Energy Efficiency – Insulation and Heat Pump Retrofits

Understanding efficiency and clean energy from a consumer perspective

January 2022

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Project Background

- Vector and EECA (Energy Efficiency and Conservation Authority) have a shared interest in understanding the impact of energy efficiency and clean energy improvements to housing.
- Combining data supplied by EECA on insulation and clean heater retrofits from the Warmer Kiwi Homes and predecessor Warm Up New Zealand programmes*, and smart meter data from Vector, Vector modelled the impact of these retrofits on electricity consumption.
- These results help inform future demand projections, which are used for network planning and management, and may be used to further analysis of emission reduction opportunities.

**The next slide, and Appendix A, provides more information from EECA on these programmes.*

The Warmer Kiwi Homes and Warm Up New Zealand programmes

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ENERGY EFFICIENCY & CONSERVATION AUTHORITY

- The Warmer Kiwi Homes (WKH) and predecessor Warm Up New Zealand (WUNZ) programmes, administered by EECA, are together an ideal case study for residential energy efficiency upgrades.
- The Warmer Kiwi Homes programme provides subsidies for insulation and clean heaters to homeowners with Community Services Cards, and those living in low-income areas, with the aim of making homes warmer, drier and healthier. The Warm Up New Zealand programme provided similar subsidies. Points of difference were the inclusion of rentals, and broader income eligibility.
- Over 365,000 insulation retrofits and 60,000 heating retrofits have been delivered since the start of the Warm Up New Zealand programme in 2009.
- The programmes were evaluated in 2012 and 2020, with the most up to date economic analysis indicating a benefit-cost ratio of 4.7. This is primarily the result of the health benefits which result from warmer, drier homes. This is enabled by improving energy efficiency. Further study is ongoing.
- Electricity saving is not the primary focus of Warmer Kiwi Homes as many eligible homes may be underheated. However, savings do occur, and the current analysis from Vector provides new insight into the time of day and time of year when these occur. Where comparisons can be made with previous work, the agreement is very good, as per Appendix B.
- Information on how Vector and EECA collaborated on this project, including data privacy specification, is also provided in Appendix C.

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Key Insights

Houses retrofitted with Insulation:

- Made relatively small savings in electricity usage with an average yearly saving of 80 kWh pa or 1.08% - the savings were 180 kWh or 2.44% when compared to the control sample;
- Saved more electricity when it was cold;
- Have a reduction in electricity use over peak periods;
- Saved more electricity if their electricity usage before the retrofit was high and less if it was low; and
- Made more savings if they were owner occupied less if they were rentals.

Houses retrofitted with heat pumps:

- Showed no savings when compared to the control sample; and
- Used less electricity then the control sample when it was cold and more when it was hot.

Methodology

How can we measure changes in electricity use for retrofitted households?

Methodologies used to evaluate the impact of insulation and heat pump retrofits on energy efficiency

Comparing treated households with:	Details	Benefits	Limitations
Their baseline usage	For each retrofit the changes in energy consumption are measured by comparing smart meter data from the year prior to the retrofit (baseline period) to data from the year after the retrofit (reporting period). The CalTRACK methodology is then applied to model the relative electricity use.	• Inherently accounts for the characteristics of the house • Normalises for weather variations • Heating and cooling electricity loads can be extracted • Daily and hour of week models can be applied	• Modelled savings are affected by behavioural changes • Modelled savings are effected by macro-economic factors • Can't be reliably used for retrofits after Feb 2019 (The COVID-19 lockdowns impact the required 1 year reporting period)
A representative control sample	A suitable control sample is selected based on the SA1 region, the electricity consumption profile and the time of the retrofits. The CalTRACK methodology is then applied to both the treated and control samples.	• Accounts for underlying macroeconomic changes • Can be used to compare electricity usage during COVID lockdowns • Partially accounts for the impact of temperature take-back*	• Can't accurately determine if the control houses already have insulation and/or a heat pump • Due to data availability the control sample can't be selected to align with key characteristics (rental status, house size, etc.)

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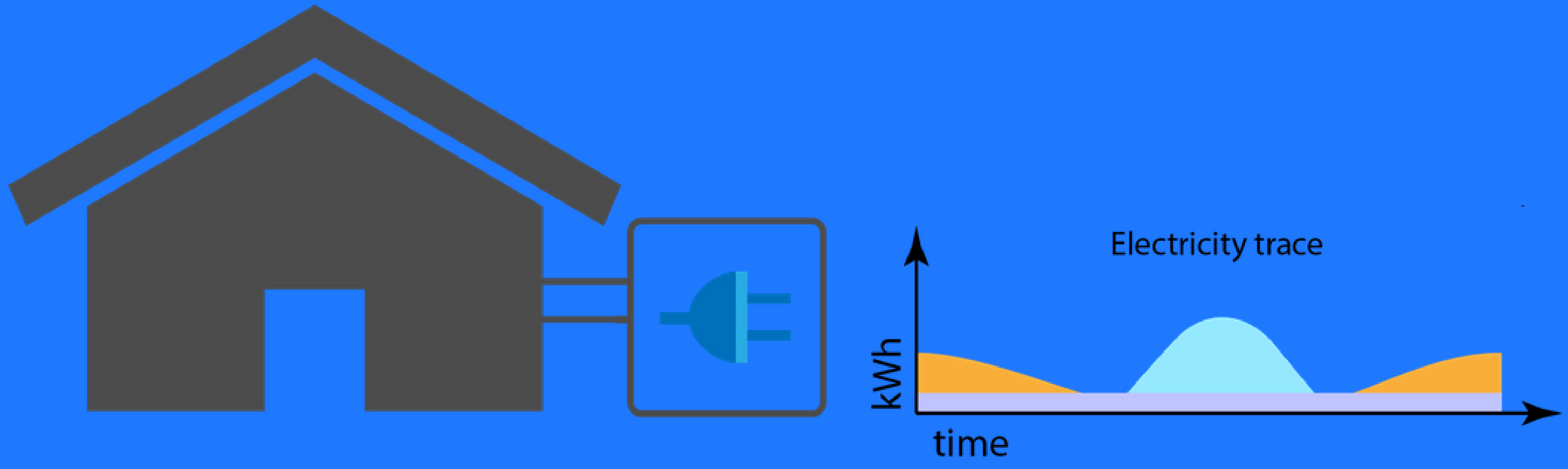
* Temperature take back refers to underheated houses increasing their internal temperatures following a building retrofit and the increase in energy use (reduction in energy savings) associated with that change.

Comparing retrofitted households with their baseline usage

The CALTRACK Methods and LF ENERGY OPENEEMETER



“The central problem the OpenEEmeter solves for is estimating how energy consumption changes after an intervention in a consistent and replicable way.”

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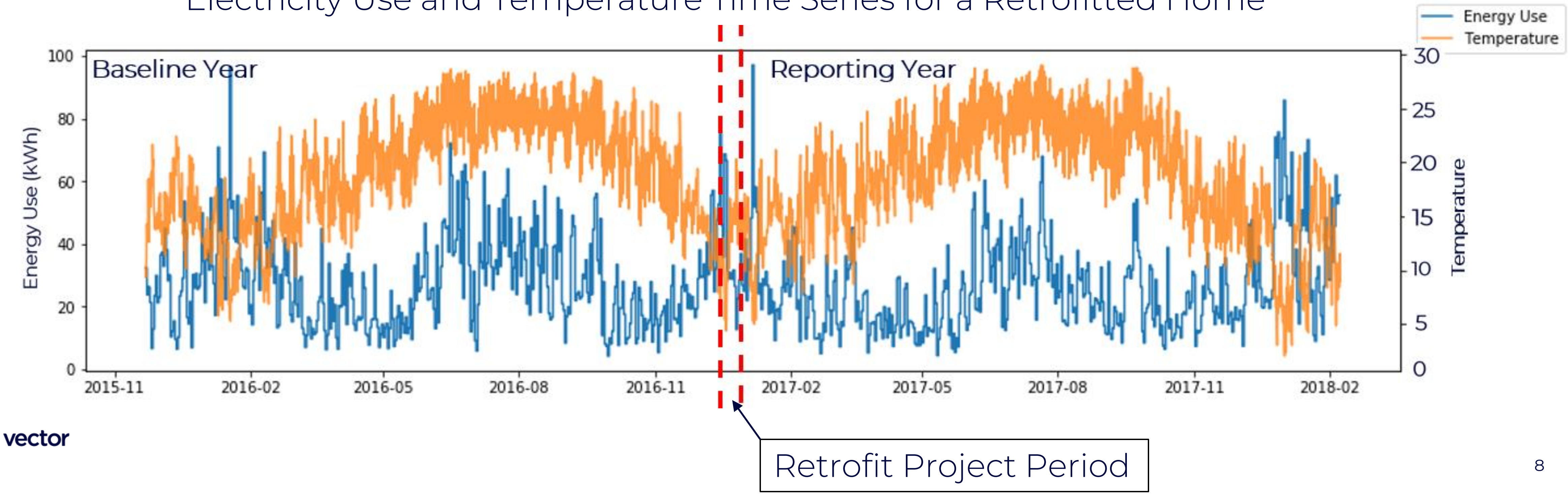
How can we measure changes in a household's energy efficiency?

- For each retrofit job (provided by EECA), the changes in energy consumption can be measured by comparing the prior to the subsequent year's **smart meter data**.
- The prior year is used as a baseline period, the subsequent year (or reporting year) for comparison.

Electricity Use and Temperature Time Series for a Retrofitted Home



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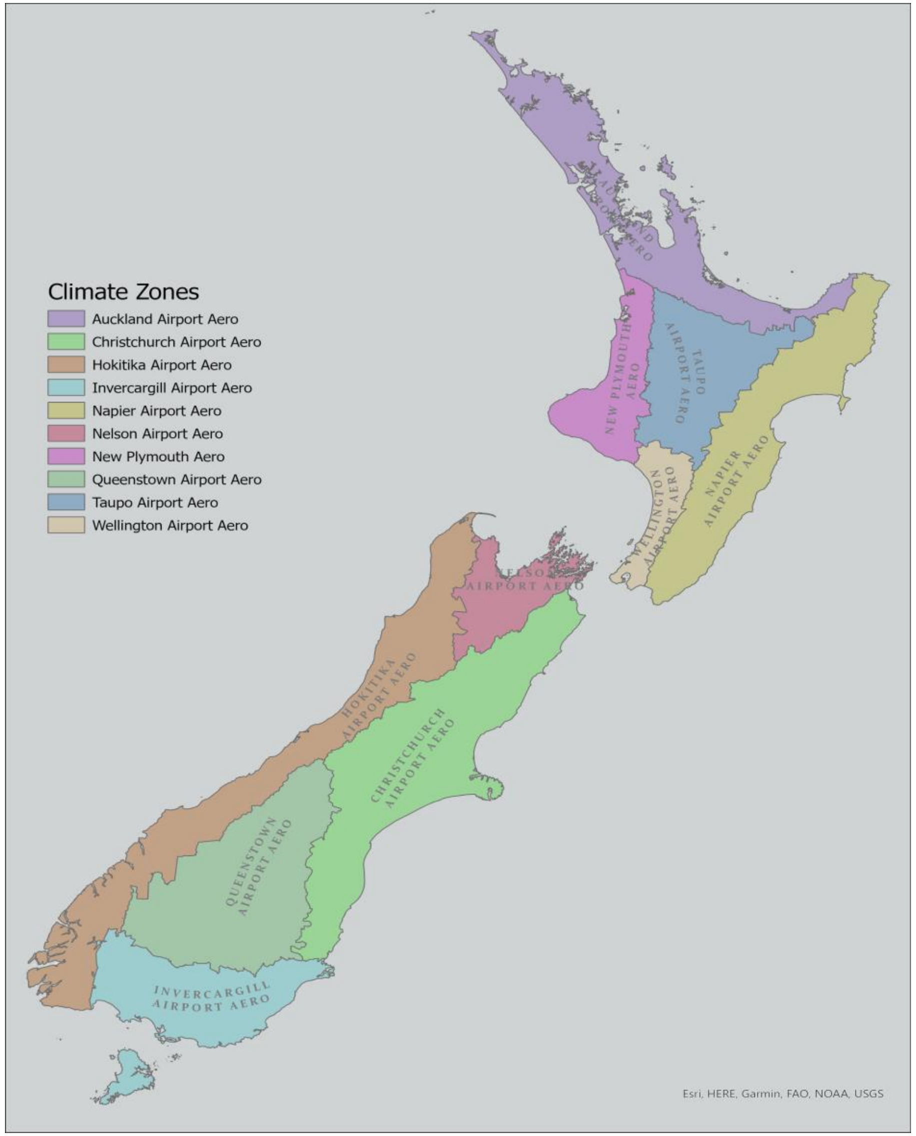
Temperature drives residential electricity fluctuations

- To understand the impact of insulation or heat pumps retrofits, we need to know the temperature.

- Weather data was sourced from MetService for 10 weather stations strategically selected across New Zealand and matched to each house through their installation control point (ICP) to provide the best point in time weather reading for each customer.



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A robust reproducible methodology

- The CALTRACK methodology is applied using LF ENERGY OPENEEMETER to create a temperature dependent model of energy use before and after the installation.
- A range of piecewise linear regression models are fitted with various heating and cooling degree points and tested to find the best fit for each of the baseline and reporting periods.
- For the hourly method separate models need to be found for each month of the year.

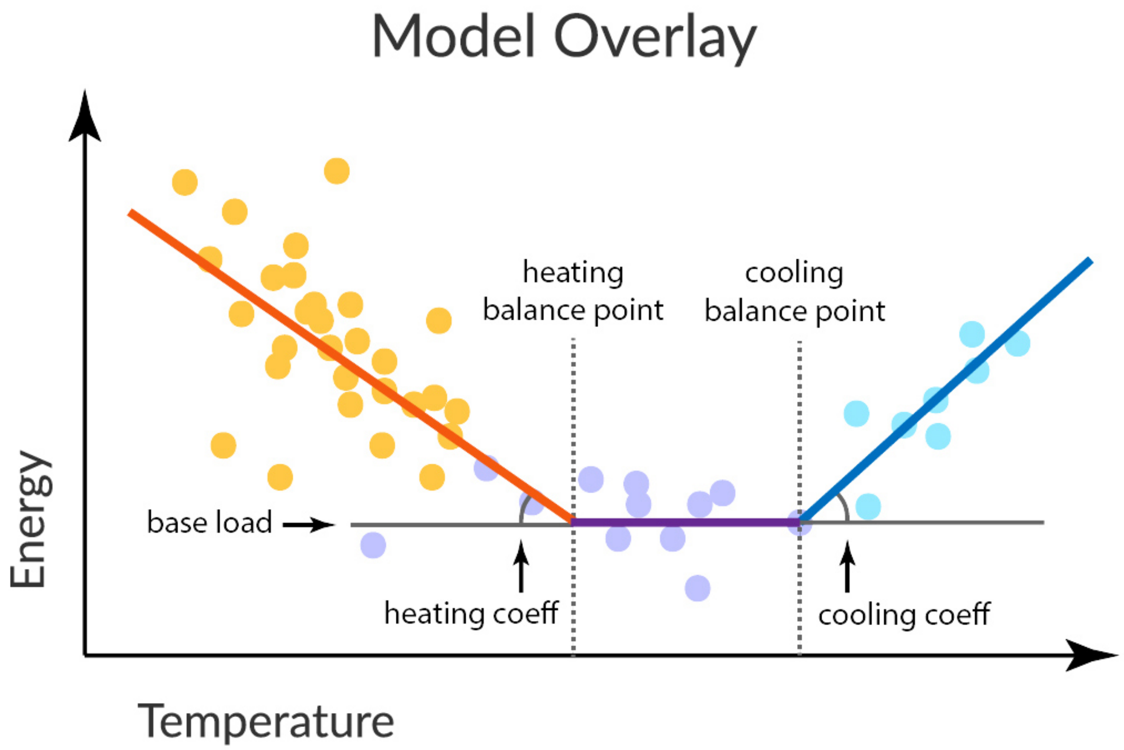


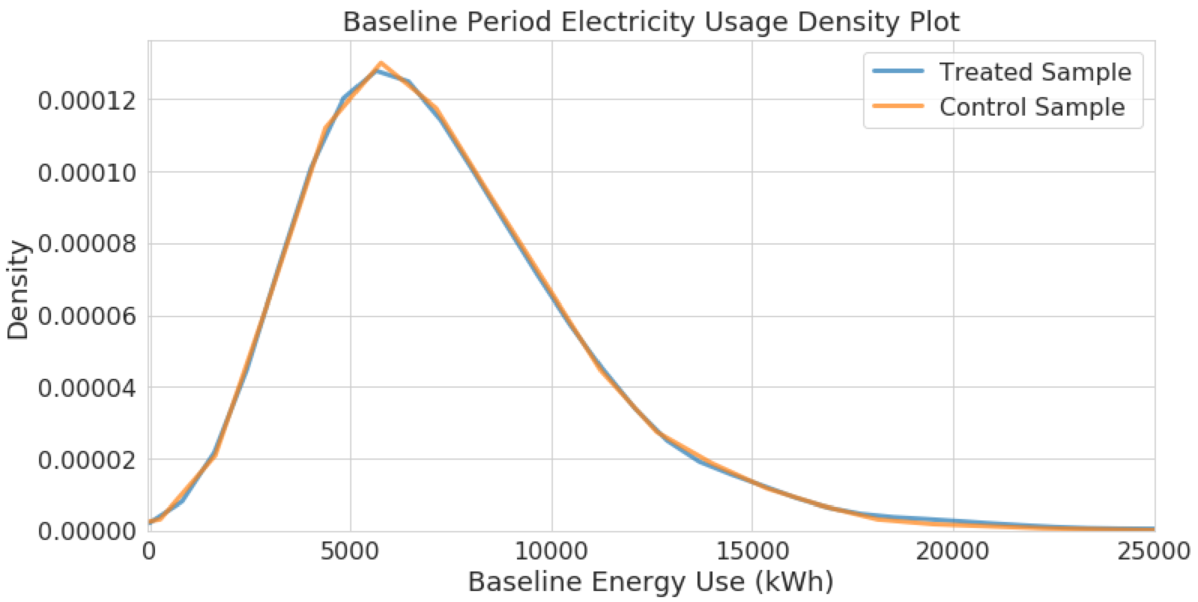
Image sourced from: https://www.recurve.com/how-it-works/caltrack-billing-daily-methods

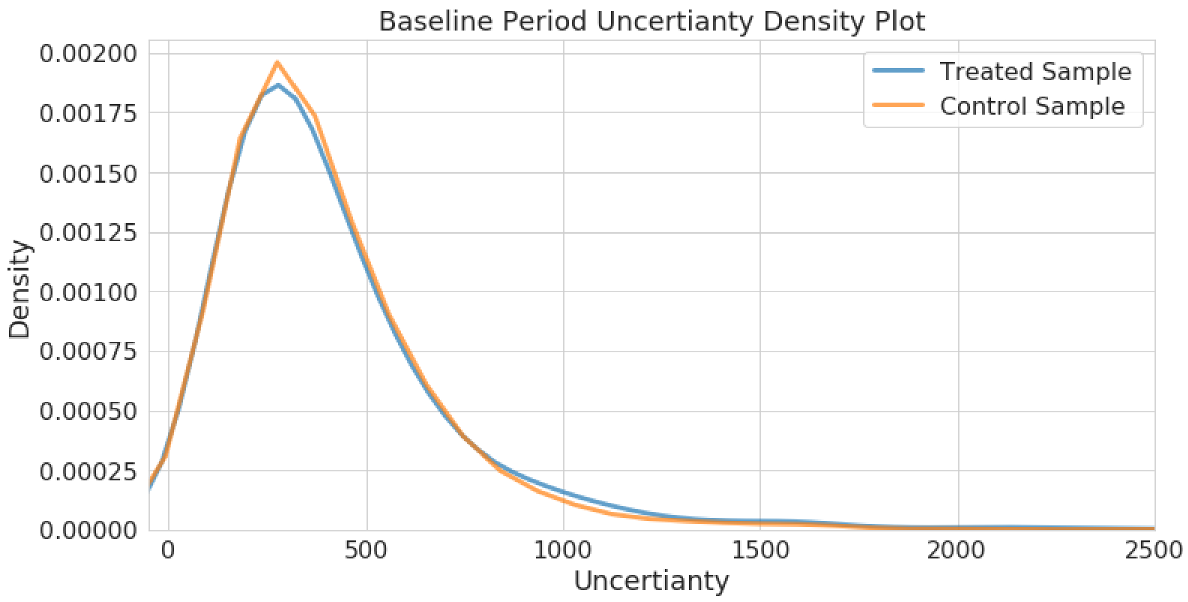
CalTRACK: http://docs.caltrack.org/en/latest/index.html
OpenEEmeter: https://github.com/openeemeter

Establishing a representative control sample

Comparing like with like

- The control group was created by finding houses (ICPs) with similar energy consumption profiles to houses that were treated with a retrofit.
- Each ICP in the control group was selected by comparing the energy use profile of a treated ICP to all other ICPs in the same SA1 region. The ICPs that had the smallest differences in the mean and variance of their electricity use over the baseline period were added into the control group.





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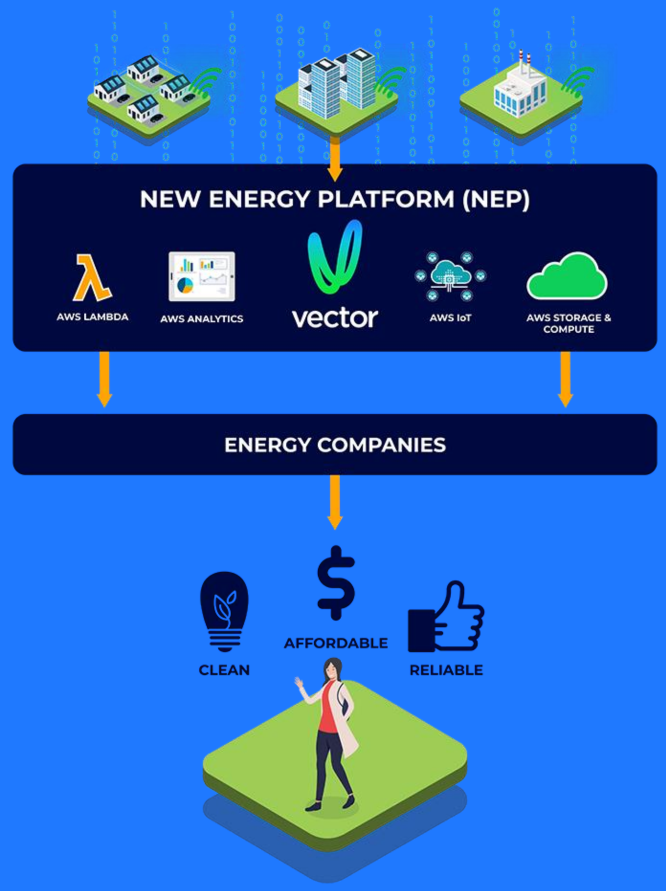
WUNZ: Warm Up New Zealand
WKH: Warmer Kiwi Homes

Computationally expensive? Enter the cloud.

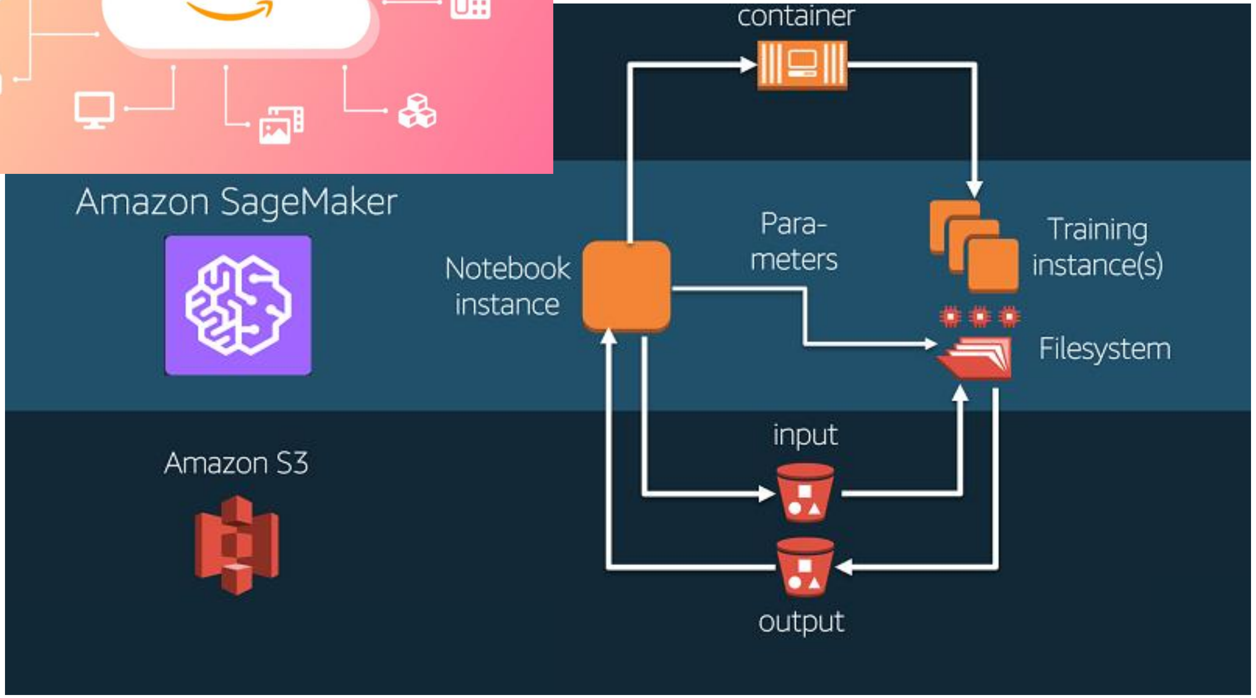


Vector's New Energy Platform will provide cutting edge cloud computing edge resources to tackle large data computing.

Modelling at scale

- The treatment sample contained 2748 insulation and 500 heat pump retrofits across NZ.
- Trillions of rows of data needed to be scanned.
- Millions of models had to be fitted and compared.
- This is computationally intensive.

- Using AWS this load was distributed across 100s of training instances and ran in hours.



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Insulation Retrofit Results

So what impact does an insulation retrofit have on a household's electricity usage?

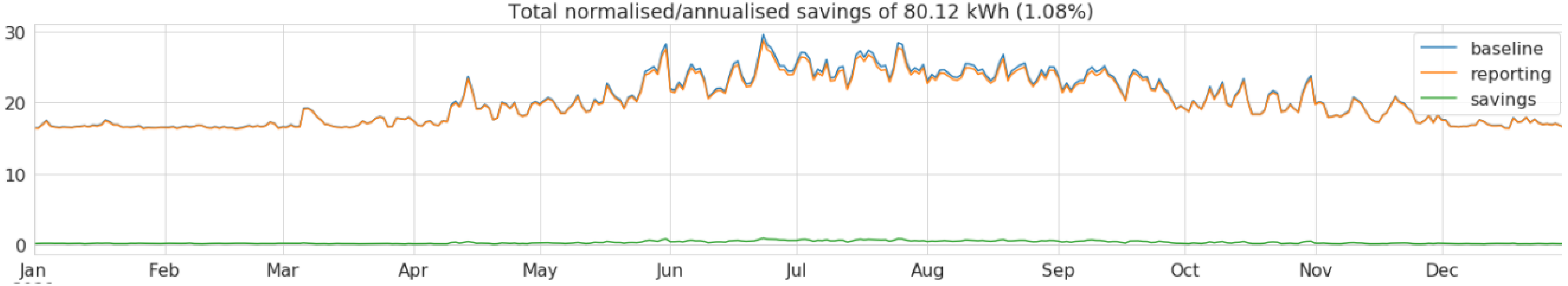
First we need to address the COVID-19 impact.

Insulation retrofits after Feb 2019 are removed to avoid the effects of the COVID-19 lockdowns impacting the reporting period.

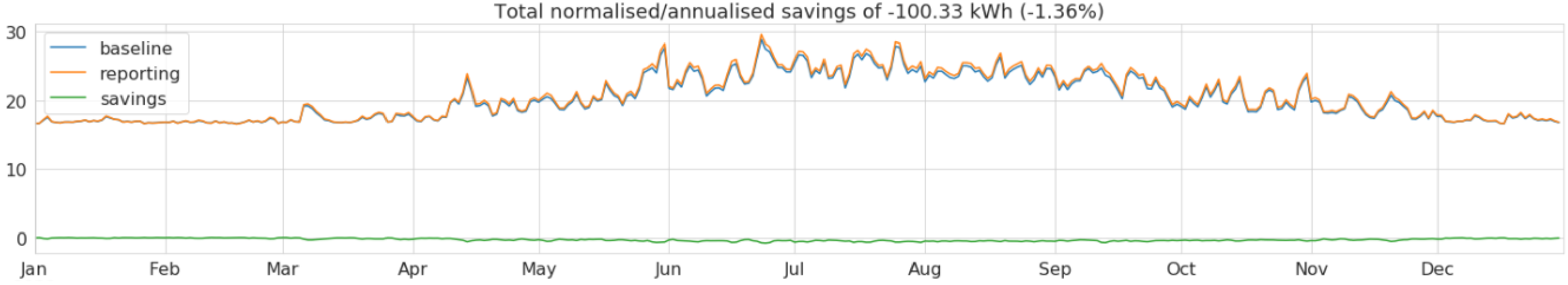
Insulation retrofits produce relatively small savings in electricity usage

- The treated households showed a small but statistically significant average annual savings from their baseline electricity load of 80 ± 14 kWh (1.08%).
- In comparison, the control sample had a negative saving of -100 ± 16 kWh. The comparative difference in electricity is therefore (180 kWh or 2.44%).

Treated Households



Control Households



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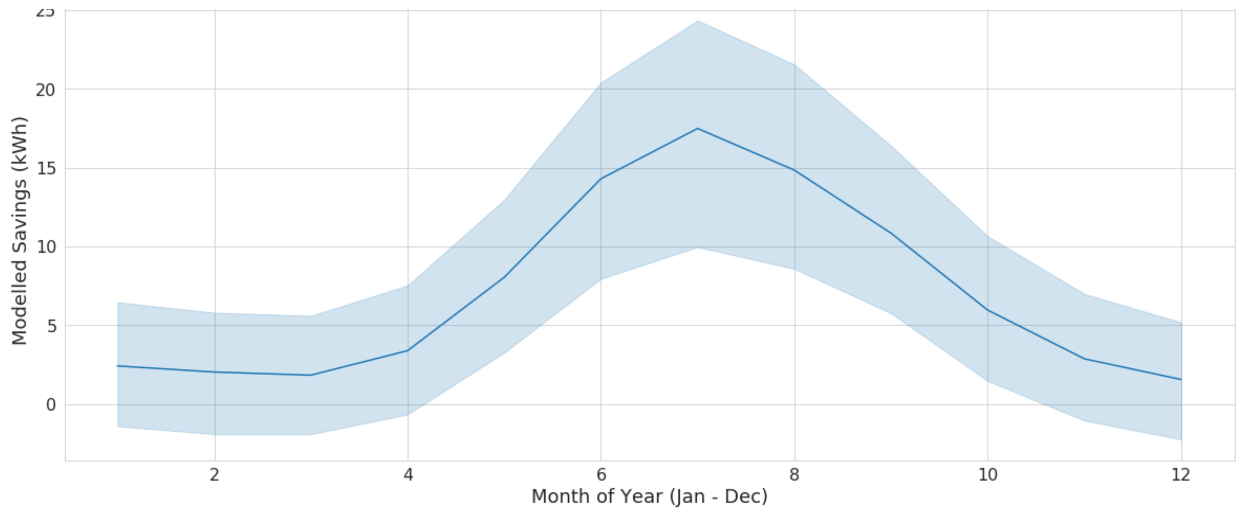
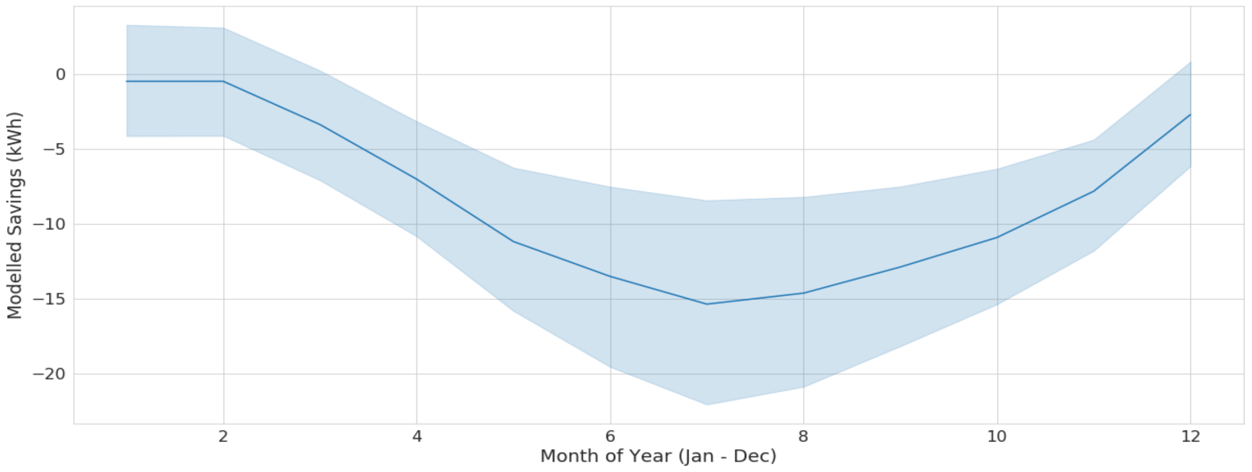
Insulated savings peak strongly in the winter

- Monthly savings peak strongly in the winter months for houses treated with insulation retrofits.
- The insulation control sample increased their consumption over winter (they had negative savings).
- The control samples increase in the electricity use may be due to a form of temperature take-back.
  - Temperature take-back refers to both the treated and control households being cold and underheated in the baseline year and (effectively having nowhere to go but up) are on average kept warmer in the reporting year (more energy is used to heat the households).

Treated households' savings by month of year



Control households' savings by month of year



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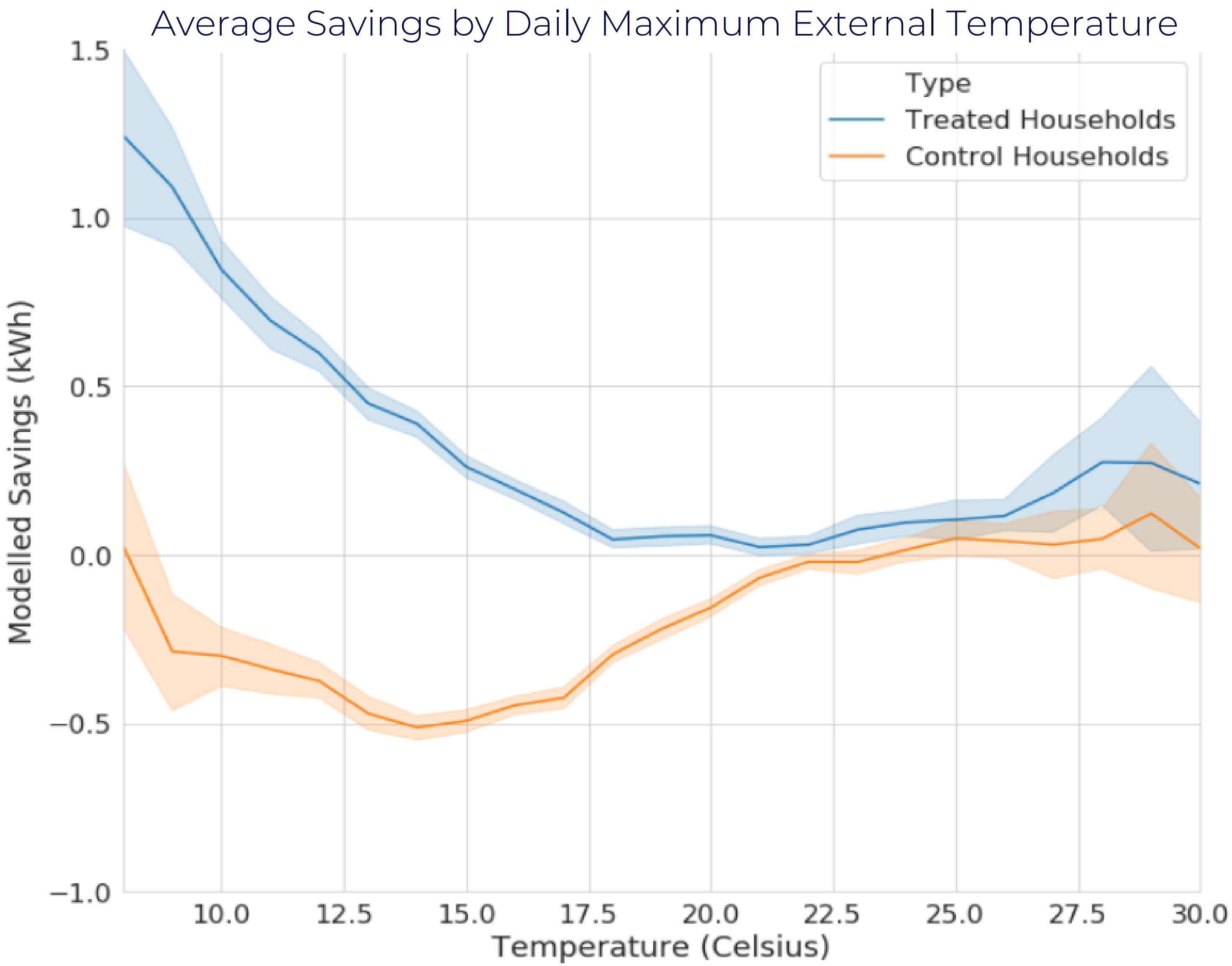
Treated households save more when it's cold

- For daily max temperatures below 17.5 degrees, the colder it gets the more electricity is saved during an insulation retrofit.
- The control sample used more electricity at colder temperatures.



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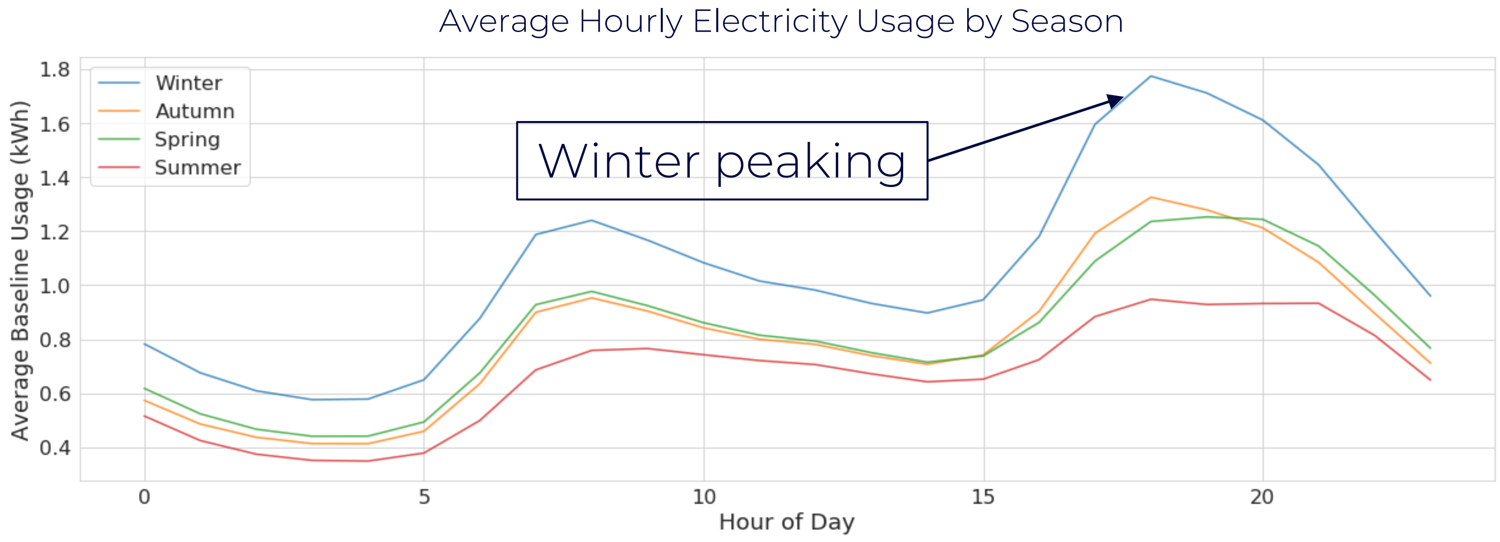
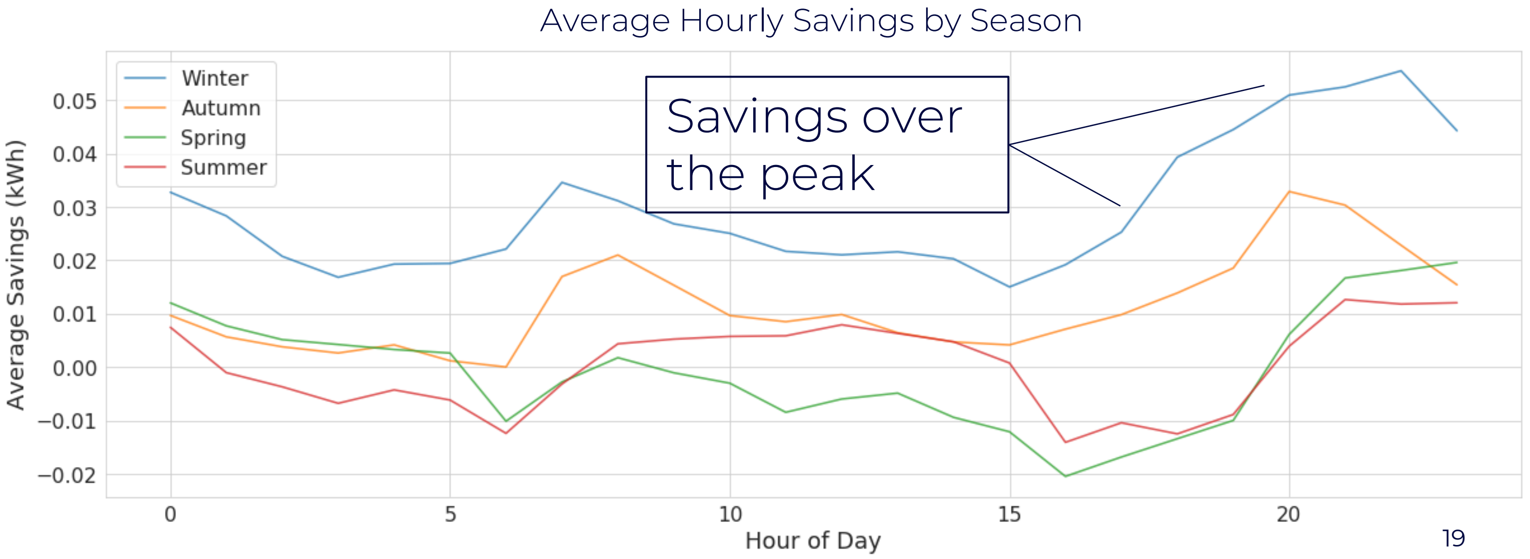
Insulation retrofits improve energy efficiency over peak periods

- New Zealand is winter peaking.
- Retrofits decrease electricity demand over the winter peak.
- Looking at the period of 9-5pm for the 10 coldest days in each region the savings are (2.40%).





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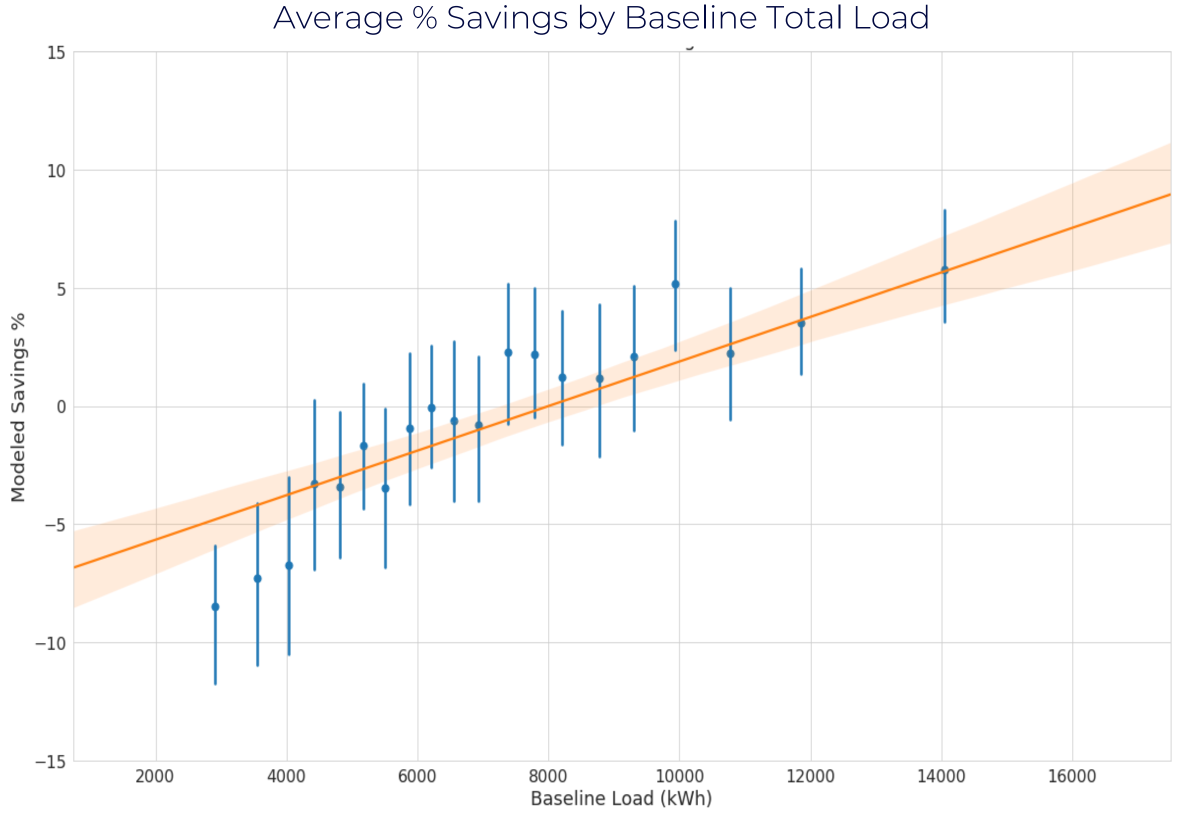
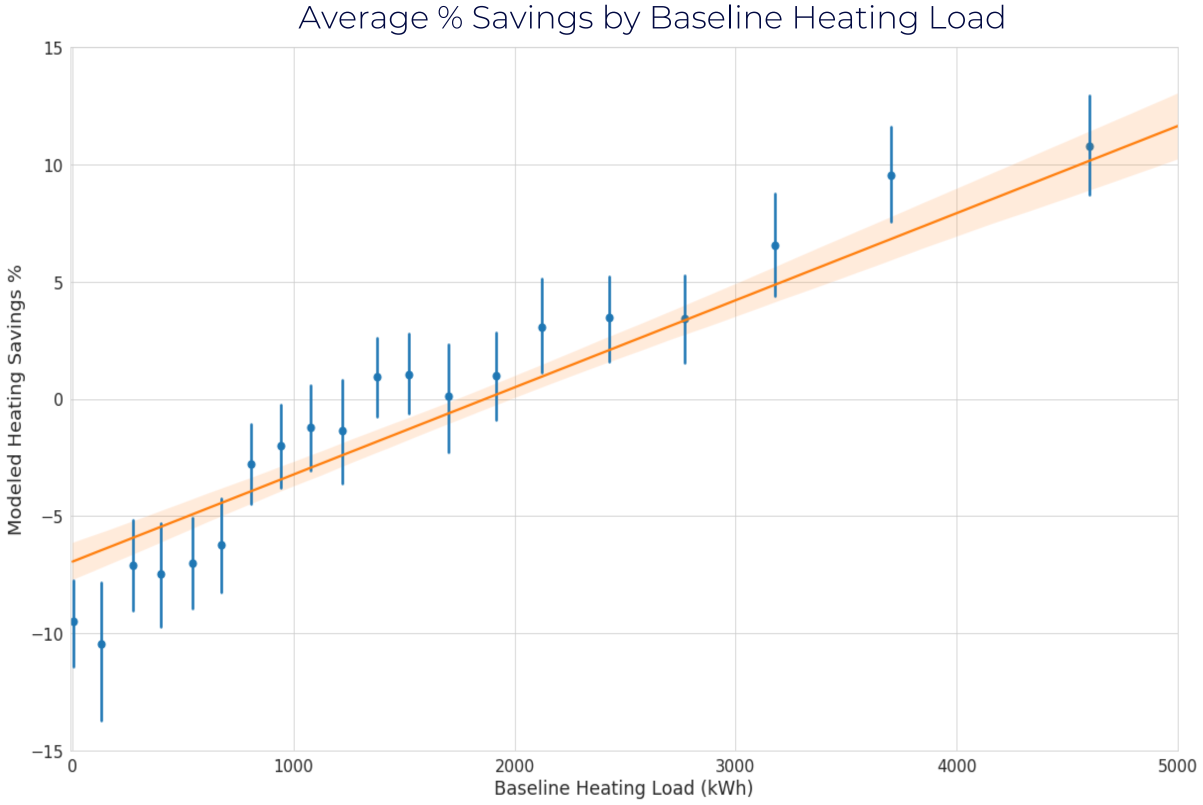
The more baseline electricity households used the more they saved

- The overall savings are strongly related to the total electricity usage over the baseline period.
- This is even more pronounced for the savings in relation to the underlying heating load.





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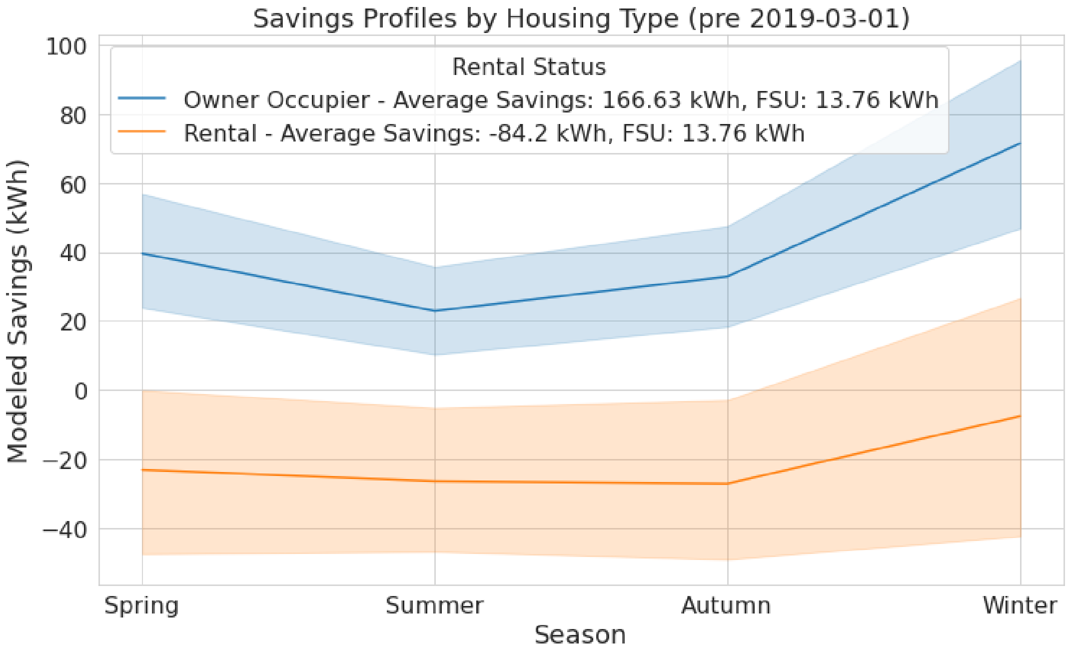
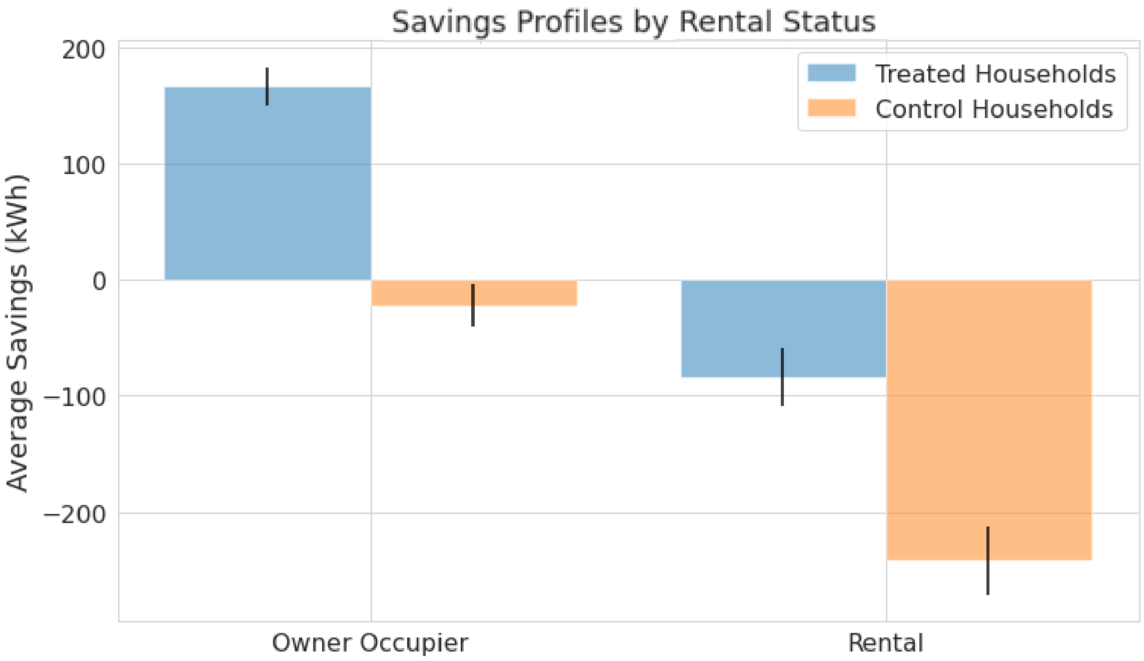
Owners save more electricity than renters

With new healthy homes legislation in effect, it is important to understand the differences between owner occupiers and renters.

- Compared to their prior usage, owner occupied households fitted with insulation saved electricity (167 kWh), while renters increased electricity usage (-84 kWh savings).
- Compared to the baseline sample owner occupiers saved 189 kWh more than the control sample, while renters saved 157 kWh more than the control sample.





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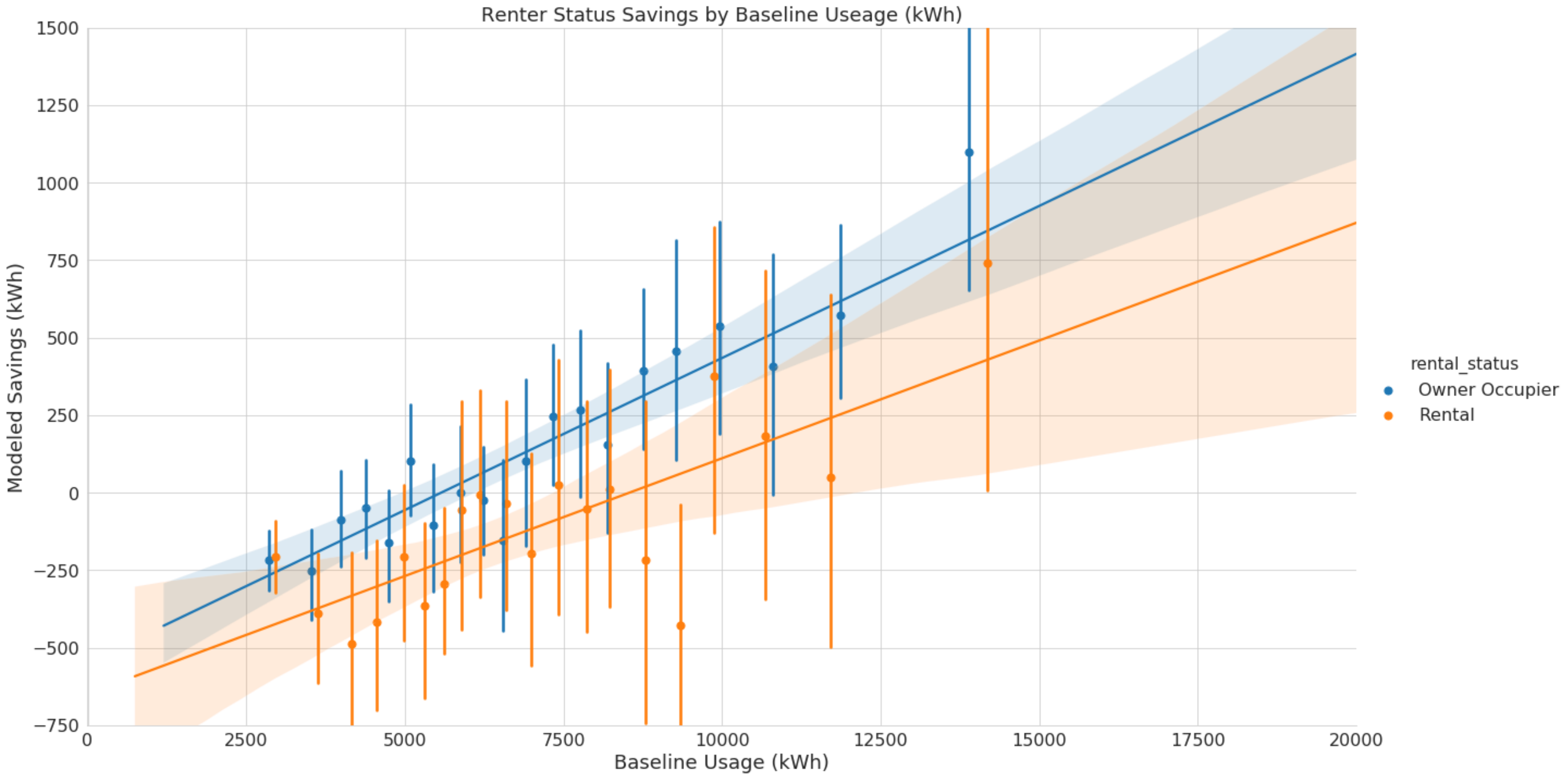
Savings by consumption and rental status

- The differences between renters and owner occupiers are evident at all baseline usage amounts.



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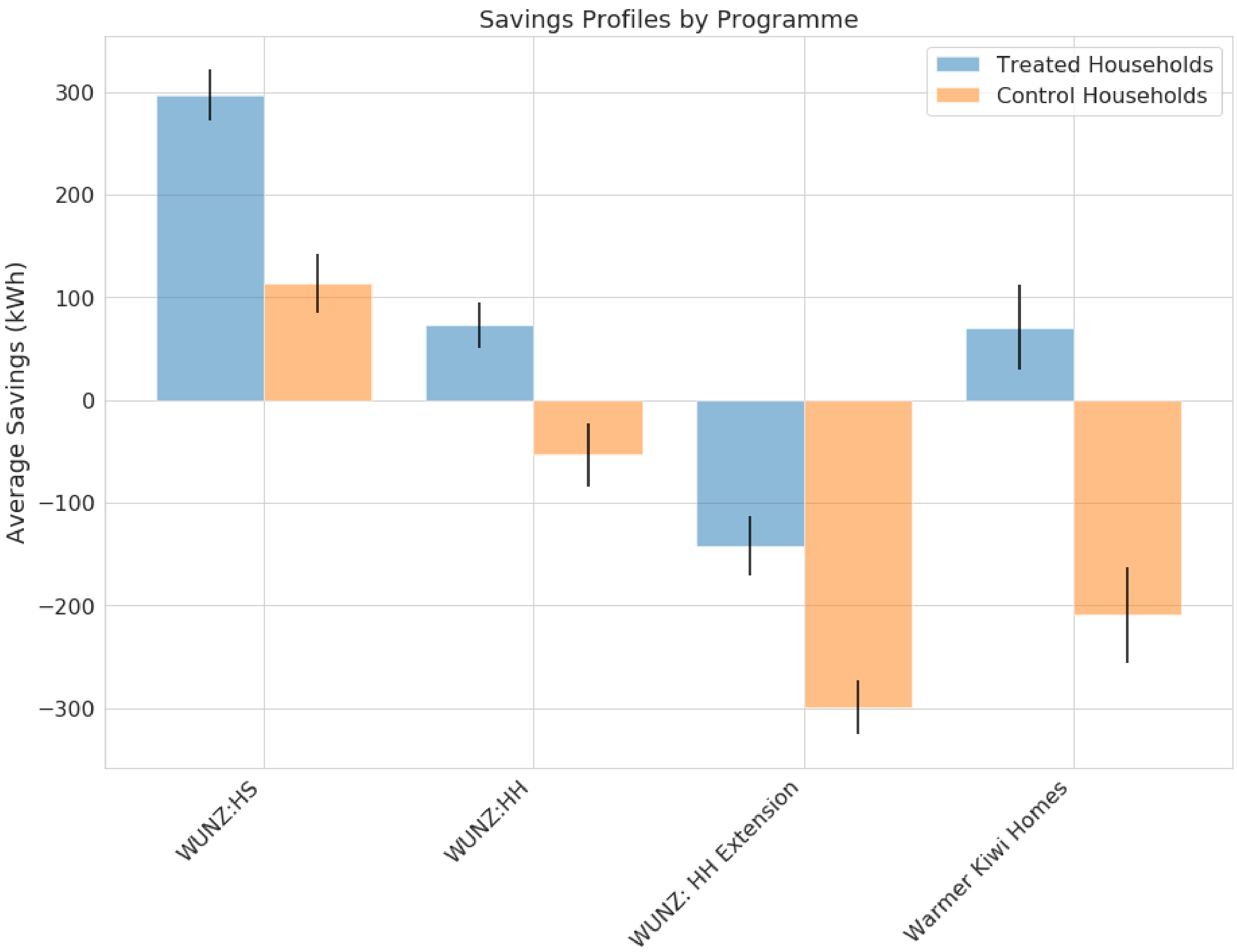
Electricity savings vary significantly by programme

- The electricity savings are significantly different across the WUNZ and WKH activities (Appendix A).

- Comparing the control sample with each programme indicates that a significant portion of the differences between programmes are driven by changes unrelated to the retrofits.



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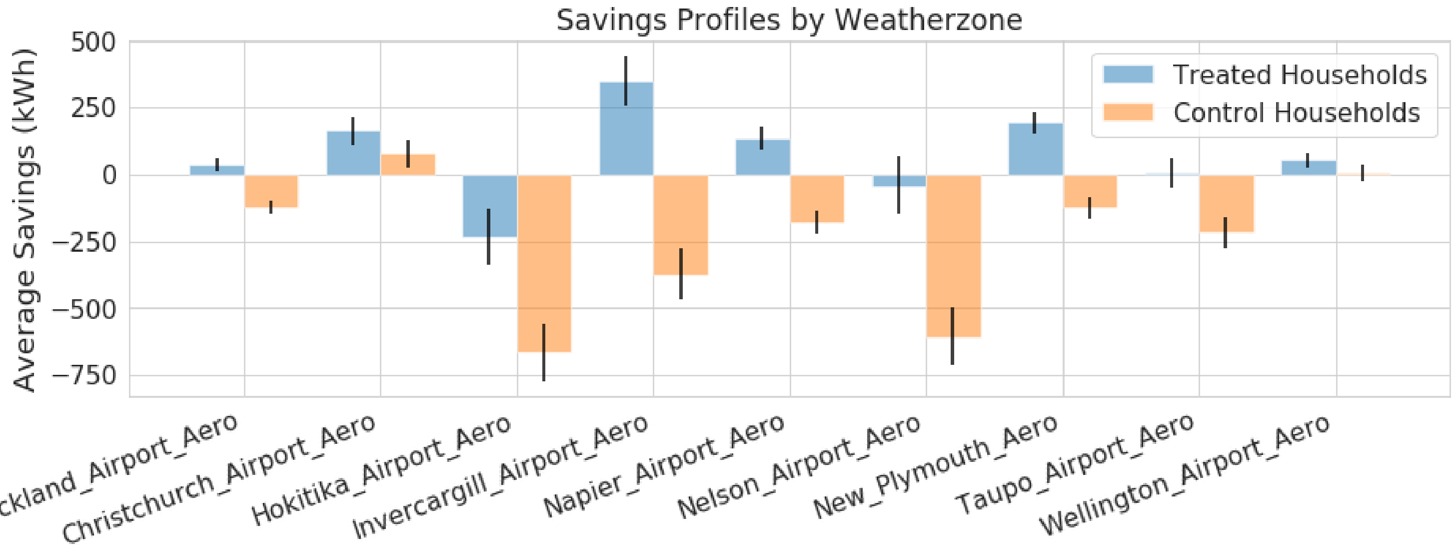
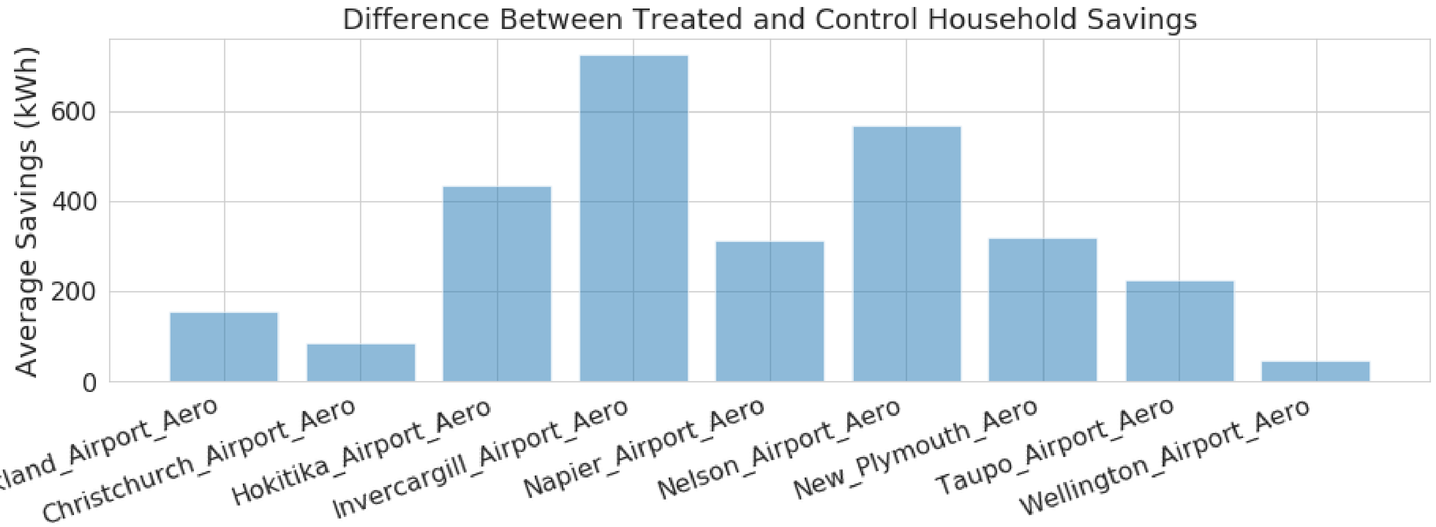
Savings profiles change significantly by region

- There are large differences in the modelled savings profiles across the different regions.
- Comparing savings between the treated and control households shows that treated houses consistently save more than the control households; although the magnitude varies significantly.





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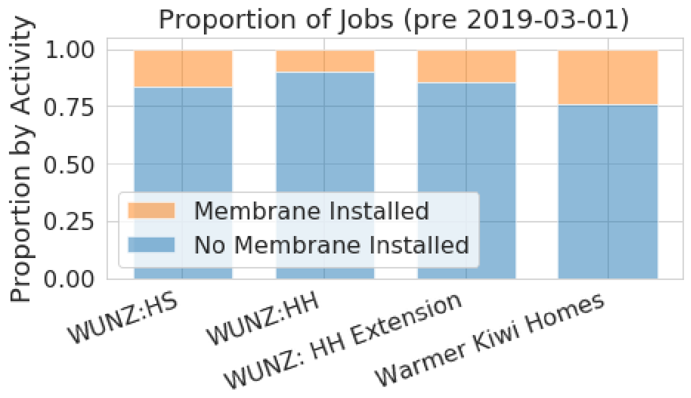
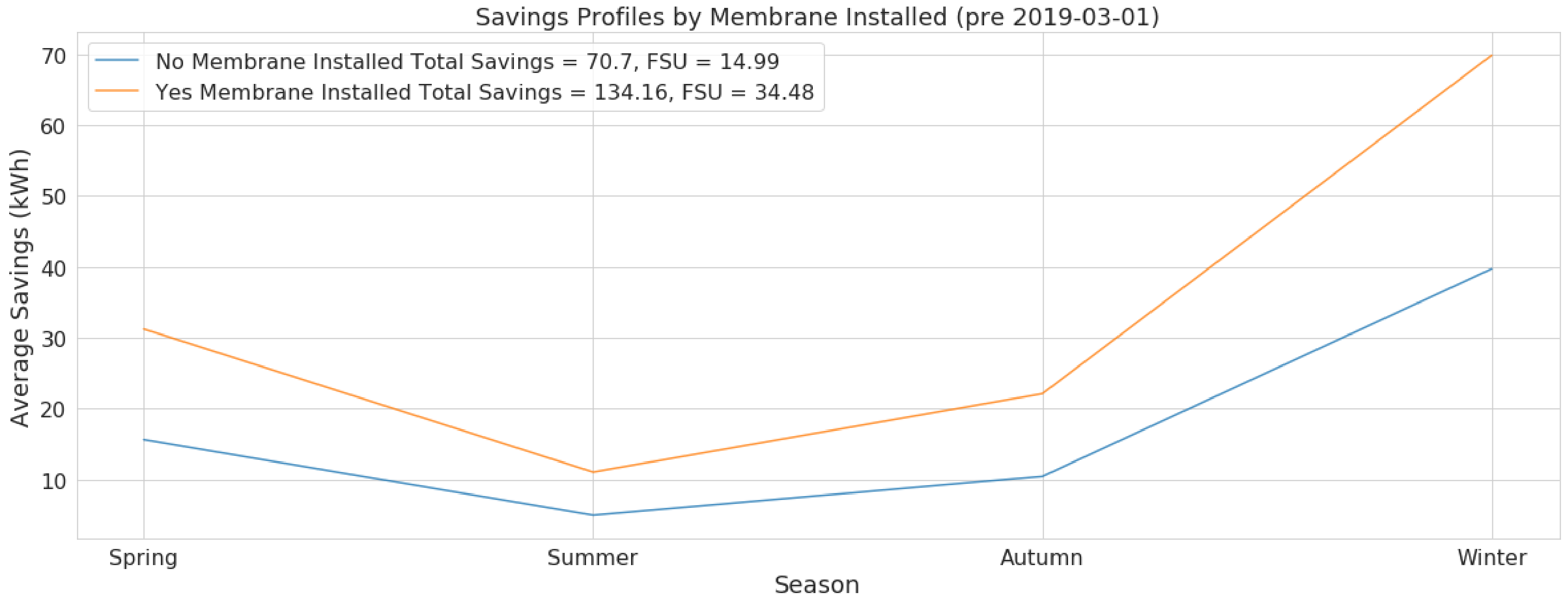
Waterproof membrane installations improve energy savings

- Households retrofitted with a waterproof membrane saved more energy than those retrofitted only with insulation.





Heat Pump Retrofit Results

How does electricity usage change for households retrofitted with a heat pump?

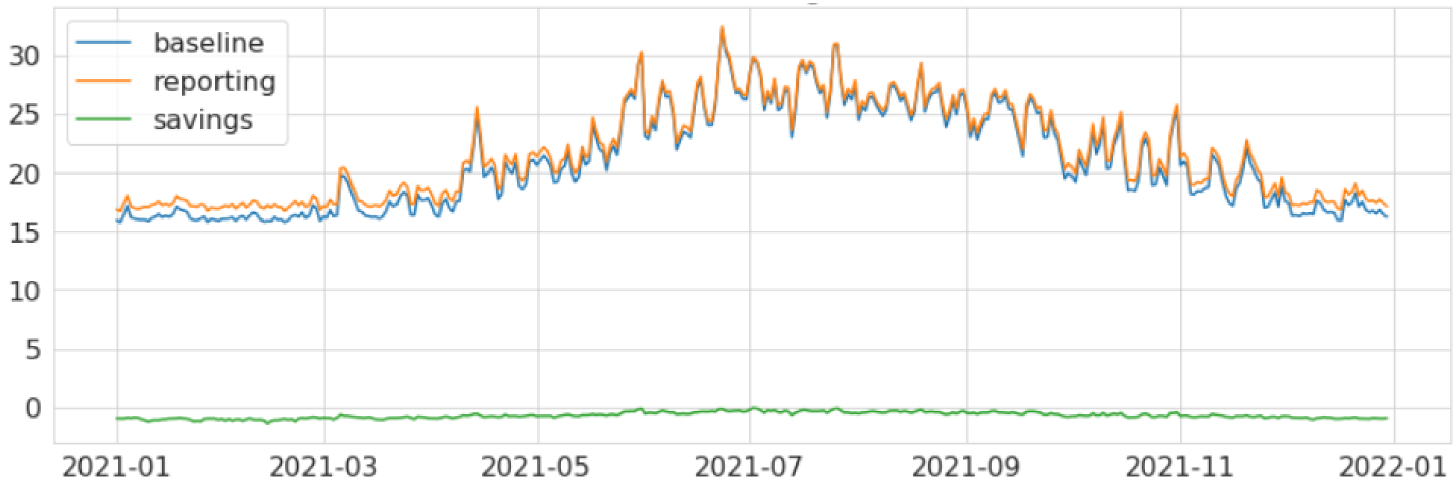
The COVID-19 Impact:

- The Majority of heat pump installations from the Warmer Kiwi Homes programme occurred after July 2020.
- This means that their reporting periods are impacted by COVID-19.
- In order to measure retrofit impacts a control sample needs to be used.

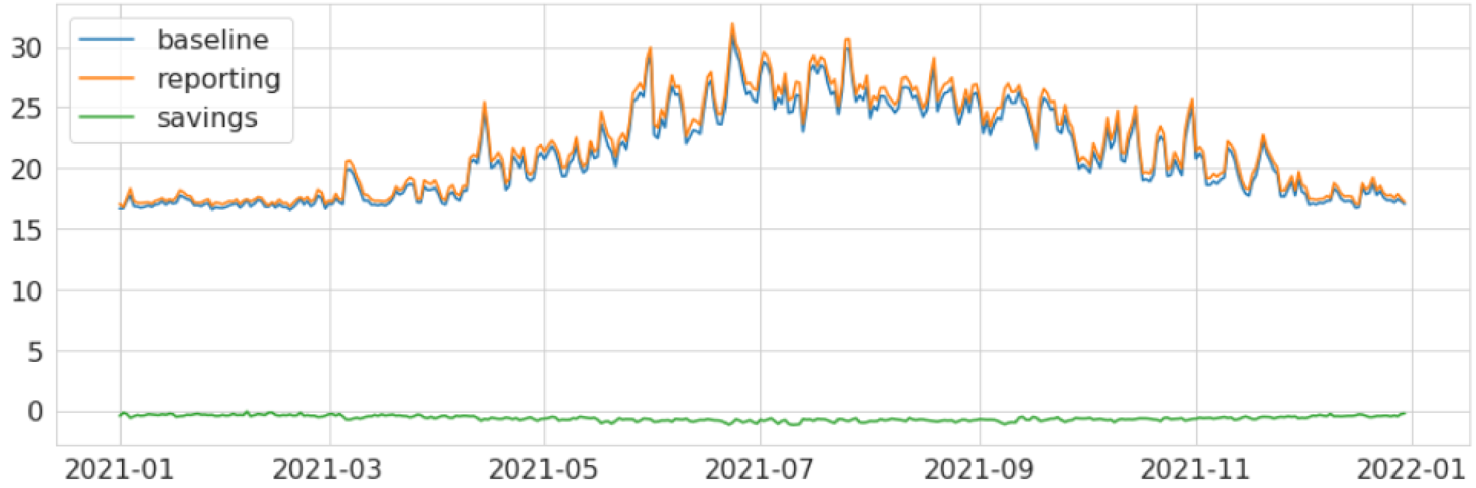
Heat pumps did not affect overall consumption

- The treated households had no significant savings when compared to the control sample.
- The modelled savings should not be considered independently due to the impact of COVID lockdowns.

Treated Households Annual Savings = -247 kWh (± 40 kWh) or -3.23%



Control Households Annual Savings = -214 kWh (± 66 kWh) or -2.78%



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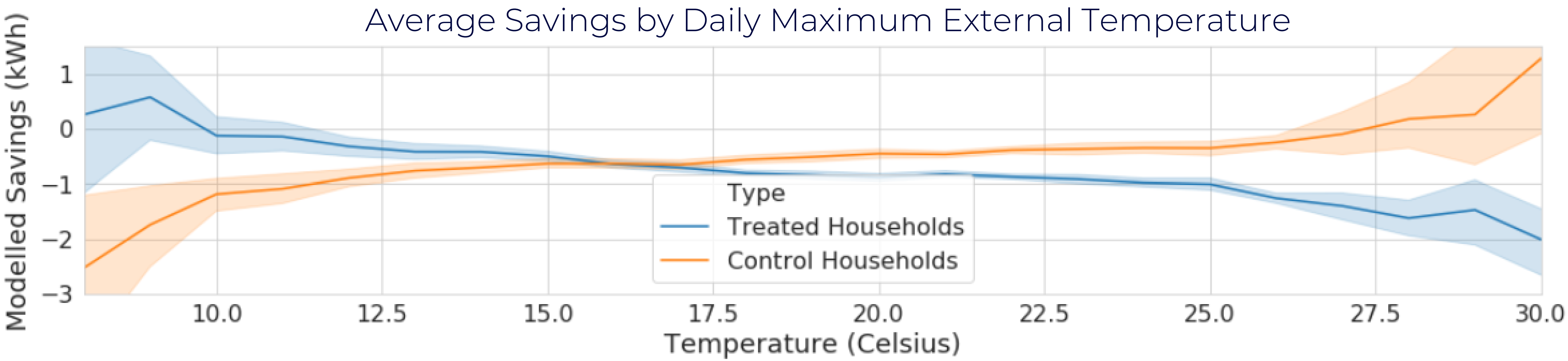
Households retrofitted with a heat pump reacted differently to temperature than the control group

- The households treated with heat pumps used less energy (saved more) at lower temperatures and used more energy (saved less) at higher temperatures.
  - This is inline with expectations that heat pumps use less energy to heat households but also enable the occupants to cool the house.



Appendix:

- Appendix A to C – background information provided by EECA
- Appendix D – background information provided by Vector

Appendix A – Summary of WUNZ and WKH programmes

WUNZ: Heat Smart (2009-2013)

- Eligible households:
  - Owners of houses built pre-2000 (all households – general income and low income, owner-occupiers and landlords)
  - Landlords eligible: Yes
- Government funding available:
  - 60% of total insulation cost for owner-occupier households or tenants of rental households with a Community Services Card (CSC)
  - 33% of total insulation cost for all other (general income) owner-occupiers or tenants, up to $1,300
  - Using third party funding, some retrofits were provided at low or no cost to the homeowner

WUNZ: Healthy Homes (2013-2016)

- Eligible households:
  - Owners of houses built pre-2000, with occupiers or tenants with a Community Services Card (CSC) and:
  - someone under the age of 17 or over 65 living in the house; or
  - with housing related health needs
  - Landlords eligible: Yes
- Government funding available:
  - Up to 60% for eligible households
  - Using third party funding, owner-occupiers received insulation retrofits at no cost
  - Some landlords contributed towards the cost of insulation retrofits of rental properties

WUNZ: Healthy Homes (extension) (2016-2018)

- Eligible households:
  - Owners of houses built pre-2000 with occupiers or tenants with a Community Services Card (CSC); or
  - The owner-occupier or tenant has high health needs related to cold, damp housing and their income is just over CSC level; or
  - The owner-occupier or tenant is referred by the Ministry of Health's Healthy Homes programme.
  - Landlords eligible: Yes (when this phase was first launched it was landlords only (for rental properties occupied by low income tenants and/or tenants with high health needs) but the eligibility criteria was broadened July 2017).
- Government funding available:
  - 25% for eligible rental properties
  - Government grants are topped up by both third party funders (at least 25%) and homeowners (50% maximum)

Warmer Kiwi Homes (2018-)

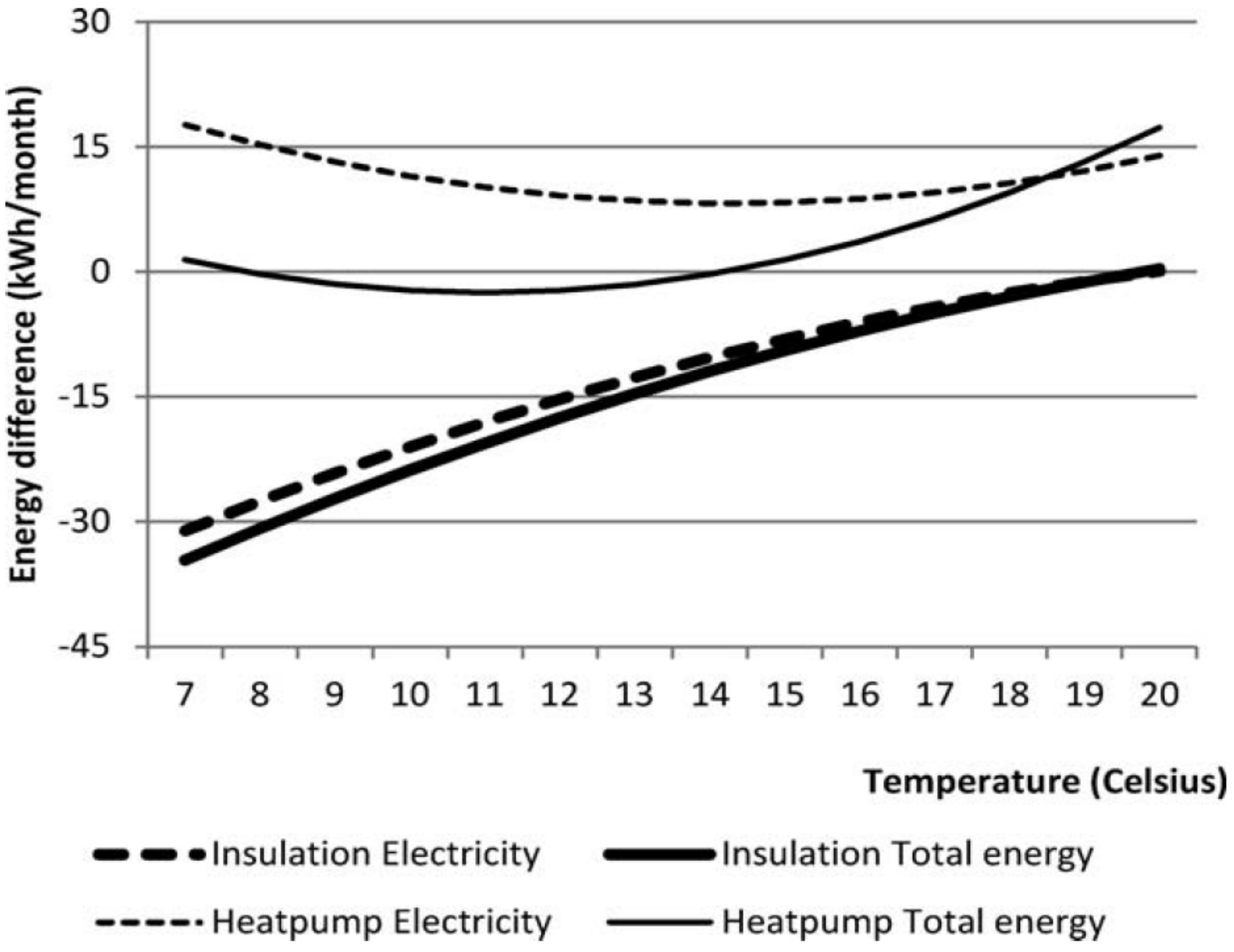
- Eligible households:
  - Owners of houses built pre -2008 and have a CSC or SuperGold combo card, or
  - own and be living in a home in an area identified as lower-income (deprivation index decile 8, 9 or 10); or
  - be referred by the Healthy Homes Initiative
  - Landlords eligible: No
- Government funding available:
  - Two-thirds (67 per cent) of the cost of installing insulation and heating (the latter from 2019)
  - From Budget 2020: 90% grants
  - From Budget 2021: 80% grants

Appendix B – Comparisons with previous work

- Changes in energy use following an insulation or heating retrofit were analysed for the 2012 Warm Up New Zealand evaluation, and subsequently in a 2016 journal paper by the same authors:
    - Grimes et al. (2016). *Does retrofitted insulation reduce household energy use? Theory and practice,* The Energy Journal, 37(4).
- These analyses utilised monthly meter data and mean monthly outdoor temperatures.
- The 2016 results showed:
    - For insulation: A 1.9% reduction in electricity use, and also a 1.9% reduction in total metered energy use.
    - For heat pumps: A 1.6% increase in electricity use, and a 0.3% increase in total metered energy use.
    - Variation in energy use with outdoor temperature as per the next slide.

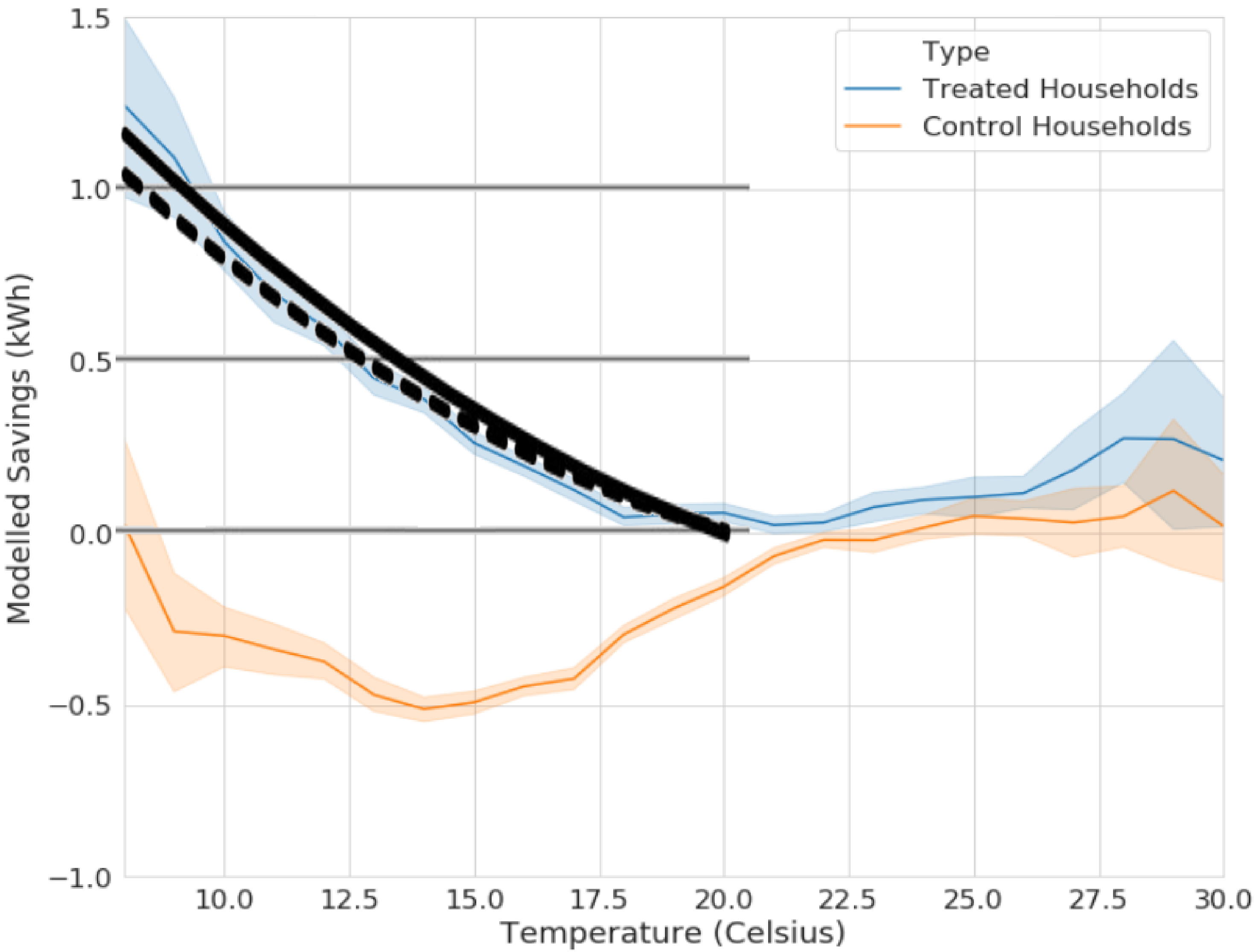
Appendix B – Comparisons with previous work

- Source: Grimes et al. (2016).
- Note that energy savings (negative values of energy difference) are shown below the x-axis in this graph.
- Also note temperatures are mean monthly outdoor temperatures.

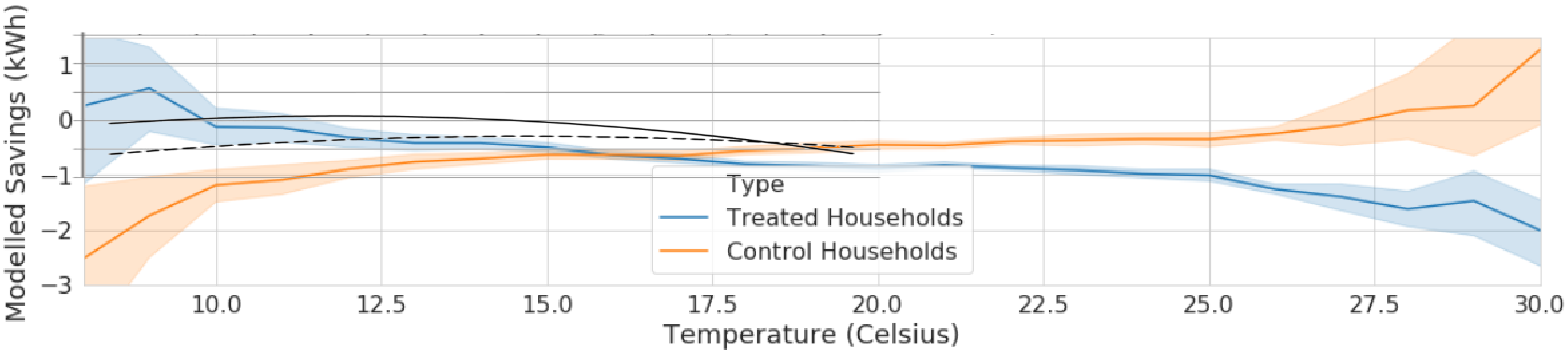


Appendix B – Comparisons with previous work

- Previous results from Grimes et al. (2016) for **insulation** overlaid on results from the present work.
- Note present work uses daily maximum outdoor temperature while previous work uses mean monthly outdoor temperature and so comparison is indicative.



Appendix B – Comparisons with previous work



- Previous results from Grimes et al. (2016) for **heat pumps** overlaid on results from the present work.
- Note present work uses daily maximum outdoor temperature while previous work uses mean monthly outdoor temperature and so comparison is indicative.

Appendix C – Data privacy

- EECA maintains a record of all homes which have received insulation and heating subsidies. This includes details of the retrofit, and the date on which it was carried out.
- EECA securely shared this information with Vector, subject to an NDA, with the provision that use was limited to the energy efficiency analysis work described here. The only information shared was the address of the house, the retrofit measures installed, the date of the install, and the housing tenure. No details of the occupants were included.
- Vector matched smart meter data records to these addresses, and generated the insights included here. Only anonymised and aggregated results have been shared with EECA, and all published results will also be anonymised and aggregated.

Appendix D – Data Lineage

- There were 361,890 retrofit jobs in the dataset provided by EECA.
- 23,042 were unable to be matched to an ICP.
- 43,275 of the remaining jobs could not be matched 1:1 to an address (1 or more ICPs within the address boundary).
- 114,460 were removed because they occurred before January 2012 and we do not have sufficient data for their baseline period.
- 87 couldn't be matched to the weather datasets.
- 92,544 couldn't be matched to a metered ICP.
- 3,725 were unable to be processed due to multiple matched ICPs.
- 45,381 were removed because they did not have data for more then 90% of the baseline or reporting periods.
- 10,190 were removed because they had periods of data without occupancy (periods where the usage was below 30% of the mean).
- 21,320 jobs were removed because of data access constraints
- 1,757 had an error when processing or a Coefficient of Variation of the Root Mean Squared Error greater then 1.0 (as advised by CalTRACK 4.3.2.1.).
- This left 6,109 retrofit jobs that could be modelled.

For insulation retrofits	For heat pump retrofits
2840 retrofit jobs were removed because the COVID-19 lockdowns impacted the required 1 year reporting period.	5,581 retrofit jobs were removed as they didn't have a heat pump installed.
487 were removed because they were part of the voluntary targeted rates programme.	28 were removed as they weren't part of the Warmer Kiwi Homes programme.
34 jobs were removed for having multiple jobs at the address.	
This left 2748 insulation retrofits.	This left 500 heat pump retrofits.
2510 suitable control ICPs were matched.	492 suitable control ICPs were matched.

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