with and without a WKH heat pump



Second, a heat pump is less effective in raising the indoor temperature when a house is perceived as draughty; indeed, the effect of having a draughty house reduces the estimated impact of the heat pump – evaluated at the mean outdoor temperature – on indoor temperature from 2.4°C to 1.1°C. Other than draughtiness, house condition (measured via a composite variable) has no separate effect on heat pump efficacy (though it may still affect underlying temperature, with this effect being captured through the house fixed effect.) Further work will examine whether specific aspects of house condition affect heat pump efficacy.

Third, heat pump effects are estimated to vary according to occupancy. The estimates indicate that heat pump installation raises living area temperature by a greater amount (relative to the counterfactual) in households with 3-4 occupants than in households with 1-2 or 5+ occupants. Further examination of this result is warranted. It is possible that households with 3-4 occupants are more likely to include dependent children than are 1-2 person households; if so the positive heat pump impact on temperatures may be magnified for families with children. Households with 5+ occupants may have fewer spare financial resources than in smaller households; if this were the case, then it may imply that heat pump use is dependent on the household's financial situation. Further analysis of each of these hypotheses will follow in the final report from this study.

Table 5.2: Extended modelling of indoor temperature impacts

	(3a)	(3b)	(3c)	(3d)
Outdoor temperature ($Temp^{O}_{iht}$)	0.223***	0.224***	0.227***	0.231***
	(0.0199)	(0.0202)	(0.0204)	(0.0209)
Heat pump (HP_{iht})	2.248***	3.206***	2.000***	2.021***
	(0.573)	(0.872)	(0.730)	(0.535)
Interaction (HP_{iht}*$Temp^{O}_{iht}$)	-0.0769**	-0.0719**	-0.0772**	-0.0855**
	(0.0377)	(0.0353)	(0.0377)	(0.0389)
Light ($Light_{iht}$)	0.299***			
	(0.0690)			
Draughtiness ($Draughty_{i}$)		-1.333**		
		(0.638)		
House condition ($Condition_{i}$)			0.266	
			(0.567)	
Occupancy ($Occupants(2-4)_{i}$)				1.073**
				(0.502)
Occupancy ($Occupants(5+)_{i}$)				-0.748
				(0.652)
Day fixed effects	YES	YES	YES	YES
Hour fixed effects	YES	YES	YES	YES
House fixed effects	YES	YES	YES	YES
R^2	0.638	0.637	0.634	0.637
Number of houses	95	95	95	95
Observations	161,237	161,237	161,237	161,237

Notes: Constant included but not reported.
*Standard errors (clustered on households) in parentheses; *** p<0.01, ** p<0.05, * p<0.1.*

Tables 5.3 to 5.6 present hour-specific estimates for specification (1) excluding the hour-of-day fixed effects which are redundant given that each regression subsets on a single hour of the day. Each table shows results for six separate hourly regressions; for instance, Table 5.3 presents results for midnight through to 5 a.m., while Table 5.6 has results for 6 p.m. through to 11 p.m. The results show that there is a statistically significant increase in temperature as a result of the installed heat pump for each hour of the day.

Table 5.3: Indoor temperature impacts (Midnight – 5.00 a.m.)

	0 a.m.	1 a.m.	2 a.m.	3 a.m.	4 a.m.	5 a.m.
Outdoor temperature ($Temp^{O}_{iht}$)	0.114***	0.137***	0.154***	0.174***	0.193***	0.211***
	(0.0139)	(0.0138)	(0.0133)	(0.0138)	(0.0138)	(0.0133)
Heat pump (HP_{iht})	1.343***	1.236***	1.193***	1.188***	1.177***	1.385***
	(0.273)	(0.283)	(0.295)	(0.304)	(0.304)	(0.316)
Day fixed effects	YES	YES	YES	YES	YES	YES
Hour fixed effects	NO	NO	NO	NO	NO	NO
House fixed effects	YES	YES	YES	YES	YES	YES
R^2	0.688	0.700	0.709	0.707	0.713	0.703
Number of houses	95	95	95	95	95	95
Observations	6,715	6,651	6,648	6,654	6,656	6,691

Notes: Constant included but not reported.
*Standard errors (clustered on households) in parentheses; *** p<0.01, ** p<0.05, * p<0.1.*

Table 5.4: Indoor temperature impacts (6.00 a.m. – 11.00 a.m.)

	6 a.m.	7 a.m.	8 a.m.	9 a.m.	10 a.m.	11 a.m.
Outdoor temperature ($Temp^O_{iht}$)	0.222***	0.205***	0.196***	0.202***	0.180***	0.191***
	(0.0143)	(0.0139)	(0.0144)	(0.0186)	(0.0277)	(0.0369)
Heat pump (HP_{iht})	1.484***	1.586***	1.657***	1.613***	1.552***	1.385***
	(0.345)	(0.373)	(0.378)	(0.381)	(0.344)	(0.300)
Day fixed effects	YES	YES	YES	YES	YES	YES
Hour fixed effects	NO	NO	NO	NO	NO	NO
House fixed effects	YES	YES	YES	YES	YES	YES
R^2	0.691	0.693	0.672	0.646	0.618	0.603
Number of houses	95	95	95	95	95	95
Observations	6,675	6,688	6,686	6,694	6,697	6,712

Notes: Constant included but not reported.
*Standard errors (clustered on households) in parentheses; *** p<0.01, ** p<0.05, * p<0.1.*

Table 5.5: Indoor temperature impacts (Midday – 5.00 p.m.)

	12 p.m.	1 p.m.	2 p.m.	3 p.m.	4 p.m.	5 p.m.
Outdoor temperature ($Temp^O_{iht}$)	0.230***	0.262***	0.269***	0.282***	0.281***	0.236***
	(0.0453)	(0.0451)	(0.0415)	(0.0378)	(0.0385)	(0.0379)
Heat pump (HP_{iht})	1.203***	1.073***	1.028***	1.093***	1.107***	1.390***
	(0.258)	(0.232)	(0.212)	(0.209)	(0.206)	(0.236)
Day fixed effects	YES	YES	YES	YES	YES	YES
Hour fixed effects	NO	NO	NO	NO	NO	NO
House fixed effects	YES	YES	YES	YES	YES	YES
R^2	0.591	0.594	0.601	0.611	0.623	0.627
Number of houses	95	95	95	95	95	95
Observations	6,742	6,736	6,745	6,772	6,761	6,755

Notes: Constant included but not reported.
*Standard errors (clustered on households) in parentheses; *** p<0.01, ** p<0.05, * p<0.1.*

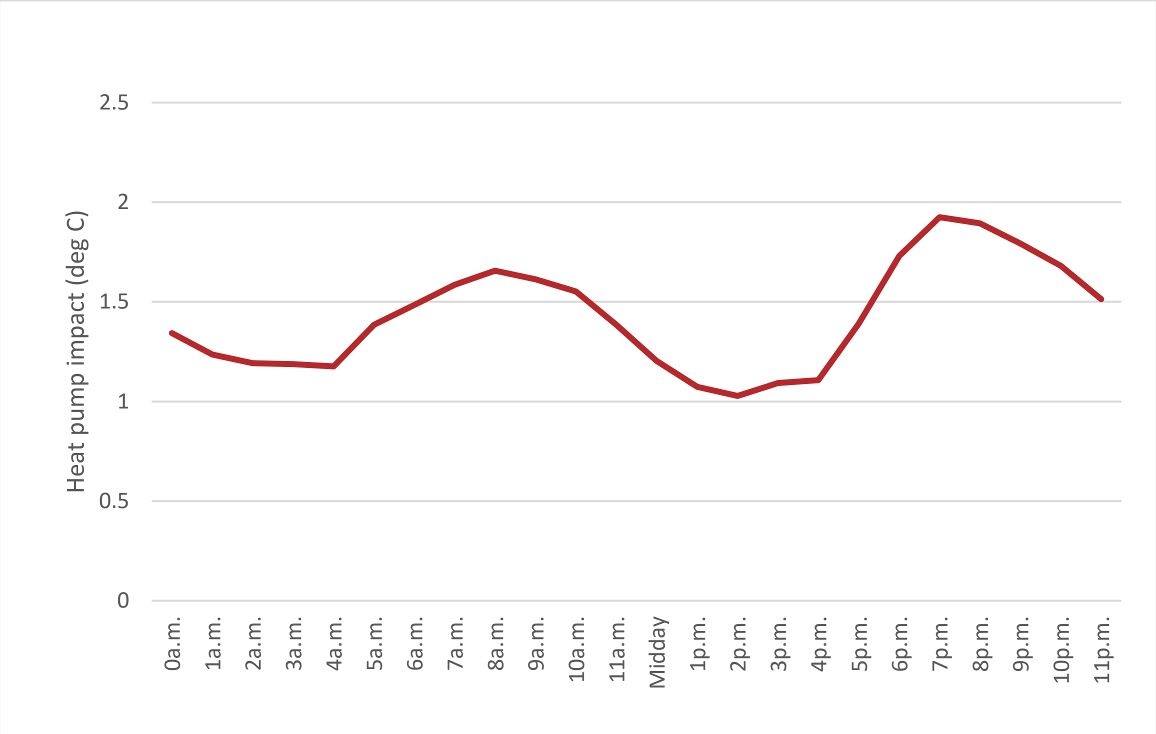
Table 5.6: Indoor temperature impacts (6.00 p.m. – 11.00 p.m.)

	6 p.m.	7 p.m.	8 p.m.	9 p.m.	10 p.m.	11 p.m.
Outdoor temperature ($Temp^O_{iht}$)	0.154***	0.089***	0.069***	0.067***	0.075***	0.091***
	(0.0356)	(0.0265)	(0.0233)	(0.0204)	(0.0185)	(0.0153)
Heat pump (HP_{iht})	1.730***	1.925***	1.895***	1.793***	1.681***	1.514***
	(0.282)	(0.282)	(0.279)	(0.272)	(0.258)	(0.267)
Day fixed effects	YES	YES	YES	YES	YES	YES
Hour fixed effects	NO	NO	NO	NO	NO	NO
House fixed effects	YES	YES	YES	YES	YES	YES
R^2	0.629	0.631	0.643	0.639	0.660	0.673
Number of houses	95	95	95	95	95	95
Observations	6,782	6,780	6,762	6,761	6,735	6,739

Notes: Constant included but not reported.
*Standard errors (clustered on households) in parentheses; *** p<0.01, ** p<0.05, * p<0.1.*

These average hourly effects of heat pump installation on indoor temperature are summarised in Figure 5.2. The figure shows that the increased temperatures (relative to the counterfactual) occur most prominently at around the morning breakfast period and the evening dinner period with the latter lingering through the evening. Nevertheless, the house is also estimated to be warmer throughout the night and in the middle hours of the day.

Figure 5.2: Average temperature impact of heat pump by hour of day



5.3.2 Indoor Relative Humidity

Table 5.7 presents results from estimating specifications (1) and (2), with indoor and outdoor relative humidity in place of indoor and outdoor temperature. The results show that indoor relative humidity is, as hypothesised, positively related to external relative humidity. Controlling for this effect, installation of a heat pump significantly reduces relative humidity in the living area. The interaction term is not significant, so we concentrate on the effect estimated using specification (1).

The reduction in relative humidity due to the installed heat pump is estimated to be equal (on average) to 6.4% of the average level of indoor relative humidity across the sample (and is equal to 35.2% of the sample standard deviation). Thus a heat pump installed through WKH not only increases the temperature but also materially reduces dampness in the living area.

Table 5.7: Modelling indoor relative humidity impacts of heat pump installation

	(1)	(2)
Outdoor humidity ($Humidity_{iht}^{O}$)	0.125***	0.128***
	(0.0117)	(0.0138)
Heat pump (HP_{iht})	-3.988***	-3.462*
	(0.758)	(1.862)
Interaction (HP_{iht}*$Humidity_{iht}^{O}$)		-0.00660
		(0.0229)
Day fixed effects	YES	YES
Hour fixed effects	YES	YES
House fixed effects	YES	YES
R^2	0.696	0.696
Number of houses	95	95
Observations	161,237	161,237

Notes: Constant included but not reported.
*Standard errors (clustered on households) in parentheses; *** p<0.01, ** p<0.05, * p<0.1.*

5.3.3 Indoor CO_2

Table 5.8 presents results from estimating specifications (1) and (2), with indoor CO_2 (measured as ppm) as the dependent variable and with both outdoor temperature and outdoor relative humidity included as explanatory (and interaction) variables. The results show that indoor CO_2 is positively related to external relative humidity and negatively related to external temperature. Heat pump installation is associated with a reduction in living area CO_2, which is especially clear in specification (1). The estimated effect of the heat pump on living area CO_2 is specification (1) is 56 ppm, which is equal to approximately one-eighth of the average CO_2 concentration in the atmosphere. Specification (2) shows that the heat pump effect on CO_2 dissipates as external temperature rises.

While we do not have strong theoretical priors on the impacts of external temperature and relative humidity on the efficacy of the heat pump with respect to CO_2, one potential explanation for these results is that household members may be more likely to leave the living area door open when a heat pump is operating than otherwise. (There is some evidence of these behaviours in the responses to the second household survey.) The greater airflow can then act to reduce CO_2 in the room. We will investigate this hypothesis further in the final study by drawing on additional information from the second household survey.

Table 5.8: Modelling indoor CO_2 impacts of heat pump installation

	(1)	(2)
Outdoor temperature ($Temp^{O}_{iht}$)	-7.729***	-9.632***
	(2.705)	(3.052)
Outdoor humidity ($Humidity^{O}_{iht}$)	2.253***	2.532***
	(0.463)	(0.628)
Heat pump (HP_{iht})	-55.57**	-83.73
	(24.05)	(75.50)
Interaction (HP_{iht}*$Temp^{O}_{iht}$)		5.770**
		(2.801)
Interaction (HP_{iht}*$Humidity^{O}_{iht}$)		-0.427
		(0.792)
Day fixed effects	YES	YES
Hour fixed effects	YES	YES
House fixed effects	YES	YES
R^2	0.885	0.885
Number of houses	95	95
Observations	161,237	161,237

Notes: Constant included but not reported.
*Standard errors (clustered on households) in parentheses; *** p<0.01, ** p<0.05, * p<0.1.*

5.4 Summary of Indoor Environmental Impacts

The design of the evaluation, in conjunction with the (unintended) randomisation of heat pump installation dates across houses, has enabled clear results to emerge regarding the impacts of WKH heat pump installation on indoor environmental outcomes over winter and early spring months. Relative to the counterfactual of having no heat pump in the living area, installation of a WKH heat pump is estimated to increase living area temperature by 1.4°C on average across the day.

Gains in heat are more pronounced when outdoor temperatures are low; for instance, relative to the counterfactual, a heat pump is estimated to add 2.3°C to living area temperature when the outdoor temperature is 0°C. Time of day is also a factor, with greater increases in average temperature in the morning and evening periods when homes are more likely to be occupied.

One finding that may have importance for the WKH programme is that the efficacy of the heat pump on temperature is significantly curtailed when a house is draughty. Draught-stopping within houses may therefore be a particularly important complement to heat pump installation. In addition, we find that installation of a heat pump reduces relative humidity in the living area, so the overall effect of heat pump installation is to have a warmer, drier living area in a treated house. CO_2 in the living area is also reduced following heat pump installation.

The results in this section provide clear evidence that installation of a WKH heat pump improves environmental outcomes within the living area. In the next section, we test how these beneficial outcomes relate to changes in electricity use by the house.

6: Modelling the Electricity Use Impacts of Receiving a Heat Pump

6.1 Data Analysis

A housing retrofit such as installation of a heat pump may result in either a rise or a fall in a household's electricity use depending on prior heating options, the relative efficiency of the heat pump and the use of the heat pump by the household.[29] Here, we analyse how installation of a heat pump in WKH houses has affected household electricity use.

Datasets from the previous section have been used in the analysis of electricity use, with the addition of:

- half hourly electricity consumption data collected from individual energy providers through the Electricity Authority transfer hub (*see section 2*);
- an *electric heater* dummy variable to denote houses that used electric heating in the living area prior to their heat pump being installed. Data for this variable was collected through the baseline household survey.

6.2 Modelling Approach

As with the previous section which examined indoor environmental outcomes, our modelling approach is based on a 'difference-in-difference' (DiD) analysis assessing the impact that installation of a heat pump has on electricity consumption.

To ensure that the analysis is comparable to that conducted for indoor environmental outcomes, we adopt specifications based on those in the previous section. We hypothesise that over and above the impacts of day, hour-of-day and house fixed effects, electricity use will reflect the outdoor temperature for the house. This hypothesis reflects prior findings that a substantial portion of household electricity use is attributed to space heating, especially in winter months.[30] Consistent with the previous analysis, we estimate specifications (4) and (5) in which electricity use in each hour is the dependent variable:

$$Electricity_{iht} = \beta_0 + \beta_1 Temp_{iht}^O + \beta_2 HP_{iht} + \mu_t + \mu_h + \mu_i + \varepsilon_{iht} \quad (4)$$

$$Electricity_{iht} = \beta_0 + \beta_1 Temp_{iht}^O + \beta_2 HP_{iht} + \beta_3 HP_{iht} Temp_{iht}^O + \mu_t + \mu_h + \mu_i + \varepsilon_{iht} \quad (5)$$

where: $Electricity_{iht}$ is electricity use (measured as kilowatts, kW) of house *i* during hour *h* on day *t*; and other variables are as described in section 5.

We have tested extensions of specification (5) to include each of the additional variables that were added to the temperature equation, plus a further extension to include a variable indicating whether the house previously had an electric heater in the living area. None of the additional variables was significant at the 5% level ($p \leq 0.05$), so these extended results are not presented here. In addition to estimating specifications (4) and (5), we also estimate specification (4) for each hour as in the temperature estimates in section 5.

6.3 Results

Table 6.1 presents the estimates from specifications (4) and (5). The results show that, as hypothesised, electricity use rises as external temperatures fall. In specification (4), we find no significant overall change in electricity use associated with heat pump installation (although the estimated parameter is negative – i.e., a non-significant overall reduction in electricity consumed). Once we include the interaction effect, we do find significant coefficients relating to electricity use with installation of a heat pump. Electricity use falls (relative to the counterfactual) at low temperatures: for instance, at an outdoor temperature of 0^{o}C hourly electricity use falls by 0.149 kW, with savings diminishing as outdoor temperature rises. At the mean outdoor temperature, electricity savings are estimated at an average of 0.056 kW, while at 18^{o}C the electricity saving is approximately zero (a 0.005 kW increase).

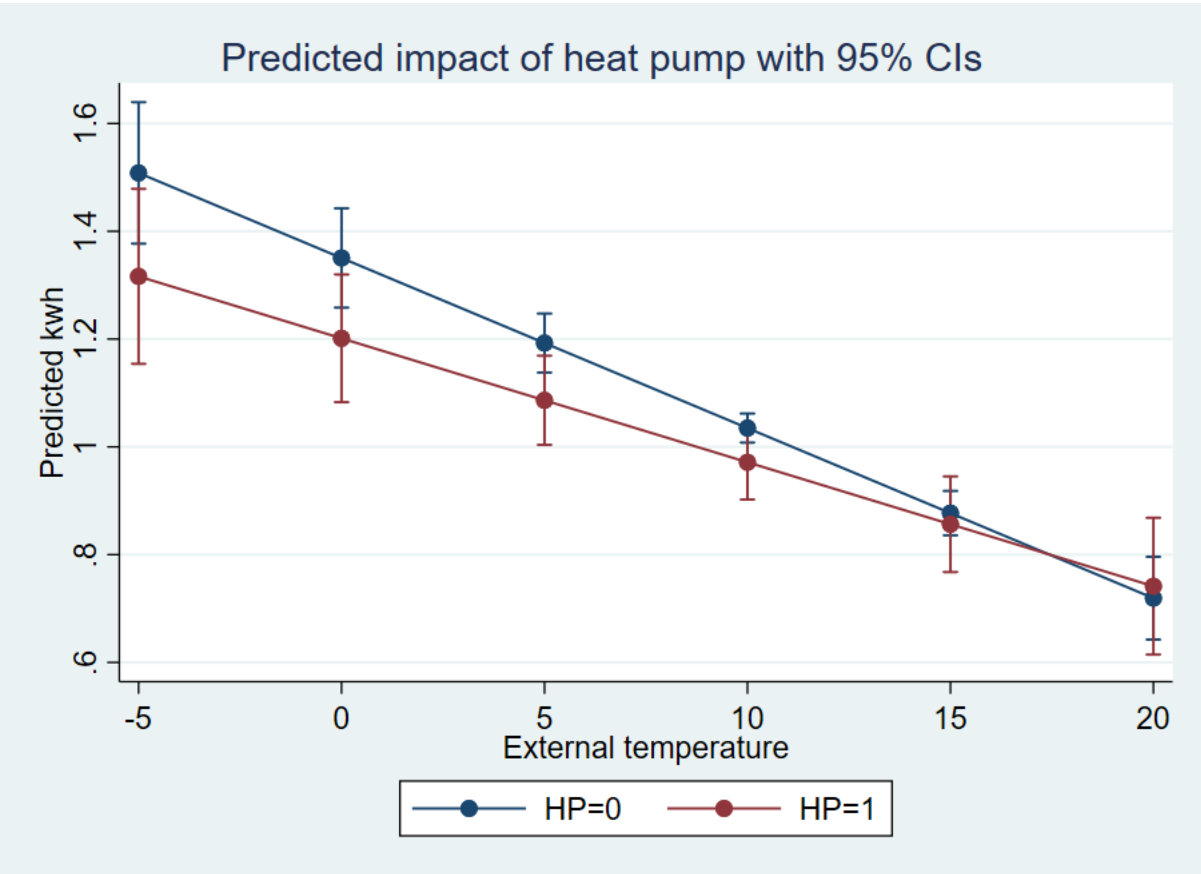
Figure 6.1 depicts estimated hourly electricity use across outdoor temperatures from -5^{o}C to 20^{o}C for a house with a WKH heat pump installed (HP=1) relative to the same house without the heat pump (HP=0). Again, the 95% confidence intervals (CI) are shown. At an external temperature of 0^{o}C, the household is estimated to use approximately 1.35 kW of electricity without a heat pump fitted and 1.2 kW with a heat pump installed. The figure shows that the estimated difference in electricity use converges as external temperature rises. However, it is also the case that the confidence intervals overlap throughout the external temperature range so – while indicative – the evidence is not conclusive that the household saves electricity with a heat pump fitted when results are estimated across all hours of the day.

Table 6.1: Modelling electricity use impacts of heat pump installation

	(4)	(5)
Outdoor temperature ($Temp^{O}_{iht}$)	-0.0296***	-0.0316***
	(0.00377)	(0.00401)
Heat pump (HP_{iht})	-0.0542	-0.149**
	(0.0491)	(0.0643)
Interaction (HP_{iht}*$Temp^{O}_{iht}$)		0.00856*
		(0.00470)
Day fixed effects	YES	YES
Hour fixed effects	YES	YES
House fixed effects	YES	YES
R^2	0.344	0.344
Number of houses	58	58
Observations	150,163	150,163

Notes: Constant included but not reported.
*Standard errors (clustered on households) in parentheses; *** p<0.01, ** p<0.05, * p<0.1.*

Figure 6.1: Modelled electricity use with and without a WKH heat pump



Tables 6.2 – 6.5 present the 24 separate hour-of-day estimates for electricity use based on specification (4). These tables indicate that for most hours of the day, there is no statistically significant change in household electricity use; however, three hours (10a.m., 7p.m. and 9p.m.)

show statistically significant electricity savings. The average hourly electricity use impacts associated with heat pump installation, as summarised in Figure 6.2, show consistent reductions in electricity use from 5 p.m. to 9 p.m. compared with the counterfactual.

Overall, the electricity modelling results indicate that heat pump installation may be associated with electricity savings during winter and early spring months for houses treated within the WKH programme (or, at worst, no increase in electricity consumption). Electricity savings appear to be greatest (relative to the counterfactual) when external temperatures are low and in the evening hours.

Table 6.2: Electricity use impacts (Midnight – 5.00 a.m.)

	0 a.m.	1 a.m.	2 a.m.	3 a.m.	4 a.m.	5 a.m.
Outdoor temperature ($Temp^O_{iht}$)	-0.010**	-0.010***	-0.008**	-0.007**	-0.011***	-0.016***
	(0.0039)	(0.0029)	(0.0036)	(0.0030)	(0.0025)	(0.0048)
Heat pump (HP_{iht})	-0.095	-0.022	0.012	0.026	-0.007	0.104
	(0.0590)	(0.0442)	(0.0439)	(0.0434)	(0.0481)	(0.0700)
Day fixed effects	YES	YES	YES	YES	YES	YES
Hour fixed effects	YES	YES	YES	YES	YES	YES
House fixed effects	YES	YES	YES	YES	YES	YES
R^2	0.663	0.602	0.458	0.400	0.429	0.506
Number of houses	58	58	58	58	58	58
Observations	6,269	6,259	6,257	6,259	6,257	6,254

Notes: Constant included but not reported.
*Standard errors (clustered on households) in parentheses; *** p<0.01, ** p<0.05, * p<0.1.*

Table 6.3: Electricity use impacts (6.00 a.m. – 11.00 a.m.)

	6 a.m.	7 a.m.	8 a.m.	9 a.m.	10 a.m.	11 a.m.
Outdoor temperature ($Temp^O_{iht}$)	-0.023***	-0.022***	-0.020***	-0.028***	-0.043***	-0.061***
	(0.0056)	(0.0056)	(0.0062)	(0.0086)	(0.0092)	(0.0104)
Heat pump (HP_{iht})	0.045	0.041	-0.018	-0.095	-0.170**	-0.072
	(0.0724)	(0.0856)	(0.0851)	(0.0725)	(0.0800)	(0.0781)
Day fixed effects	YES	YES	YES	YES	YES	YES
Hour fixed effects	YES	YES	YES	YES	YES	YES
House fixed effects	YES	YES	YES	YES	YES	YES
R^2	0.451	0.460	0.456	0.500	0.486	0.380
Number of houses	58	58	58	58	58	58
Observations	6,258	6,257	6,257	6,256	6,257	6,255

Notes: Constant included but not reported.
*Standard errors (clustered on households) in parentheses; *** p<0.01, ** p<0.05, * p<0.1.*

Table 6.4: Electricity use impacts (Midday – 5.00 p.m.)

	12 p.m.	1 p.m.	2 p.m.	3 p.m.	4 p.m.	5 p.m.
Outdoor temperature ($Temp^{O}_{iht}$)	-0.068***	-0.074***	-0.069***	-0.067***	-0.069***	-0.075***
	(0.0093)	(0.011)	(0.011)	(0.011)	(0.013)	(0.014)
Heat pump (HP_{iht})	-0.030	-0.028	0.018	-0.003	0.015	-0.113
	(0.0801)	(0.0791)	(0.0754)	(0.0816)	(0.1020)	(0.1070)
Day fixed effects	YES	YES	YES	YES	YES	YES
Hour fixed effects	YES	YES	YES	YES	YES	YES
House fixed effects	YES	YES	YES	YES	YES	YES
R^2	0.349	0.336	0.338	0.341	0.375	0.460
Number of houses	58	58	58	58	58	58
Observations	6,259	6,259	6,256	6,259	6,252	6,261

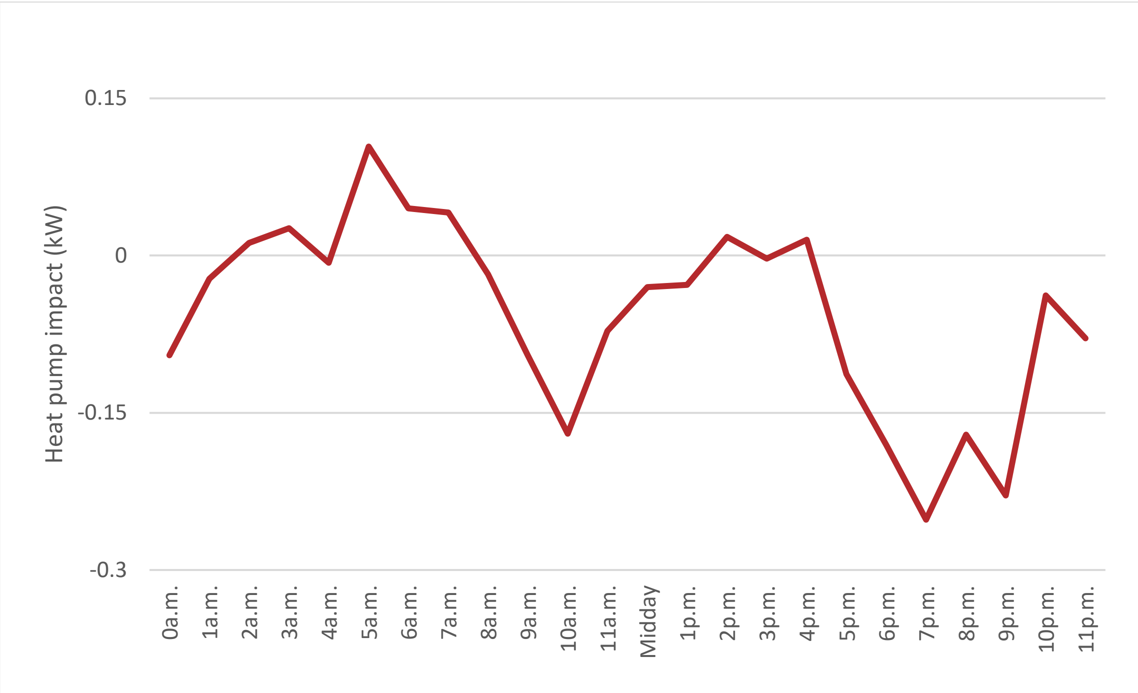
Notes: Constant included but not reported.
*Standard errors (clustered on households) in parentheses; *** p<0.01, ** p<0.05, * p<0.1.*

Table 6.5: Electricity use impacts (6.00 p.m. – 11.00 p.m.)

	6 p.m.	7 p.m.	8 p.m.	9 p.m.	10 p.m.	11 p.m.
Outdoor temperature ($Temp^{O}_{iht}$)	-0.072***	-0.044***	-0.041***	-0.028***	-0.023***	-0.014**
	(0.0137)	(0.0135)	(0.0085)	(0.0075)	(0.0054)	(0.0053)
Heat pump (HP_{iht})	-0.181	-0.252*	-0.171	-0.229*	-0.038	-0.079
	(0.1220)	(0.1270)	(0.1150)	(0.1250)	(0.0835)	(0.0592)
Day fixed effects	YES	YES	YES	YES	YES	YES
Hour fixed effects	YES	YES	YES	YES	YES	YES
House fixed effects	YES	YES	YES	YES	YES	YES
R^2	0.457	0.494	0.505	0.584	0.533	0.606
Number of houses	58	58	58	58	58	58
Observations	6,262	6,253	6,253	6,252	6,252	6,250

Notes: Constant included but not reported.
*Standard errors (clustered on households) in parentheses; *** p<0.01, ** p<0.05, * p<0.1.*

Figure 6.2: Average electricity use impact of heat pump by hour of day



We note two caveats here surrounding the electricity estimates. First, issues experienced in gathering data on electricity consumption from some electricity companies mean that our sample of houses (58) is smaller for this analysis than it is for the environmental monitoring analysis (95). We anticipate that we will be able to enlarge the sample for the final report from this study as difficulties in accessing the electricity data are resolved. Second, our estimates do not include any savings in gas use that result from heat pump installation. As noted in section 3, 18 houses used gas heating in the living area prior to the heat pump being installed. We expect that gas use will have been reduced as a result, and these reductions in gas use will magnify the amount of estimated energy savings following heat pump installation.

7: Synthesis and Future Work

7.1 Study Population

These interim results are based on 127 houses that applied to receive a heat pump under the programme through 2021. The WKH eligibility criteria require applicant households to be owner-occupiers and to reside in either NZDep 8-10 (more deprived) areas or have a homeowner with a Community Services Card. Since the 2018 census, upon which the deprivation deciles were based, continued increases in house prices may have resulted in demographic changes within the deprivation deciles – particularly for owner-occupied properties - as first-time home buyers seek more affordable areas in which to live. In addition, Community Services Card holders include asset rich, cash poor New Zealanders who purchased properties before the steep rise in house prices from 2000 onwards. Therefore, despite the restrictions on eligibility for the WKH heat pump subsidy, the houses included in the evaluation cover a diverse set of house types and households.

7.2 Key Results

Analysis of the household and house condition surveys, indoor environmental readings and electricity use indicate a comprehensive set of benefits achieved through installation of heat pumps within the WKH programme. Key findings from the three components of the study are listed below.

7.2.1 Household Surveys

Analyses of the household surveys show that households with a WKH heat pump reported a range of improvements both in terms of indoor comfort and heating expenditures, though we again caveat these findings by noting that the first survey was conducted during winter and the second survey was conducted in the spring. Key survey results included:

- The proportion of households that reported ever having restricted heating due to cost fell from 80% to 21% after a heat pump was installed.
- The proportion of houses reported ever having condensation on windows in their living room or bedroom fell from 95% to 30% after the heat pump was installed.
- The proportion of houses that reported ever having damp in the living room or bedroom fell from 55% to 12% after having the heat pump installed.
- 82% of households said their house was much more comfortable or more comfortable from having a heat pump.
- 79% of respondents said they were more satisfied with their home after having the heat pump installed.

Anecdotal feedback noted improvements in both physical and mental health, particularly around a reduction in stress from households knowing that they had an affordable means of keeping the home warm. These survey comments are consistent with the findings from the indoor environmental analysis and the electricity use analysis so provide a useful triangulation on the results derived from the quantitative data. Further analysis over a second winter, which will be included in the final report of this study, will help to verify whether these beneficial impacts are experienced over successive winters.

7.2.2 Indoor Environmental Impacts

Analysis of the indoor environmental impacts of fitting a heat pump finds that over winter and early spring months:

- Living area temperatures increase with heat pump installation by an average of 1.4^{o}C relative to a house without a heat pump fitted under WKH.
- The indoor temperature gains are highest when outdoor temperatures are low.
- Indoor temperature gains are estimated to be greatest at ‘breakfast’ time (approximately 1.7^{o}C) and ‘dinner/evening’ time (approximately 1.9^{o}C).
- Draughty houses experience lower gains in indoor temperature following heat pump installation.
- Installation of a heat pump reduces indoor relative humidity.
- Installation of a heat pump also appears to reduce CO_2 in the living area.

7.2.3 Electricity Use

Analysis of electricity use in relation to the WKH programme, while not as clear-cut in statistical terms, indicates that:

- Electricity use falls (relative to the counterfactual) in a house fitted with a heat pump.
- The electricity savings are greatest when external temperatures are low.
- Electricity savings are most pronounced in the evening hours.

7.2.4 Summary of Findings

Together these findings indicate that installation of a heat pump through the WKH programme results in households that are more comfortable in their homes, with living areas that are materially warmer and drier. These benefits occur despite the treated households reducing (or at least not increasing) their electricity use. In addition, some households will have saved on gas use, a factor that is not incorporated into our study. Thus, the comfort, temperature and dampness benefits from a heat pump have been achieved at the same time as energy use is likely to have been reduced.

7.3 Strengths, Limitations, and Future Work

These interim results come from an evaluation that is more comprehensive than any prior evaluation of heat pump use in New Zealand or elsewhere. Strengths of the study include the incorporation of linked household survey data (taken both before and after heat pump installation), a house survey, and quantitative data on indoor environmental quality and on electricity consumption. An unplanned strength of the study was the randomisation of heat pump treatment due to COVID-19 and related supply chain issues that affected whether or not a house received a heat pump and, if so, randomised the timing of installation. This randomisation resulted in a natural experiment which we have leveraged in our statistical work.

The study also has a number of limitations. While COVID-19 (and especially the Delta variant community outbreak) assisted with randomisation, it led to a reduction in the sample of households surveyed relative to planned numbers. It also led to the follow-up survey having to be conducted remotely by telephone. While this was achieved successfully in a technical sense, it may have resulted in some shading of respondents' answers to certain personal questions, such as when answering questions about their own health and wellbeing. The delay in the second survey also meant that respondents answered that survey in mid-late spring (October/November) whereas the quantitative environmental and electricity data pertained to winter and early spring. Technical difficulties meant that remote collection of energy flow data from heat pumps could not be used in the analysis. Furthermore, differences in specifications and data quality between energy companies resulted in some households having to be dropped from the analysis of electricity consumption.

Many of these limitations will be rectified in the second year of the evaluation which is due to run through to Spring 2022. For instance, we will be able to measure electricity flow through the heat pump using an alternative energy flow meter, and we anticipate accessing a wider set of electricity records for survey and control houses to expand the electricity use analysis.

Extension of the evaluation through to Spring 2022 will enable deeper analysis of the effects of the programme both through a summer and through another winter, with the opportunity also to add extra depth to the analysis of the first winter's data. In particular, we expect to incorporate more information from the baseline household and house surveys into analyses of indoor environmental outcomes and household electricity use. In addition, with a winter clear of further lockdowns, we expect to increase the confidence we can place on the health and wellbeing impacts for householders of installing a heat pump.

The results of all facets of the study will be brought together in a cost benefit analysis of the WKH programme in our final report in late 2022. The results of this further analysis will shed even more light on the impacts of installing a heat pump in households eligible for the WKH scheme.

Appendix

Appendix 1: Demographic Tables from Section 3: Baseline Survey

Table A.1.1 Socio-demographic characteristics of Study households at baseline

Socio demographic characteristic	**Number of households**				**Percentage of each category**			
	Auckland and Waikato	Christchurch	Wellington	Total	Auckland and Waikato	Christchurch	Wellington	Total
Age								
Pre-school (<5 years)	24	7	24	55	13.9	12.1	22.6	16.3
School age (5-17 years)	19	6	15	40	11.0	10.3	14.2	11.9
Adult (18-64 years)	95	30	45	170	54.9	51.7	42.5	50.4
Older adult (≥65 years)	30	14	19	63	17.3	24.1	17.9	18.7
Did not state	5	1	3	9	2.9	1.7	2.8	2.7
Ethnicity*								
New Zealand European	51	55	48	154	28.0	96.5	49.0	45.7
Māori	16	2	22	40	8.8	3.5	22.4	11.9
Pacific peoples	89	1	22	112	48.9	1.8	22.4	33.2
Asian	25	4	9	38	13.7	7.0	9.2	11.3
Middle Eastern	3	0	1	4	1.6	0.0	1.0	1.2
Did not state	1	0	0	1	0.6	0.0	0.0	0.3
Gender								
Female	91	27	53	171	50.0	47.4	54.0	50.7
Gender neutral	1	1	1	3	0.6	1.8	0.91.0	0.9
Male	90	29	44	163	49.4	50.9	45.0	48.4
Work status								
Homemaker	4	1	4	9	2.2	1.8	4.1	2.7
Unable to work (medical)	4	2	0	6	2.2	3.5	0.0	1.8
Seeking work	7	0	4	11	3.8	0.0	4.1	3.3
Pre-schooler	9	2	6	17	4.9	3.5	6.1	5.0
Student	39	10	21	70	21.4	17.5	21.4	20.8
Working	80	23	45	148	44.0	40.4	45.9	43.9
Retired	32	15	18	65	17.6	26.3	18.4	19.3
Did not state	7	4	0	11	3.8	7.0	0.0	3.3

Note: ** Ethnicity is not prioritised.*

Table A.1.2 Internal condition of houses in the Study

House condition	Number				Percentage of each category			
	Auckland and Waikato	Christchurch	Wellington	Total	Auckland and Waikato	Christchurch	Wellington	Total
Too cold in winter								
Always	21	5	4	30	32.3	20.0	10.8	23.6
Often	19	9	14	42	29.2	36.0	37.8	33.1
Sometimes	15	7	15	37	23.1	28.0	40.5	29.1
Never	2	3	3	8	3.1	12.0	8.1	6.3
Don't know	6	1	1	8	9.2	4.0	2.7	6.3
Didn't answer	2	0	0	2	3.1	0.0	0.0	1.6
Limit heating due to cost								
Always	10	5	7	22	15.4	20.0	18.9	17.3
Often	10	3	5	18	15.4	12.0	13.5	14.2
Sometimes	28	9	14	51	43.1	36.0	37.8	40.2
Rarely	4	1	3	8	6.2	4.0	8.1	6.3
Never	10	6	7	23	15.4	24.0	18.9	18.1
Don't know	3	1	1	5	4.6	4.0	2.7	3.9
Condensation on living room windows								
Always	23	8	13	44	35.4	32.0	35.1	34.6
Often	15	8	10	33	23.1	32.0	27.0	26.0
Sometimes	24	8	11	43	36.9	32.0	29.7	33.9
Never	3	1	3	7	4.6	4.0	8.1	5.5
House dampness								
Always	4	1	4	9	6.2	4.0	10.8	7.1
Often	10	3	4	17	15.4	12.0	10.8	13.4
Sometimes	24	9	13	46	36.9	36.0	35.1	36.2
Never	24	12	16	52	36.9	48.0	43.2	40.9
Don't know	3	0	0	3	4.6	0.0	0.0	2.4
Mould in living or bedroom								
Always	3	0	2	5	4.6	0.0	5.4	3.9
Often	10	1	4	15	15.4	4.0	10.8	11.8
Sometimes	21	12	16	49	32.3	48.0	43.2	38.6
Never	27	12	14	53	41.5	48.0	37.8	41.7
Don't know	4	0	1	5	6.2	0.0	2.7	3.9

Table A.1.3: Household characteristics of Study participants

Household characteristic	Number				Percentage of each category			
	Auckland and Waikato	Christchurch	Wellington	Total	Auckland and Waikato	Christchurch	Wellington	Total
Number of people								
1	10	7	11	28	15.4	26.9	29.7	21.9
2	20	11	9	40	30.8	42.3	24.3	31.3
3	15	5	5	25	23.1	19.2	13.5	19.5
4	15	1	5	21	23.1	3.8	13.5	16.4
5	3	1	3	7	4.6	3.8	8.1	5.5
6	2	0	2	4	3.1	0.0	5.4	3.1
7	0	1	1	2	0.0	3.8	2.7	1.6
8	0	0	1	1	0.0	0.0	2.7	0.8
Length of residence								
Less than six months	11	1	6	18	16.9	4.0	16.2	14.2
Six to twelve months	1	2	2	8	1.5	8.0	5.4	3.9
One to two years	6	1	5	12	9.2	4.0	13.5	9.4
More than two years	47	21	24	92	72.3	84.0	64.9	72.4
House size								
less than 100m^2	61	1	12	74	95.3	4.0	32.4	58.7
100m^2 to 200m^2	2	18	22	42	3.1	72.0	59.5	33.3
more than 200m^2	1	6	3	10	1.6	24.0	8.1	7.9

Table A.1.4: Sufficient income to meet needs for Study participants

Sufficient income to meet needs?	Number				Percentage			
	Auckland and Waikato	Christchurch	Wellington	Total	Auckland and Waikato	Christchurch	Wellington	Total
More than enough	2	0	6	8	3.1	0.0	16.2	6.3
Enough	31	11	15	57	47.7	44.0	40.5	44.9
Just enough	26	9	11	46	40.0	36.0	29.7	36.2
Not enough	5	4	5	14	7.7	16.0	13.5	11.0
Don't know	1	1	0	2	1.5	4.0	0.0	1.6

Table A.1.5: Life satisfaction by area

Life satisfaction	Number				Percentage			
	Auckland and Waikato	Christchurch	Wellington	Total	Auckland and Waikato	Christchurch	Wellington	Total
0: Totally dissatisfied	0	0	0	0	0.0	0.0	0.0	0.0
1	0	0	0	0	0.0	0.0	0.0	0.0
2	1	0	0	1	1.5	0.0	0.0	0.8
3	0	2	0	2	0.0	7.7	0.0	1.6
4	1	2	0	3	1.5	7.7	0.0	2.4
5	4	0	2	6	6.2	0.0	5.6	4.7
6	4	2	2	8	6.2	7.7	5.6	6.3
7	12	10	12	34	18.5	38.5	33.3	26.8
8	15	3	14	32	23.1	11.5	38.9	25.2
9	13	3	4	20	20.0	11.5	11.1	15.7
10: Totally satisfied	13	4	2	19	20.0	15.4	5.6	15.0
Don't know	2	0	0	2	3.1	0.0	0.0	1.6

Table A.1.6: Answers to wellbeing questions based on the two weeks prior to the survey

Wellbeing indicators	Always	Most of the time	More than half the time	Less than half the time	Sometimes	Never	Don't know
	Number						
How often have you felt cheerful and in good spirits?	6	78	26	8	6	0	3
How often have you felt calm and relaxed?	5	60	41	11	8	0	2
How often have you felt active and vigorous?	6	40	38	20	16	5	2
How often have you woken up feeling fresh and rested?	4	43	37	20	17	4	2
How often have you felt that your daily life has been filled with things that interest you?	7	55	37	9	16	1	2
	Percentage						
How often have you felt cheerful and in good spirits?	4.7	61.4	20.5	6.3	4.7	0.0	2.4
How often have you felt calm and relaxed?	3.9	47.2	32.3	8.7	6.3	0.0	1.6
How often have you felt active and vigorous?	4.7	31.5	29.9	15.7	12.6	3.9	1.6
How often have you woken up feeling fresh and rested?	3.1	33.9	29.1	15.7	13.4	3.1	1.6
How often have you felt that your daily life has been filled with things that interest you?	5.5	43.3	29.1	7.1	12.6	0.8	1.6

Appendix 2: Tables Comparing Results from Section 4: Baseline and Follow-Up Surveys

Table A.2.1: Restricting heating due to cost after a heat pump was installed compared to baseline

Restricting heating due to cost before heat pump installed		**Restricting heating due to cost after heat pump installed**					
		Always	**Often**	**Sometimes**	**Rarely**	**Never**	**Total**
Always	number	0	2	2	0	10	14
	percentage	0.0	14.3	14.3	0.0	71.4	15.4
Often	number	1	2	1	0	11	15
	percentage	6.7	13.3	6.7	0.0	73.3	16.5
Sometimes	number	0	0	3	2	29	34
	percentage	0.0	0.0	8.8	5.9	85.3	37.4
Rarely	number	0	0	0	0	5	5
	percentage	0	0	0	0	100	5.5
Never	number	0	1	2	0	15	18
	percentage	0.0	5.6	11.1	0.0	83.3	19.8
Don't know	number	0	1	0	2	2	5
	percentage	0.0	20.0	0.0	40.0	40.0	5.5
Total	number	1	6	8	4	72	91
	percentage	1.1	6.6	8.8	4.4	79.1	

Table A.2.2: Condensation in the living area after a heat pump was installed compared to baseline

Condensation before heat pump install		**Condensation after heat pump install**					
		Always	**Often**	**Sometimes**	**Never**	**Don't know**	**Total**
Always	number	0	1	11	17	0	29
	percentage	0	3.5	37.9	58.6	0	31.9
Often	number	0	0	7	18	0	25
	percentage	0	0	28	72	0	27.5
Sometimes	number	1	0	5	24	1	31
	percentage	3.2	0	16.1	77.4	3.2	34.1
Never	number	0	0	1	5	0	6
	percentage	0	0	16.7	83.3	0	6.6
Total	number	1	1	24	64	1	91
	percentage	1.1	1.1	26.4	70.3	1.1	

Table A.2.3: Self reported health after a heat pump was installed compared to baseline

Self reported health before heat pump installed*		Self reported health after heat pump installed					
		Excellent	Very good	Good	Fair	Poor	Total
Excellent	number	2	3	1	0	0	6
	percentage	33.3	50.0	16.7	0.0	0.0	6.6
Very good	number	2	26	3	5	0	36
	percentage	5.6	72.2	8.3	13.9	0.0	39.6
Good	number	3	12	13	2	0	30
	percentage	10.0	40.0	43.3	6.7	0.0	33.0
Fair	number	2	4	2	5	0	13
	percentage	15.4	30.8	15.4	38.5	0.0	14.3
Poor	number	0	0	0	1	2	3
	percentage	0.0	0.0	0.0	33.3	66.7	3.3
Don't know	number	0	3	0	0	0	3
	percentage	0.0	100.0	0.0	0.0	0.0	3.3
Total	number	9	47	19	14	2	91
	percentage	9.9	51.6	20.9	15.4	2.2	

Note: restricted to households with a heat pump at follow-up only.

Table A.2.4: Damp in the living area or bedroom after a heat pump was installed compared to baseline

Damp in living room or bedroom before heat pump install		Damp in living room or bedroom after heat pump install					
		Always	Often	Sometimes	Never	Don't know	Total
Always	number	0	0	2	4	0	6
	percentage	0.0	0.0	33.3	66.7	0.0	6.6
Often	number	0	1	2	10	0	13
	percentage	0.0	7.7	15.4	76.9	0.0	14.3
Sometimes	number	0	1	3	22	1	27
	percentage	0.0	3.7	11.1	81.5	3.7	29.7
Never	number	0	0	1	40	0	41
	percentage	0.0	0.0	2.4	97.6	0.0	45.1
Don't know	number	0	0	1	3	0	4
	percentage	0.0	0.0	25.0	75.0	0.0	4.4
Total	number	0	2	9	79	1	91
	percentage	0.0	2.2	9.9	86.8	1.1	

Appendix 3: Comments About Changes to Household Comfort and Satisfaction with the Home Following a Heat Pump being Installed

At least when it's cold, we have the option of turning it on.

Before we had the heat pump we had a living space that was impossible to heat so it was always cold. Now we can heat up the whole space really quickly and it has made being in the space much more pleasant.

Being in the living area, where we spend most time, instead of having to wrap up, we can enjoy the space at a nice temperature. It makes the space more pleasant to be in.

Can stay warm if I need to.

Constant comfy temperature, no need to wear jacket in the house

Cosy and efficient heating

Could not previously be in the lounge because it was too cold. Grandchildren would not visit because of this. Now they do

Didn't use oil heater

Don't use any other heater the whole outer is warmer

Easy relaxing warm very nice convenient

Having the ability to control temperature. We have used both the heating and the cooling and it's great knowing that using it is not a ridiculous price.

Heats up the house nicely when its on

House is consistently a reasonable temperature and it is also much drier.

I can keep the whole house warm. Don't get cold when I need to go to the bathroom. I enjoy being able to turn it on and make myself comfortable

I had a long wait and was as cold as when I flatted in Dunedin as a student. It was bone chilling, so made a huge difference.

I have only just got the heat pump and am still learning how to use it, I should really read the instructions!

I think it will when I get to use it.

Instant heat and less worry about having a gas heater and nice to control the temperature.

Instant heat room warms up within 15 minutes. Don't run it too hot, just comfortable. Pretty uncomfortable before the heat pump was fitted as the fireplace was decommissioned. I went to bed early then, to keep warm.

Instant heat which we love. The kids love it. We also like the cooling option on hot days as the lounge gets very hot on sunny days.

It has made the living area a bit more comfortable but I haven't had it long enough, and through a winter to really answer.

I do find it has a cold draught that points down, as it's right above where I sit. I have a blanket over my legs. I wish it would angle warm air down because that's why I turn it on.

It keeps the room warmer and drier and has meant we no longer get condensation on the windows.

It made the house warm

It's amazing, it heats the house way better than before, and I also have Wi-fi with it, so can turn it on when I'm in bed. Next winter, I can see that it will be great - I'll be able to turn it on the way home. I can also see the temperature in my house.

It's really good.

it's fast, and heats up the room so not sitting around and waiting to get warm. It's instantaneous.

It increased comfort greatly. Especially like how the heat spreads through the house compared to the little old heater that only heated one room

It's just so much warmer, it's easier to heat. and it's pretty instant

It's made the air nice and snug around me, because it flows into the other room, it makes it more comfortable in there too. I'm using my lounge much more, and shut all the doors off. Now I can sit in my lounge and stay there longer, it's much more comfortable.

It's nice when we have used it but haven't used it often

It's quicker to heat and you get a good temperature.

Keeps it warm and very easy to control and heats up quickly

Living area is much warmer and new heat pump heats quickly and no condensation

Make it warmer and hopefully my electricity bills will go down. Also more convenient as I like the instant heat as previously I had a night storage heater.

Made lockdown cozier

More even temperature for longer periods throughout the day

More recently it's not freezing. We have used it on cool to make it less humid and damp. Haven't really used the heat function yet

My gas heater didn't dry my eyes out. Old heater was quite good but not flued so hence replaced with a heat pump.

Notice it is drier and in the evening when we are heating we don't get headaches that we used to get from the gas. Really noticed it when we started using the heat pump - that and the condensation going. Unflued gas heater before.

On hotter days can cool rooms down and keeps air clearer

Prior to moving in, there was no insulation or heating and there was a condemned fireplace. It was a horrible home. In the first year, we insulated the whole home, and put in the heat pump and now we're really, really good.

Prior to this heat pump being installed, we had used a very old on - it was was 12 years old, This one is much more efficient,

Similar to using the old heater

Son used to have itchy skin and history of asthma, it is better with the heat pump

Spreads heat throughout whole house, no need to heat only one room

The heat is instant and dry. No longer have problems with condensation on windows and dampness. The house is more comfortable as the family are no longer worried about high power bills so turn the heat pump on whenever they feel cold.

The heat is instant and it heats the whole house. We used to wrap ourselves in blankets

The insulation has really been the thing that's changed the house, and we've hardly had to use the heat pump. However, when we have used it, it's been quicker to heat the house and make it more comfortable.

The living room is warmer and heats up more quickly.

Toward the back of the house there's natural lighting

Warmer (18)

Warmer and dry

Warmer more relaxing, new HP powerful enough to heat more of house, reduced condensation significantly, less use of oil heaters and dehumidifier

We kind of have to say we love it!

We use the heat pump when we have guests or family over, because they like living in the tropics.

We used to get runny nose now its better

We used to use a little heater that did nothing, even on full bore. The HP has now taken away the cold. Can turn it on and quite often it gets too hot so will adjust.

It's also made the house quieter, without heaps of heaters blasting. The heaters we have on a lower setting now.

We used to use it every morning but that's changed now

When we need the heating it’s really quick. When you have been out in the cold you can come in and turn it on and it warms up really quickly.

Yes - when the family and friends used to visit, they would call the house 'the freezer'. Now they no longer do that. It is more comfortable.

Adds value (7)

Adequate heating when needed.

Definitely - more comfortable and now we realise we can keep the house at a comfortable temperature - we are a lot happier living here. Before we wondered what we had done, buying such a cold house.

Easy to warm up in the evening and can stay up a bit later because it's comfortable

Feel that we will be able to keep the house warmer.

For a while, we weren't overly happy with the house - it's single glazed and the windows have draughts. When we wake in the morning, the air is really damp, not comfortable. The house is genuinely better - and even overnight it's more comfortable. It's made a huge difference

Good. I used to have an old floor one which took up a lot of space. Now it's on the wall so it frees up some space.

Heating is wonderful inside

I am happy that we've got it

I just feel happy and grateful. Feel like I want to be home and look forward to being home. On the first day it was a horrible cold wet day. I was out relieving while it was installed. The good fairies installed it and left it on and everything tidy and when I walked in it was warm and I nearly cried with gratitude.

I really enjoy it and it's much more comfortable in the living area. I feel healthier

I think it will next winter

I’m like yay I've got a heat pump

It has added value, although a nice warm house already.

It is warmer and more convenient.

it's been in since 1 Sept but haven't had to turn it on

it's just warmer and feels way better

it's nice and easy and convenient should we need it

It's nice and inviting and comfortable

It's not cold and damp like it was

Knowing we have the option for both heating or cooling especially cooling at nights so don't have to open windows

Less clothing inside

Like it if people come around I can turn on the heat pump and they don't have to freeze until the heater warms up.

Like my home anyway

Looks like we are using less power and the house is much warmer and when we want we can cool it down

Lot more satisfaction because comfort of warm

lot warmer and better heat pump than previous one

Made it way better. more comfortable. Looking forward to cooling in summer as well

Make the household members more comfortable

More comfortable

More pleasant to be at home (2)

More satisfied because it is more comfortable

More up to date and fits better with the house.

No, we're very happy with the heat pump, very impressed with its effectiveness.

The assessor and I agreed where the heat pump should go, but when the installer came he said it couldn't go in the place we agreed and put it somewhere else. My neighbour has exactly the same layout as me and they put her heat pump in the place I wanted mine. It's a bit ugly where it is.

The few times that we used it, yes we were satisfied with the heat pump.

The living room is nice and warm.

Used to log fire, however with the heat pump I no longer have fires to keep warm, she feels fumes from the fire were harmful

Very satisfied

We are so much better, the house feels better, and it's improved my sons heath exponentially

We had a bunch of things we wanted to get sorted and getting a heat pump was high on the list.

We love our home anyway, but we are definitely more happy that people aren't complaining about how cold it is anymore. Guests are more comfortable.

We use the living room a lot more in the evenings because we can heat it better.

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