Examining the Factors affecting Household Energy Expenditures

Lynn Riggs (MOTU),
Nigel Isaacs (School of Architecture, VUW), and
Vicki White (BRANZ)

Report for Affordable Housing for Generations – Component D

March 2023

Acknowledgements
This research is funded through the Building Better Homes, Towns and Cities National Science Challenge: *Affordable Housing for Generations*. The views expressed in this paper are those of the authors. Every effort has been made to ensure the soundness and accuracy of the opinions and information expressed in this report. While we consider statements in the report are correct, no liability is accepted for any incorrect statement or information.

Author Contact Details
Lynn Riggs undertook this research while at Motu - she is now with the Productivity Commission.

Lynn Riggs
Principal Advisor
New Zealand Productivity Commission
Email: Lynn.Riggs@productivity.govt.nz

Nigel Isaacs
Senior Lecturer
Wellington School of Architecture, Victoria University of Wellington
Email: nigel.isaacs@vuw.ac.nz

Vicki White
Senior Research Scientist
BRANZ
Email: Vicki.White@branz.co.nz

Citation
Riggs, L., Isaacs, N., and V. White, (2023) Examining the Factors affecting Household Energy Expenditure, Report for Building Better Homes, Towns and Cities, Affordable Housing for Generations – Component D, March 2023, Wellington: BBHTC.

Contents

Tables

Figures

Executive Summary

Being able to affordably heat the home and access other essential energy services is a challenge faced by many New Zealand households, and a wide range of factors contribute to a household's energy expenditures. For example, energy performance of the dwelling (e.g., design, location, size, heat retention, efficiency of appliances,) as well as fuel prices, household income, and energy needs, to name just a few, are all factors expected to affect household expenditures.

We examine household-level energy expenditure data as collected in the expenditure component of the Household Economic Survey to determine which factors, statistically and economically, affect these expenditures. By examining differences between actual expenditures in colder months relative to other months, we aim to have a better understanding of the factors that drive heating behaviours among households in New Zealand.

Our results indicate that a number of factors play a role in household energy expenditures. Outdoor temperatures – proxied using interview month and location of the dwelling in the warmer Auckland region – expectedly play a role. The results showed that households in the Auckland region reported lower energy expenditures in general (about $200 annually in the main sample) and substantially lower expenditures for those Auckland households surveyed in colder months (about $270 annually in the cold-months sample) compared to their counterparts in the rest of the country. This indicates that milder temperatures in Auckland are correlated with lower energy expenditures for those who live there when compared to similar households in the rest of the country.

In general, households surveyed in colder months reported significantly higher energy expenditures relative to similar households surveyed in warmer months. These results are not just statistically significant but are also economically significant with expenditures in the coldest months about $50 higher (on a monthly basis) than expenditures in the warmest months. This result is exacerbated, however, by the method used to annualise these expenditures, with households surveyed in colder months appearing to spend $500-$600 more annually than their counterparts surveyed in warmer months. These results indicate that using the annualised household energy expenditures for analyses at the individual household level is likely to be problematic without some form of seasonal adjustment.

We also find that stand-alone dwellings and larger dwellings are associated with higher energy expenditures, with the difference between a 1- or 2-room dwelling and a 9+-room dwelling being between $1200 and $1700 annually.

Households in rental dwellings also tend to have higher energy expenditures relative to similar households in owner-occupied dwellings.

Household income is also a statistically significant predictor of household energy expenditures, where a 1% increase in income is associated with a $3-$4 increase in annual expenditures for our overall sample but with a $1.70-$2 increase for our low-income sample. Hence, the effect of income on energy expenditures is not linear. For lower income households, smaller dwellings may not reduce their energy expenditures to the extent seen for the full sample.

As there is no indoor temperature data, this analysis cannot take into account variations in heating practice – whether internal temperatures or the proportion of the house heated. Nor can we account for differences in energy-saving behaviours. However, our results suggest that households in rentals are more likely to report living in homes that are more difficult to keep warm and are more likely to be damp or mouldy. Previous literature has found similar results.

1. Introduction

Being able to affordably heat the home and access other essential energy services is a challenge faced by many New Zealand households, and a wide range of factors contribute to a household's energy expenditures. For example, energy performance of the dwelling (e.g., design, location, size, heat retention, efficiency of appliances,) as well as fuel prices, household income, and energy needs, to name just a few, are all factors expected to affect household expenditures.

Research has shown New Zealand houses are often colder than the minimum recommended indoor healthy temperature and there is a tendency for spot-heating as opposed to whole-house heating. For example, the 2018 General Social Survey showed over one in five households (21 percent) reported their house was always or often colder than they would like in winter and 46 percent of households never heated their bedroom at night in winter (White, 2020), with approximately 16% of households reporting cost as the main reason for not heating the bedroom (Statistics New Zealand, 2019). Grimes, Young, et al., (2011) found that households with newly installed heating and insulation used much of the energy savings from these improvements to increase temperatures in their homes rather than reduce their energy payments. This indicates that, prior to receiving the energy-efficient improvements, people wanted warmer homes but were unable to afford them.

Given the above and what we know about household tendencies to under-heat or ration energy use, energy expenditures on household fuels do not capture the true level of demand for energy. This also may limit the efficacy of policies to address households' vulnerability to energy hardship. Understanding the scale and distribution of energy hardship in New Zealand needs to include an understanding of household energy requirements and the thermal performance of our housing stock.

We examine household-level energy expenditure data as collected in the expenditure component of the Household Economic Survey to determine which factors, statistically and economically, affect these expenditures. By examining differences between actual expenditures in colder months relative to other months, we aim to have a better understanding of the factors that drive heating behaviours among households in New Zealand.

This research touches on a number of other literatures including, but not limited to, those on residential energy demand, residential energy efficiency, energy hardship, financial literacy, and energy literacy.

The residential energy demand and residential energy efficiency literatures both tend to examine the relationship between a household's dwelling characteristics, socioeconomic characteristics, and residential energy consumption (i.e., demand) using either household survey data on expenditures or using administrative data on actual energy consumption from energy suppliers. The main difference between the two literatures is that the residential energy demand literature tends to focus on the effect energy prices and income have on energy consumption while the focus of the energy efficiency literature tends to be on the effects different technologies, and particularly differences in uptake of these different technologies, have on residential energy consumption. Both literatures consistently find significant relationships between residential energy consumption and dwelling characteristics – size, climate (primarily temperature), degree of detachment, insulation coverage, heating/cooling sources, appliance efficiency, number and type – as well as certain socio-demographic characteristics of the household – household composition, household size, income, housing tenure. A variety of other socio-demographic characteristics have been considered but generally with inconsistent results including but not limited to age, gender, education, labour force status, ethnicity of either the household head or household members more generally. (Awaworyi Churchill & Smyth, 2020; Fuerst et al., 2020; Halleck Vega et al., 2022; Hamilton et al., 2016; Jones et al., 2015; Khan, 2019; Kriström, 2013; O'Neill & Chen, 2002; Taneja & Mandys, 2022; Trotta, 2018) One problem with estimating these relationships is the correlation between these different measures. For example, income is often highly correlated with education and dwelling size. Hence, including these different factors in the same regression analysis can be challenging and may be part of the reason for the inconsistency of results in the literature, especially when the study is also based on a small sample.

In New Zealand, a number of studies have looked at these topics. For example, the Household Energy End-use Project collected detailed energy and temperature readings, occupant surveys and energy audits for approximately 400 randomly selected New Zealand houses between 1999 and 2005. (Isaacs et al., 2010) This project provided extensive information about the role of various factors on energy efficiency and consumption but was limited to a relatively small number of observations. Other studies went beyond simply analysing the effects of energy efficiency on energy demand and consumption but also analysed the health effects of improved energy efficiency. (Grimes, Denne, et al., 2011; Grimes, Young, et al., 2011; Howden-Chapman et al., 2005, 2007, 2009, 2012)

Two New Zealand studies used household expenditure survey data and found significant relationships between energy expenditures and dwelling characteristics, household characteristics, and interview month. (Polkinghorne, 2011; Stephenson, 2021) Both studies found that households surveyed in winter months reported significantly higher energy expenditures. In fact, Stephenson (2021) showed the differences in the distribution of energy expenditures by interview month, but its main focus was primarily on estimating cross- and own-price elasticities and not on estimating the effects these different characteristics have on actual expenditures. Polkinghorne (2011) focused on estimating relationships between energy expenditures and the other household characteristics using a pooled regression approach across the entire sample but did not examine results for different subsets of the population, perhaps because the analysis used only one year of survey data (2006/07). Our analysis focuses on estimating the seasonality of energy expenditures accounting for different household and dwelling characteristics by pooling a number of survey years in order to examine other subsets of the data (e.g., low-income households, winter months).

The energy hardship literature is also related to this work but generally with a different focus. This literature is often focused on determining the best measures of energy hardship, determining the proportion of the population living in energy hardship, or both.[1] Our work is most related to studies using expenditure-based indicators, which are either expressed as a percentage of household income[2] or as a proportion of the national mean or median energy expenditure[3]. (Awaworyi Churchill & Smyth, 2020; Bardazzi et al., 2021; Legendre & Ricci, 2015; Riva et al., 2021; Siksnelyte-Butkiene et al., 2021) These expenditure-based measures are often criticised because they are based on actual expenditure and not on required expenditure, whereas the definition of energy or fuel poverty is largely related to households' ability to afford their energy needs. It is argued in the literature that energy poverty is not just income poverty but is more broadly related to the inaccessibility of affordable fuels and energy-efficient technologies. A common example is the inability of renters to improve the energy efficiency of their dwelling.

Our results indicate that these expenditure-based measures should not only take into account dwelling characteristics (i.e., energy needs) since larger, detached homes require more energy to run but also the seasonality of energy expenditures. For example, Riva et al., (2021) based their expenditure measure on a household survey which asks households about their last energy payments, and while the authors indicate that these payments have been annualised, it is unclear if these were seasonally adjusted. The data used for our analysis is based on similar survey information, and as we show the annualised expenditures vary substantially and significantly depending on survey month, which means that households could be incorrectly identified as experiencing energy poverty when they were simply surveyed in a heating-intensive location and month, especially if no seasonal adjustment is made.

This work adds to the literature by showing the extent to which different dwelling and household characteristics affect actual energy expenditures as well as how this varies for different subsets of the population. For example, our results indicate that household income is significant factor in estimating energy expenditures and that the relationship may not be linear.

The rest of the paper proceeds as follows. Section 2 provides an overview of heating in New Zealand. Section 3 examines the seasonality of energy use and winter heating, with a specific focus on differences between hot water and space heating. Section 4 outlines the data used in the analysis as well as the methods used. Section 5 provides descriptive results, whereas Section 6 provides the results from our regression analysis. Section 7 concludes.

---

[1] Energy hardship and fuel poverty can be used interchangeably. Brabo-Catala et al., (2022) include a discussion about the similarities and differences of usage of these terms. In the literature, fuel poverty, energy poverty, energy vulnerability, and energy justice are similar concepts with no clear boundaries distinguishing them. (Siksnelyte-Butkiene et al., 2021)

[2] In the literature, households spending more than 10% of their income on energy (excluding transport) are defined as experiencing energy or fuel poverty, which is based on early work in this field by Boardman (1991). Income is often measured as disposable income either before or after housing costs as in Riva et al., (2021). However, consumption (i.e., total expenditure) is smoother than income over an individual's lifetime and hence a more reliable approximation of family welfare and should be considered as an alternative to disposable income. (Alvarez, 2019)

[3] The mean or median energy expenditure can be calculated either in levels or as the share of household income allocated to energy.

2. Overview of Heating in New Zealand

In New Zealand, a large percentage of households use electricity to heat their homes but wood and gas heat have been significant fuel sources as well. This can be seen in Figure 1 which shows household reports of main heating fuels or main heating types from publicly available Census data for the time period 1986 to 2018 as reported by Statistics NZ.[4] Between 1996 and 2013, the percentage of households reporting some form of electrical heating as a main type of heating ranged between 70% and 80% as shown in Figure 1.

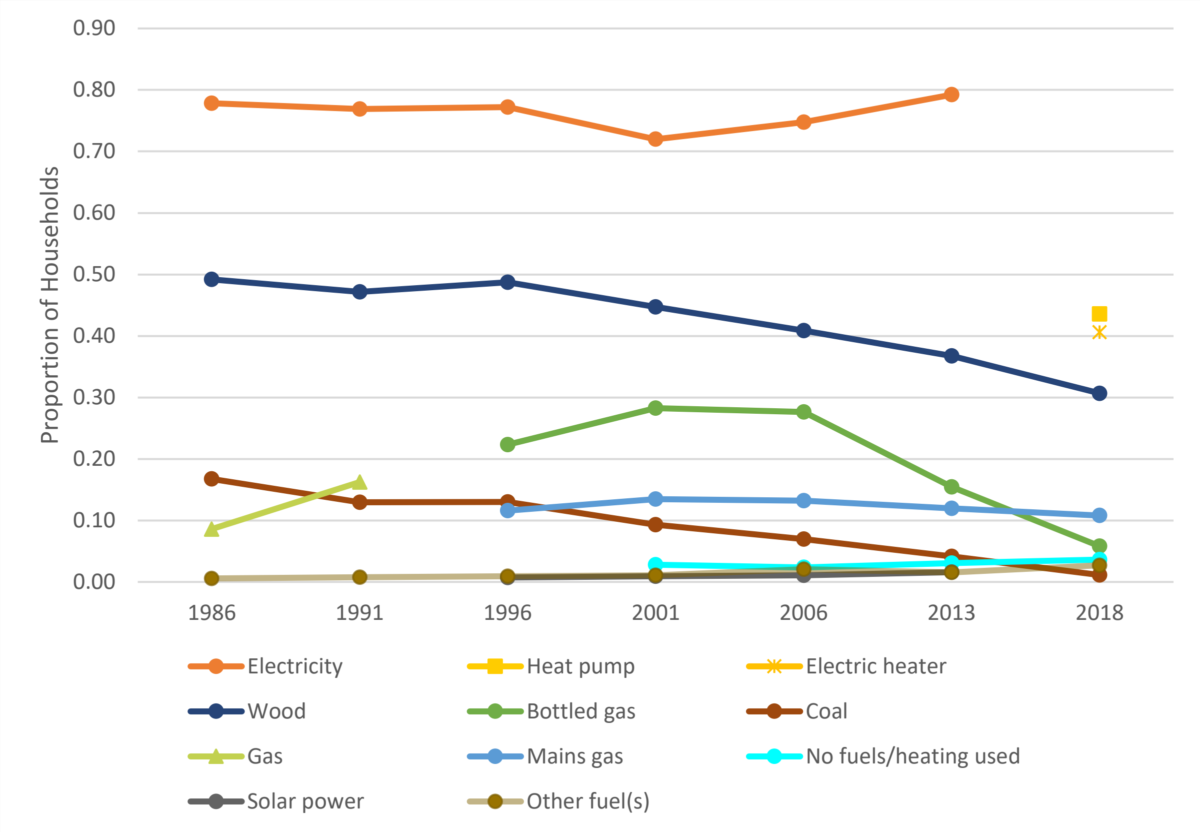
In 2018, the Census asked about heating types as opposed to heating fuels as had been asked in previous Censuses, so instead of asking about electricity as a heating fuel type, the 2018 Census asked about the use of heat pumps and electric heaters. For these heating types, 44% of households in 2018 reported using heat pumps as a main heating type and 41% reported using electric heaters. The second most common fuel source over this time period was wood – between 1986 and 1996, approximately 50% of households reported using wood for heating, but since 1996, this has steadily declined to 31% of households in 2018.[5] In 1986, coal was the third most frequently reported fuel type, with 17% of households reporting its use for heating, but this has declined steadily over the time period with approximately 1% reporting its use for heating in 2018.

Over time, gas surpassed coal as a main heating fuel type, with bottled gas being more predominant from 1996 to 2013 than mains gas. Bottled gas appears to have peaked between 2001 and 2006 with 28% reporting its use as a main heating fuel type. Mains gas remained fairly steady from 1996 to 2018 (between 10 and 14%) as did the percentage of households reporting no fuels/heating used, around 3% between 2001 and 2018.

[4] The categories of reported fuel and heating types changed between 1986 and 2018, and there is some discrepancy between the way that fuel types were reported which may affect the proportions listed. For example, electricity was split into heat pump and electric heater in 2018. For gas heating, the categories changed over time from 'gas' in 1986 and 1991, to 'mains gas' and 'bottled gas' between 1996 and 2013, to 'fixed gas heater' and 'portable gas heater' in 2018. For simplicity, we classify 'fixed gas heater' as 'mains gas' and 'portable gas heater' to 'bottled gas' in 2018.

[5] In 2018, the publicly available data had two categories pertaining to wood as a fuel source: wood burner and pellet fire. Approximately 30% of households reported using a wood burner and 1% reported using a pellet fire. For simplicity, we combined these into one category, though it is possible that there is overlap in the households reporting these.

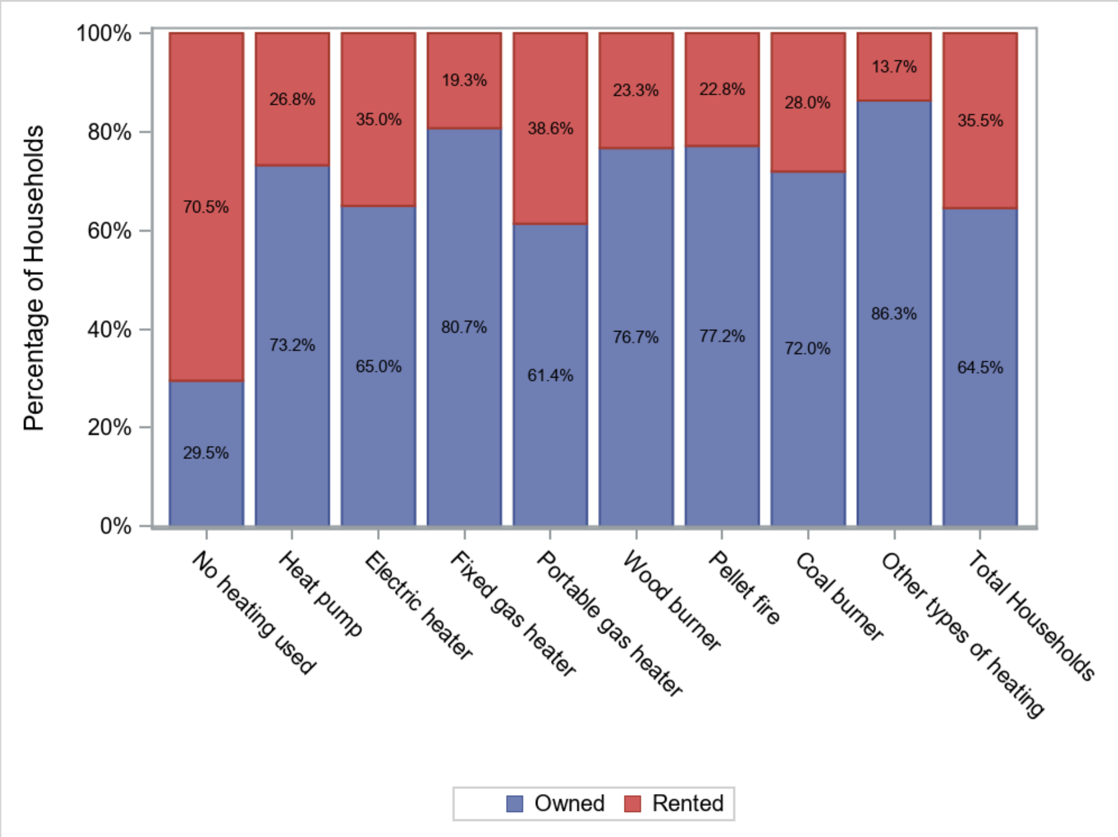
Figure 1 . Main Types of Heating and Heating Fuels Used (Total Responses), 1986-2018



Source: Calculated by the authors from publicly available Census data (1986-2018) from Statistics New Zealand.
Notes: There is some discrepancy between the way that fuel and heating types were reported over time, with the categories changing between 1986 and 2018. For example, electricity was split into 'heat pump' and 'electric heater' in 2018. For gas heating, the categories changed from 'gas' in 1986 and 1991, to 'mains gas' and 'bottled gas' from 1996 to 2013, to 'fixed gas heater' and 'portable gas heater' in 2018. For simplicity, we classify 'fixed gas heater' as 'mains gas' and 'portable gas heater' to 'bottled gas' in 2018. The 2018 publicly available data had two categories pertaining to wood as a fuel source: wood burner and pellet fire. Approximately 30% of households reported using a wood burner and 1% reported using a pellet fire. For simplicity, we added these together in order to combine them into one category, 'wood', though it is possible that there is overlap in the households reporting them.

The publicly available 2018 Census data also reported main heating types by housing tenure as shown in Figure 2. While 36% of households in the 2018 Census reported renting their dwelling, 71% of those reporting 'no heating used' were renters. Moreover, renters were underrepresented in reporting a number of main heating sources including heat pumps, fixed gas heaters, wood burners, and pellet fires. Renters were, however, evenly represented in electric heater use and portable gas heater use.

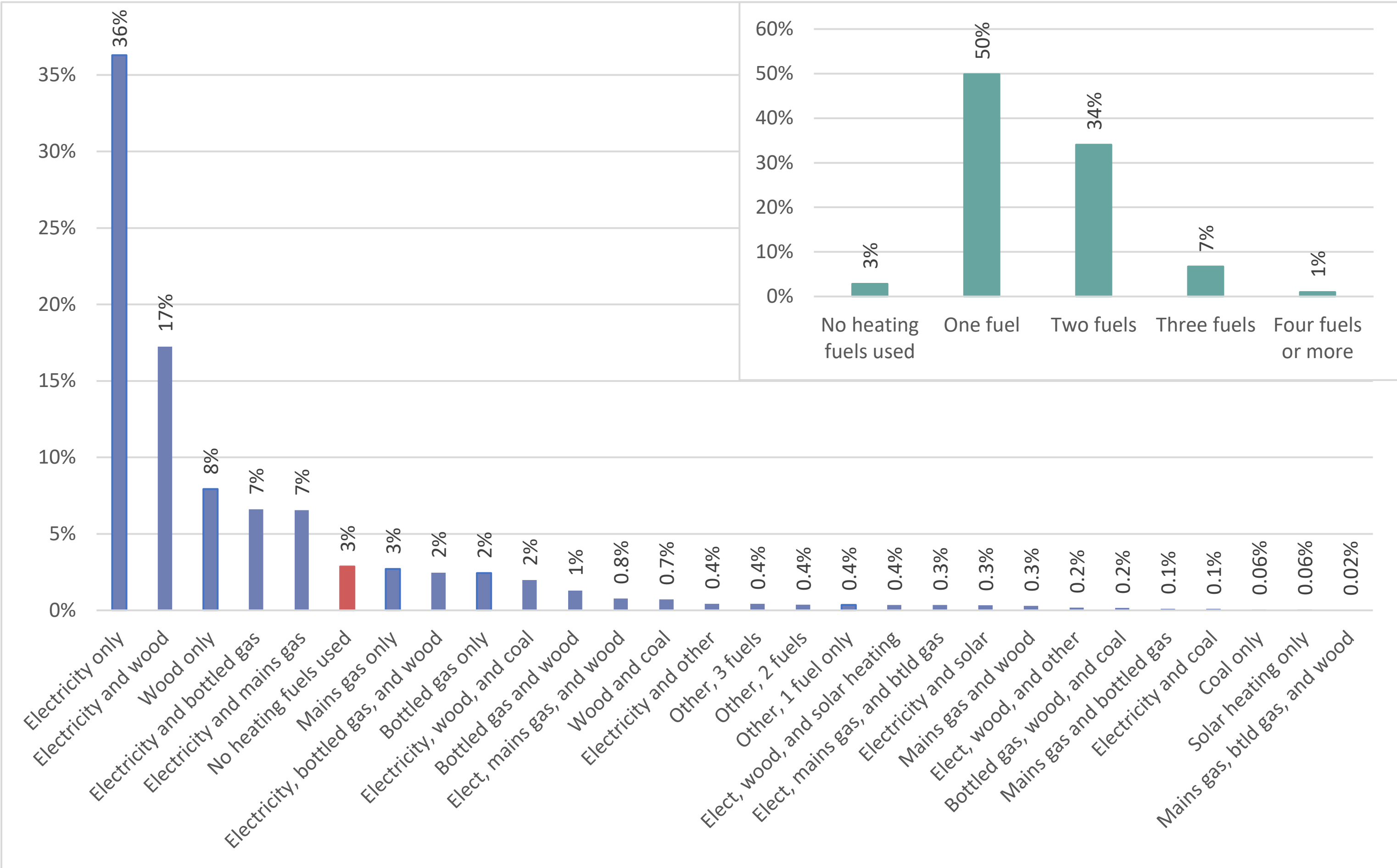
Figure 2. Main Types of Heating Used (Total Responses) in 2018 by Housing Tenure



Source: Calculated by the authors from publicly available, 2018 Census data from Statistics New Zealand.
Notes: For owned dwellings, we combined the categories 'owned or partly owned' with 'held in a family trust'. There were a small number of households (approximately 0.5%) listed as 'not elsewhere included'. Within each heating type, the number is imperceptibly small.

In 2013, the publicly available Census data reported the combinations of different fuel types households used for heating (shown in Figure 3), with most households reporting one fuel only (50% of households), 34% reporting two fuels, 7% reporting three fuels, and 1% reporting four or more fuels. Moreover, 36% of households reported using only electricity as their fuel type, making this the most frequently reported fuel-use combination in 2013. The second most frequently reported heating fuel combination in 2013 was electricity and wood (17% of households), and the third most frequently reported heating fuel was wood only. Using any combination of fuel types that includes electricity, almost 75% of households use electricity in some way for heating.

Figure 3. Main Heating Fuel Types in 2013, Combined Responses



Source: Calculated by the authors from publicly available, 2013 Census data from Statistics New Zealand.

Notes: Approximately 6% of households were reported with fuel type unstated. The percentages in the figure are based on the total number of households, including those with no stated fuel type.

3. Seasonality, Energy Use and Winter Heating

For our analysis, we assume that energy needs for purposes other than heating in winter months remain relatively similar to those in summer months. In this section, we explore the extent to which this is a robust assumption for water heating. We focus on water heating because it is likely to vary as environmental conditions vary during the year and it can constitute a significant portion of a household's energy use that is on par with space heating.

The Household Energy End-use Project (HEEP) reported that the two largest household energy end-uses involved heating – space heating at 34% and hot water heating at 29% of total energy use. (Isaacs et al., 2010) Although the HEEP research analysed the seasonality of space heating, it did not explore the seasonality of water heating. In this section, we analyse the extent to which both vary throughout the year in order to put the water heating results into context.

The amount of energy required to increase the temperature of 1 cubic metre of any material by 1°C, Q, is given by the equation below:

$$\mathrm{Q} = \Delta\mathrm{T} * \mathrm{Vol} * \mathrm{Density} * \mathrm{Specific\ Heat}$$

where ΔT is the change in temperature, Vol is the volume of the material, Density is the density or weight of the material in one cubic metre[6], and Specific Heat is the specific heat capacity of the material (generally measured in Joules per degree Celsius per kilogram ($J\ °C^{-1}\ kg^{-1}$)). The appendix provides a table of the density and specific heat capacity of air, water, and other selected building materials.

For our example, we calculate the energy requirements for a household in the Wellington suburb of Kelburn using the following assumptions:

- **internal air** is heated to 20°C from the outdoor temperature[7] in a house of volume 10 m x 10 m x 2.4 m (240 m^3) with 1 air change per hour (ACH) for 184 days per year[8]; and
- **domestic hot water (DHW)** is provided at 60°C[9] for 2 adults each using 50 litres per day[10].

[6] For water, the density is not required as 1 litre of water weighs 1 kg.
[7] Although the NZBC does not require air temperature control in houses, the definition for "heating energy" used in Clause H1 assumes a "continuous temperature of 20°C throughout the building" with a minimum air change of 1 ACH. For more information on this topic, see https://www.building.govt.nz/building-code-compliance/h-energy-efficiency/h1-energy-efficiency/.
[8] This is the number of heating days given the assumption heating only occurs in months when the average air temperature is less than 15°C, May-October. These average temperatures are provided in the appendix.
[9] We base our assumption around the temperature to which the water must be heated in the New Zealand Building Code (NZBC). NZBC Clause G12 /AS1 6.14.1 requires hot water maximum delivery at 55°C; however, Clause 6.14.2 requires the storage water heater thermostat be set at not less than 60°C in order to prevent the growth of Legionella bacteria. Hence, we use the minimum temperature of 60°C for our analysis. For more information about these requirements, see https://www.building.govt.nz/building-code-compliance/g-services-and-facilities/g12-water-supplies/.
[10] For the amount of water needing to be heated, we follow Williamson & Clark (2001, p. 25), who suggest an amount of 40-60 litres of 60°C hot water per person is required per day, and use the midpoint of 50 litres per person per day.

In practice, hot water use or the air change rate may be higher or lower than these assumed values, but they have been selected for the purpose of this analysis, which is to simply show the difference in energy requirements between the two types of heating in months with varying temperatures. For this purpose, these assumptions should provide a sufficient basis for comparison.

We first start by estimating the annual average energy used in each case (i.e., internal air and DHW heating).

The annual average energy required[11] for internal air heating is based on the outdoor heating month average temperature[12] of 12.6°C raised to 20°C indoors, giving a change in temperature (ΔT) of 7.4°C, and is calculated as follows:

$$(7.4°C)*(240\ m^3/hr)*(24\ hr/day)*(184\ day/yr)*(1.15\ kgm^{-3})*(1063\ J\ °C^{-1}\ kg^{-1})$$

$$= 2,663\ kWh/yr$$

We next calculate the annual average water heating energy required to raise the average cold-water temperature of 13.7°C[13] to 60°C (so ΔT is 46.3°C):

$$(46.3°C)*(50*2l/day)*(1\ kg/l)*(365\ day/yr)*(4187\ J°C^{-1}\ kg^{-1})*(1kWh/3.6MJ)$$
$$= 1,966\ kWh/yr$$

In addition to the energy used to provide hot water, energy is also required to maintain the water temperature ("standing losses") which the HEEP research calculated to be 2.2 kWh/day for an A or B grade or 2.7 kWh/day for a C- or D-grade, 180-litre cylinder. (Isaacs et al., 2010, p. 237) Assuming a C-grade, 180-litre cylinder, these standing losses would be equivalent to 986 kWh/year.[14] When added to the energy used to raise the temperature of the water, this gives a total of 2,951 kWh per year.

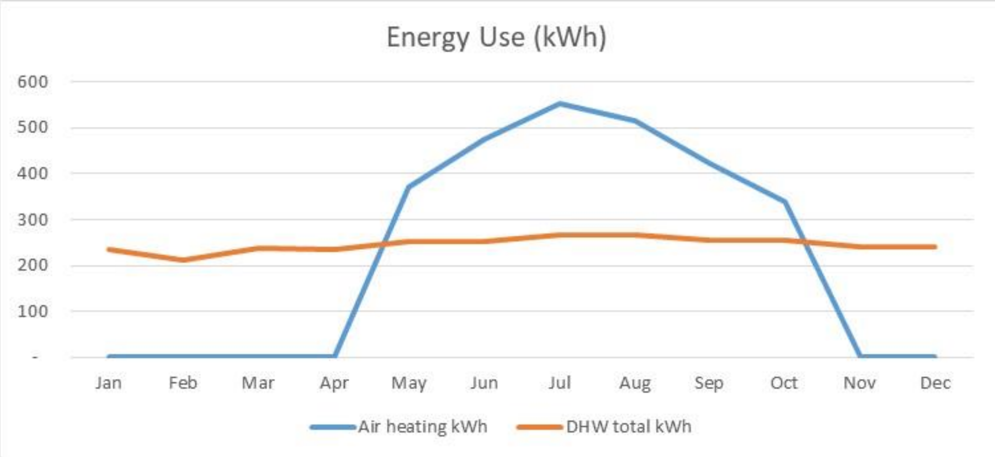
Based on these calculations, the total annual energy consumed for air heating is 2,663 kWh, which is on par with that used for water heating (2,951 kWh). Over a 365-day year, this equates to space heating averaging 7.3 kWh/day and water heating averaging 8.1 kWh/day. However, these amounts are not necessarily the same over the course of the year as the outdoor temperature can vary considerably from month to month. Figure 4 and Table 1 show the monthly energy consumption from internal air heating and from DHW.

The monthly analysis shows that while the temperature changes for DHW are higher than for internal air, the total kWh required for water heating are also more stable from month to month. The monthly total energy requirements for DHW range from 212 to 266 kWh (a 26% increase from the warmest to the coldest month), whereas the range for air heating is from 340 to 552 kWh in the

[11] To convert the result from Joules to kWh, the final term is added given that 1 kWh = 3.6 MJ = 3,600,000 J.
[12] We use the outdoor air temperature as the starting temperature from which the air must be heated. The outdoor air temperature is based on monthly average air temperatures for the Kelburn, Wellington, meteorological station, which over the period 1909 to 1980 was 12.6°C in the heating months May-October. (NZ Meteorological Service, 1983) The average air temperatures used in these calculations are provided in the appendix.
[13] For water which travels through underground pipes to arrive at the house, we use the average ground temperature at 1 m depth based on monthly average ground temperatures for the Kelburn, Wellington, meteorological station, which over the period 1909 to 1980 was 13.7°C. (NZ Meteorological Service, 1983) The average ground temperatures used in these calculations are provided in the appendix.
[14] The calculation assumes the cylinder is run every day in the year (2.7*365=985.5).

heating months (an 80% increase from the warmest to the coldest heating month). In conclusion, while there is some seasonal variation in domestic hot water energy use, it is small over the year, whereas the space heating energy use is strongly seasonal. Hence, increased energy expenditure in colder months is largely attributable to air heating and not to other energy uses.

Figure 4: Calculated Space & Water Heating Energy Use by Month



Source: Estimates calculated by the authors.

Table 1: Internal Air & Water Heating Energy Use, and Temperature Differences by Month

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Air heating kWh	-	-	-	-	**370**	**475**	**552**	**515**	**422**	**340**	-	-	**2,674**
DHW Water alone	153	136	154	155	169	171	183	183	173	172	159	158	1,965
DHW heat loss	84	76	84	81	84	81	84	84	81	84	81	84	986
DHW total kWh	**236**	**212**	**237**	**236**	**252**	**252**	**266**	**266**	**254**	**256**	**240**	**242**	**2,951**
20°C Inside air ΔT (°C)					6.1	8.1	9.1	8.5	7.2	5.6			7.4
60°C DHW ΔT @ 1m (°C)	42.3	41.9	42.6	44.3	46.8	49.1	50.7	50.7	49.6	47.7	45.7	43.8	46.3

Note: The **Year** total in this table is calculated from the sum of monthly values, which differ slightly from the values given in the text.

4. Data and Methods

Household-level microdata from the Household Economic Survey (HES) – Expenditure Component available from Statistics NZ as part of their Integrated Data Infrastructure (IDI)[15] was used as the primary data source to analyse household expenditures on energy. This component of HES is only conducted every three years. We used the following HES years: 2006/07, 2009/10, 2012/13, 2015/16, and 2018/19.[16] All households with positive energy expenditures across these years were included, and we used the household survey weights for the analysis.

[15] The IDI is a large database which holds de-identified microdata about people and households. More information about the IDI can be found on the Statistics NZ website.

[16] There was a continuity break in the survey design that reduces the comparability of data in the years prior to 2006/07, and earlier years were not available via the Statistics NZ Data Lab environment at the time of the analysis. However, the available survey years (2006/07-2018/19) provide a sufficient sample for us to analyse. This period also predates the Healthy Homes Standards for rental homes which became law on 1 July 2019. More information about these standards is available here: https://www.hud.govt.nz/residential-housing/renting/healthy-homes-standards/. The 2018/2019 survey year also includes a period where the Government provided the Winter Energy Payment to New Zealand Superannuation and Main Benefit

4.1 Dependent and Explanatory Variables

The expenditure component of HES asks respondents about household energy expenditures which include mains gas, electricity, bottled (LPG) gas, home-heating oil, firewood, coal, and other types of domestic fuels. In the data, the reported expenditures are typically annualised. However, expenditures for electricity and mains gas are generally based on the respondent's last bill, which have been annualised, but not seasonally adjusted, for each household. In addition to the amount of the expenditure, the data includes information about the time period covered by the expenditure, with most energy bills covering a one-month period. For this reason, interview month can be used to differentiate expenditures in winter months from expenditures in other months, with the difference between summer and winter expenditures providing an estimate of the amount households spend on heating their homes.

The dependent variable for our primary analysis is total household energy expenditure for the household's primary residence,[17] including supply charges (e.g., lines charges) but excluding associated fees that are in addition to households' normal energy bills (e.g., connection or disconnection fees). Specifically, we define energy expenditures as those classified in these HES categories: electricity, reticulated gas, CNG and LPG, coal, firewood, heating oil, combinations of domestic fuel, and domestic fuel not elsewhere classified (NEC). Since a large number of households only report electricity for their energy expenditures, we also used total household expenditures on electricity as a dependent variable for robustness checks.

The explanatory variables used for the main analysis are based on the following measures:

- *HES years*: binary variables which allow us to control for time effects across years including changes in fuel mix and prices over time;[18]
- *Interview months*: binary variables which allow us to control for seasonal effects including price changes and outdoor temperatures during the year;
- *Stand-alone home*: binary variable which distinguishes free-standing homes from adjacent or attached homes (e.g., townhouses, apartments, semi-detached) because free-standing homes with their greater exterior surface area are likely to require more energy to heat;[19]
- *Housing tenure*: binary variables which allow us to distinguish social housing,[20] private rentals, and owner-occupied dwellings since owner-occupiers generally have more control over the energy efficiency of their homes including heating units, insulation, and appliances;

recipients. We do not explicitly control for this since other work indicates that these payments did not significantly change energy expenditures for either group. (Hyslop et al., 2022)

[17] HES asks questions separately about energy expenditures for other New Zealand properties that are not the household's primary residence, but these are excluded from our analysis.

[18] All analyses are done using nominal dollars.

[19] Respondents are asked two questions in the survey to determine if the dwelling is a stand-alone dwelling. The first asks about the type of dwelling (house, townhouse, unit, apartment, moveable dwelling), and the second asks about whether or not the dwelling is joined to another dwelling (yes, no).

[20] Respondents are asked if the dwelling is rented, and if yes, who owns the dwelling. Potential responses include the following: private person; private trust; local authority or city council; Housing New Zealand; other state-owned corporation, state-owned enterprise, or government department; or business or other organisation. For the main analyses, the dwelling was considered social housing if the landlord was not a private person or private trust. In robustness checks, we also used different combinations of the landlord types included in social housing.

- *Number of rooms in the dwelling:*[21] binary variables which allow us to control for the size of the home given that larger homes generally require more energy to operate and heat;[22]
- *Auckland region*: binary variable which allows us to control for the warmer climate of dwellings in the Auckland region compared to other areas of the country;[23]
- *Total household income (logged)*: continuous measure of the household's total gross income from all sources to assess income effects on energy expenditures, which could have either a positive relationship with energy expenditures (e.g., higher income households can generally afford to spend more) or a negative relationship (e.g., higher income households can generally afford more energy efficient homes and appliances),[24] and
- *Household housing costs (logged):* continuous measure of the household's total housing costs, which consists of expenditures from mortgage principal repayments, mortgage interest payments, mortgage application fees, rent payments, other payments associated with renting (e.g., bonds paid in the last 12 months), property rates payments (both regional and local government), and payments associated with building-related insurance.[25]

4.2 Samples used for analysis

For our analysis, we created four different samples. First, we included households surveyed in all months ("all-months sample") but for contrast also used only those households surveyed in colder months (June to November) ("cold-months sample"). In addition, we created a sample which excluded households with nine or more rooms in the dwelling ("smaller-homes sample") given the small number of households with larger homes. This sample allows us to examine the potential influence outliers may have on the results. To examine energy expenditures for lower income households, we created a sample which includes only households in the bottom six income deciles ("low-income sample").[26] Figure 5 provides a comparison of the weighted sample sizes in each year, and Table 2 provides the overall total weighted counts.

[21] For this measure, survey respondents are instructed to count bedrooms, kitchens, dining rooms, lounge or living rooms, rumpus rooms, family rooms, conservatories you can sit in, studies, studios, hobby rooms. Respondents are instructed to exclude bathrooms, showers, toilets, spa rooms, laundries, halls, garages, and pantries. Respondents are also instructed to count an open-plan room like a kitchen-lounge-dining-room as three rooms or a kitchen-dining room as two rooms.

[22] In robustness checks, this measure was used as a continuous variable; however, using a series of binary variables allows for non-linearity. Due to small sample sizes, studios and one-room dwellings were combined into one category as were dwellings with 9 or more rooms. The HES data also includes the number of bedrooms in the dwelling, but this is highly correlated with the number of rooms. Moreover, the number of rooms provides a better indication of the overall size of the home, so this was used for the main analysis.

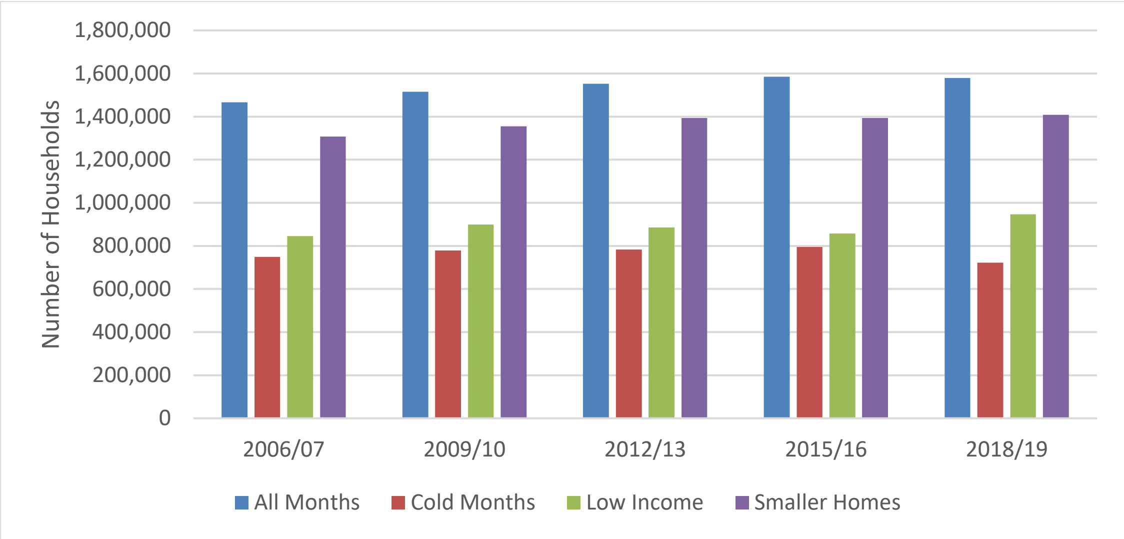
[23] When looking at the distribution of energy expenditures for dwellings in the Auckland region compared to other areas of the country, we found that the distribution for Auckland looked very different, with Auckland having less dispersion in general and a much smaller difference in the distributions for winter and summer months. Combining households in the Auckland and Northland regions gave similar results.

[24] A small number of households were reported as having negative income. These households were dropped from the regression analysis.

[25] The housing cost measure was only available for 2015/16 and 2018/19. Only actual rents (i.e., rent payments paid by the household) are included in the rent payments used in the measure – imputed rent (i.e., the benefit value from home ownership of not having to pay rent) is not included. (Statistics New Zealand, 2020)

[26] Income deciles were calculated for each survey year, with households in the bottom six deciles in the sample.

Figure 5. Number of Households by HES Survey Year and Analysis Sample



Notes: Survey weights were used to calculate the number of households.

Table 2 provides summary statistics describing the different samples, weighted to be representative of the total population. In general, the low-income sample is most different from the other three samples. However, there are also some differences between the smaller-homes sample and the all-months sample—primarily in households' average electricity and energy expenditures.

The low-income sample has a lower percentage of households in stand-alone homes (79% vs. 84%) and in owner-occupied homes (62% vs. 69%) compared to the all-months sample. The low-income sample also has a higher percentage of households in social housing (10% vs. 7%) as well as in private rentals (28% vs. 24%). Households in the low-income sample were also less likely to live in the Auckland Region (26% vs. 31%). Households in the low-income sample had lower household incomes (with an average household income of $38,000 compared to $65,000 for the whole sample), lower energy bills ($2,000 vs. $2,300), and lower housing costs ($8,900 vs. $11,700); however, given the large standard deviations, the differences are not statistically significant.

The low-income sample also tends to live in dwellings with fewer rooms than the all-months sample. In fact, as shown in Figure 6, the low-income sample is different from all the other samples in this respect, with 36 percent of households in the low-income sample living in dwellings with 5 or fewer rooms compared to 26 percent for the all-months and cold-months samples. Moreover, only 14 percent of the low-income sample lives in dwellings with 8 or more rooms, whereas 23 percent of the all-months and cold-months samples live in these larger dwellings. The bottom panel of Figure 6 shows these proportions using only those households living in dwellings with 8 or fewer rooms. We do this to compare the cold-months and low-income samples to the smaller-homes sample.[27] These comparisons show that the low-income sample still has a much greater proportion of households in smaller homes and a much smaller proportion in larger homes compared to the cold-months or smaller-homes samples. However, all three of these samples have between 34 and 35 percent of households living in 6-room dwellings.

[27] The smaller-homes sample is the all-months sample when using dwellings with 8 or fewer rooms.

Table 2: Summary Statistics by Analysis Sample

	All Months	Cold Months	Low Income	Smaller Homes
Dwelling Characteristics				
Stand-alone Home	0.838	0.839	0.785	0.821
Social Housing	0.071	0.069	0.102	0.077
Private Rental	0.240	0.238	0.279	0.260
Owned	0.685	0.690	0.615	0.659
Number of Rooms				
≤ 2	0.007	0.007	0.012	0.008
3	0.026	0.026	0.039	0.029
4	0.073	0.070	0.104	0.082
5	0.161	0.161	0.206	0.181
6	0.303	0.307	0.328	0.341
7	0.199	0.196	0.170	0.224
8	0.122	0.126	0.083	0.137
≥ 9	0.109	0.108	0.058	
Regions				
Auckland	0.305	0.286	0.263	0.300
Expenditure and Income				
Electricity	1,958 (1,304)	2,169 (1,445)	1,757 (1,132)	1,894 (1,231)
Total Energy	2,328 (1,420)	2,589 (1,589)	2,026 (1,221)	2,230 (1,331)
Total Energy (No Fees)	2,314 (1,429)	2,573 (1,597)	2,012 (1,234)	2,217 (1,339)
Housing Costs	11,703 (17,384)	11,628 (17,155)	8,904 (11,599)	11,446 (15,729)
Total HH Expenditure	61,216 (50,121)	61,181 (49,251)	41,379 (31,573)	57,188 (41,816)
Total HH Income	65,259 (83,875)	65,101 (84,388)	37,943 (21,329)	61,536 (72,561)
Number of Households				
2006/07	1,467,000	749,000	846,000	1,308,000
2009/10	1,516,000	779,000	899,000	1,355,000
2012/13	1,552,000	783,000	886,000	1,393,000
2015/16	1,585,000	795,000	857,000	1,394,000
2018/19	1,580,000	723,000	946,000	1,408,000
Total	7,700,000	3,829,000	4,434,000	6,858,000

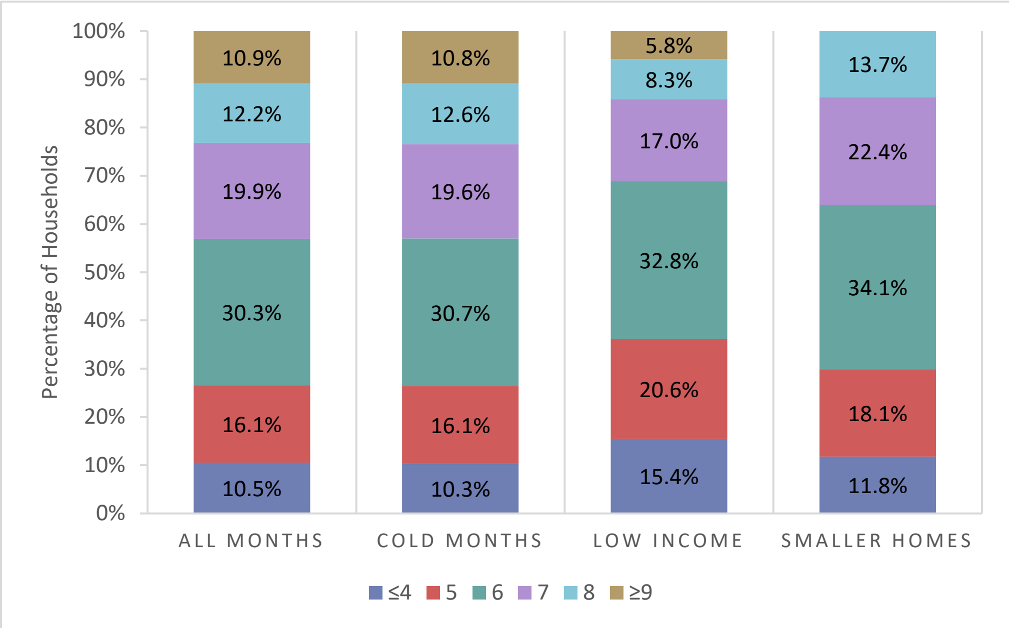
Notes: These summary statistics have been adjusted using survey weights to represent population totals and rounded to the nearest thousand to meet Statistics NZ confidentiality requirements. Average expenditure and income measures are in nominal terms, and standard deviations are in parentheses below the means. Housing costs are based on the latter two years of HES (2015/16 and 2018/19) because these are the only two survey years in which the measure was pre-calculated by Statistics NZ.

We also examined the number of rooms by housing tenure. In order to get the most consistency across the households, we used the small-homes sample using only those households in the bottom 6 income deciles. These results are shown in panel (a) of Figure 7**.** Even among this group, households in social housing are more likely to live in dwellings with fewer rooms than households in either private rentals or in owner-occupied dwellings. For example, almost 50% of households in owner-occupied dwellings have 7 or more rooms in the dwelling, whereas only 14% of households in social housing lived in dwellings with 7 or more rooms. On the other hand, almost one-third of social housing households in this sample lived in dwellings with 4 or fewer rooms while about 5% of owner-occupiers in this sample live in dwellings with 4 or fewer rooms.

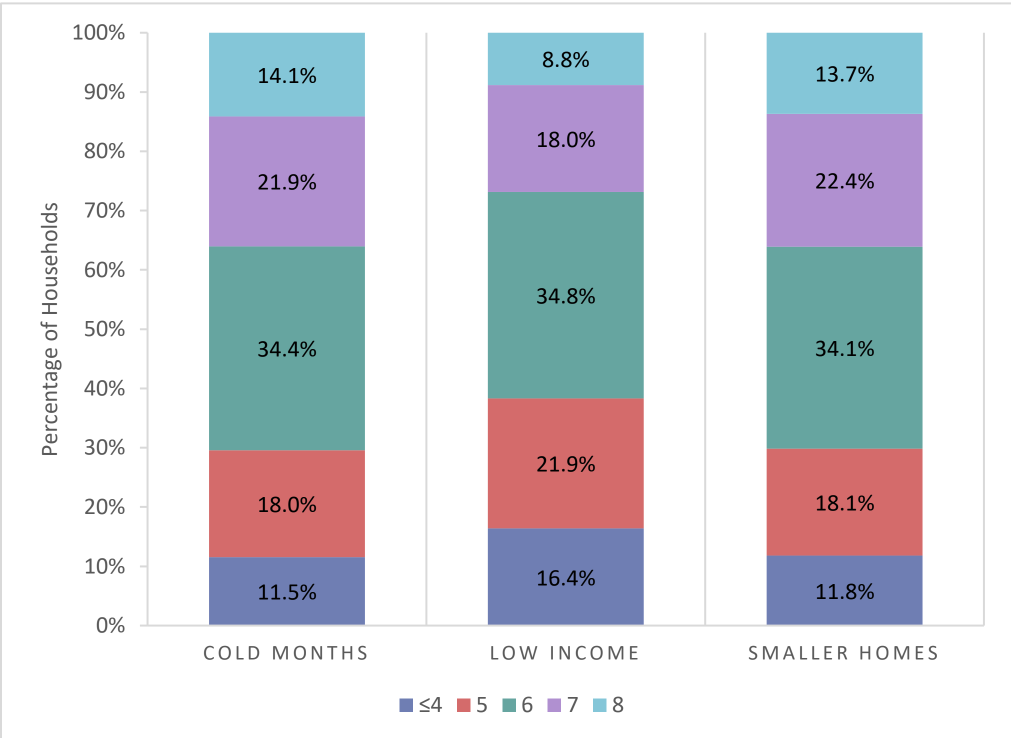
Hence, when examining energy expenditures for these different groups, we should control for the number of rooms in the dwelling given that the size of the dwelling is expected to affect expenditures. To illustrate this further, we show annual average energy expenditures by housing tenure and number of rooms for the low-income, smaller homes sample in panel (b) of Figure 7. From this, we can see that the average for each group is fairly similar when controlling for the number of rooms and that the average expenditure increases almost linearly for each group as the number of rooms in the dwelling increases. For example, households in dwellings with 3 or fewer rooms spend between $1,000 and $1,250 annually, whereas households in dwellings with 7 or more rooms spend between $2,500 and $2,750.

Figure 6. Number of Households by Number of Rooms in Dwelling and Analysis Sample

(a) Full Sample



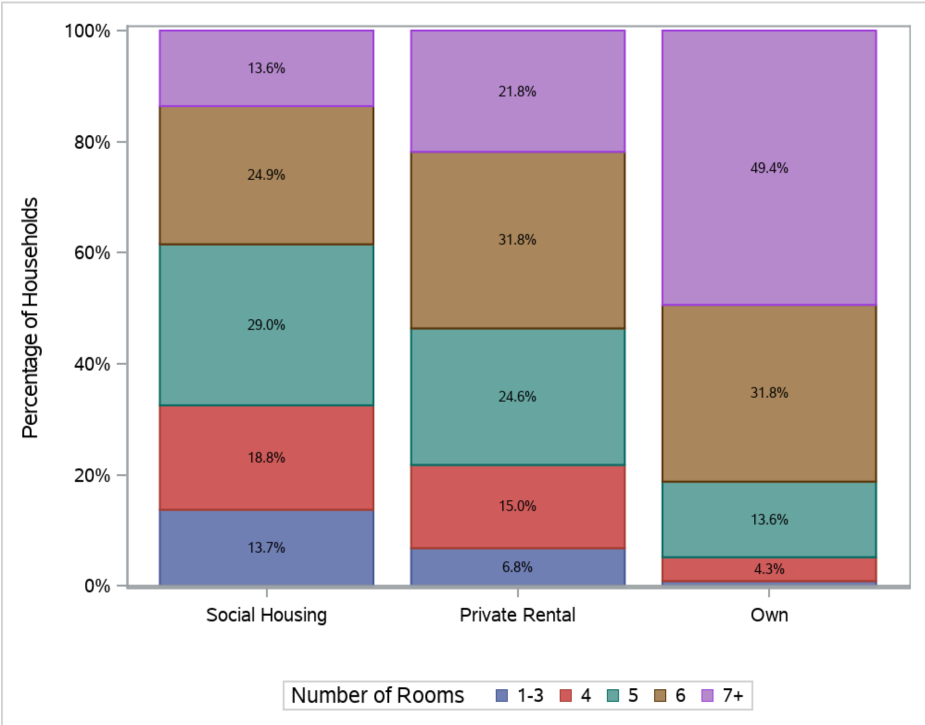
(b) Sample with Rooms ≤ 8



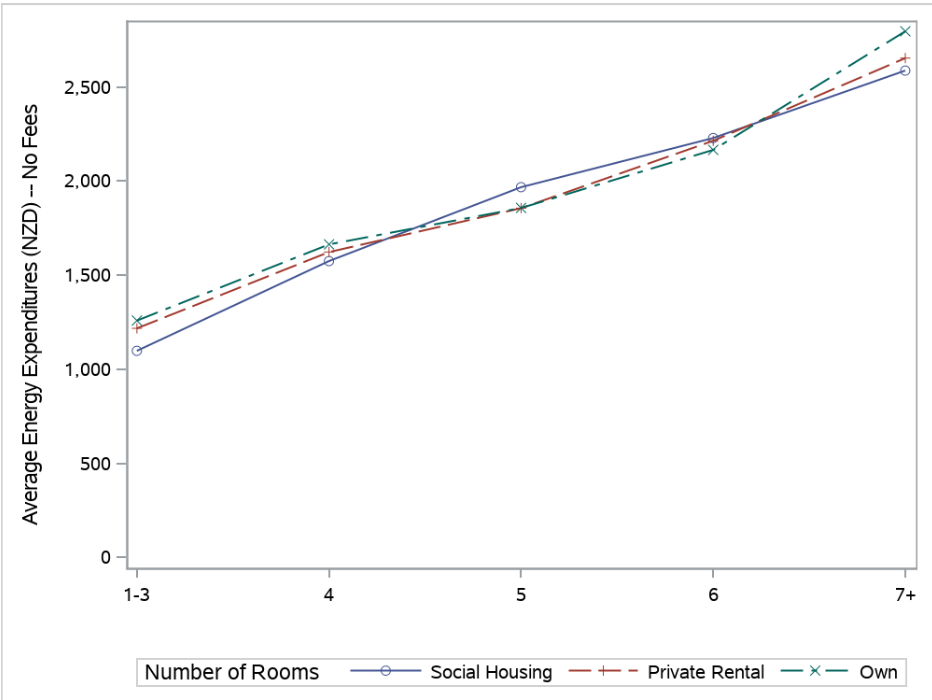
Notes: This figure shows the proportion of households in each sample by the number of rooms in the dwelling, based on weighted results using survey weights. The top panel uses the full sample to calculate the proportion, and the bottom panel uses only those households with 8 or fewer rooms in the dwelling (to compare to the small-dwelling sample). The most distinct group is the low-income sample. These results indicate that the low-income sample is more likely to live in smaller dwellings than the general population.

Figure 7. Characteristics of Low-Income, Smaller-Homes Households by Housing Tenure and Dwelling Size

(a) Percentage of Households



(b) Average Energy Expenditures



Notes: The top panel of this figure shows the percentage of households in the low-income, smaller homes sample by the number of rooms in the dwelling and housing tenure. The bottom panel shows the average annual energy expenditures, excluding fees, for this same sample by the number of rooms in the dwelling and housing tenure. All results were weighted using survey weights

5. Results – Descriptive Analysis

In order to better understand the factors that drive heating behaviours among households using these data, we need to determine that household energy expenditures do in fact vary substantially by month in our data. Hence, we examined household energy expenditures by the household's interview month and found the following key results which makes the analysis possible:

- the number of households is generally evenly distributed over interview months (proportions shown in Table 3 for each sample), and
- household energy expenditures varied substantially by interview month.

In Table 3, we can see that the proportion of households interviewed in each calendar month are fairly similar across months in each of our four samples. This indicates that our sample sizes are fairly consistent across months.

Table 3: Proportion of Households by Interview Month and Analysis Sample

Month	All Months	Cold Months	Low Income	Smaller Homes
January	0.083		0.080	0.082
February	0.086		0.083	0.085
March	0.079		0.080	0.079
April	0.088		0.087	0.087
May	0.092		0.092	0.094
June	0.088	0.177	0.087	0.089
July	0.079	0.159	0.082	0.078
August	0.078	0.157	0.077	0.076
September	0.085	0.171	0.083	0.085
October	0.074	0.149	0.077	0.075
November	0.093	0.188	0.094	0.096
December	0.075		0.078	0.075

Notes: Proportions calculated using the number of weighted survey observations.

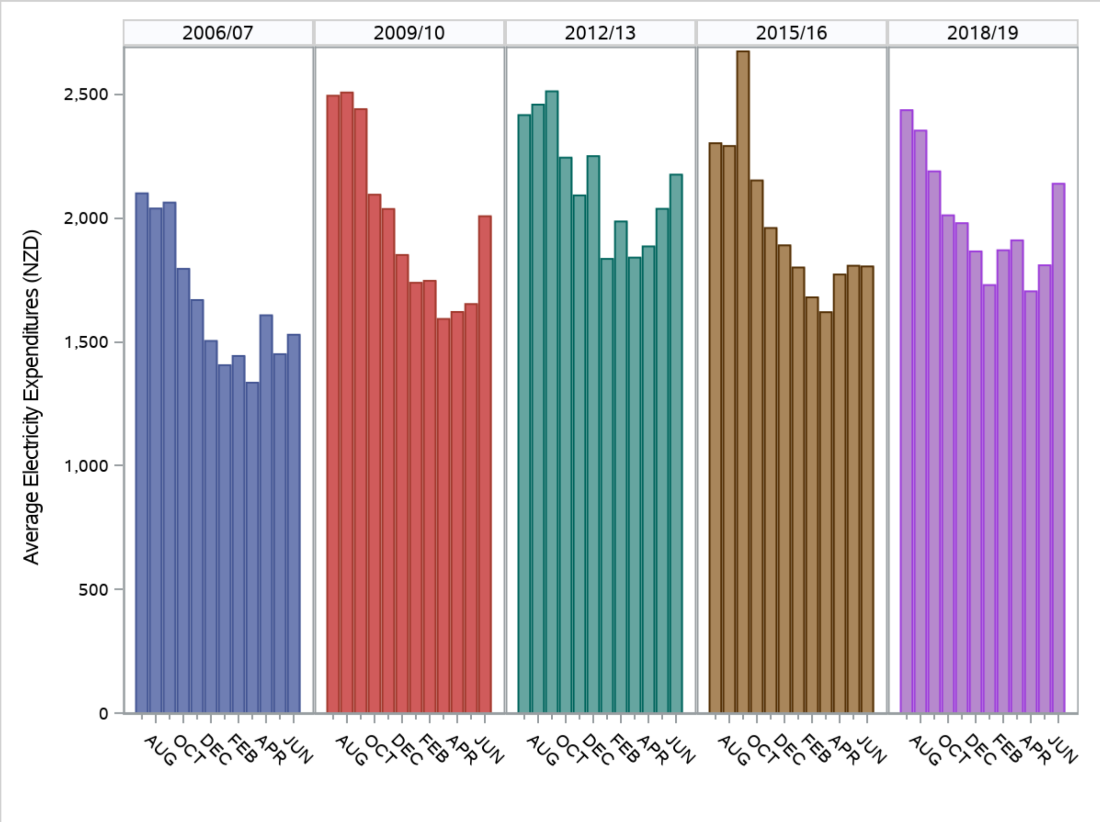
To examine the extent to which household energy expenditures vary, we start with a graphical representation as shown in Figure 8. From this figure, we can see that average annual electricity expenditures (panel a) and average annual energy expenditures without fees (panel b) vary substantially by interview month, with higher expenditures in colder months and lower expenditures in warmer months.

From Figure 8, we can also see that energy expenditures (in nominal terms) in the latter four survey years are similar and that expenditures in 2006/07 appear to be much lower, especially in colder months, than in the latter four survey years. Moreover, electricity expenditures are slightly lower than the total energy expenditures but generally follow the same monthly patterns.[28] These results indicate that we should be able to detect differences between energy expenditures in colder and warmer months.

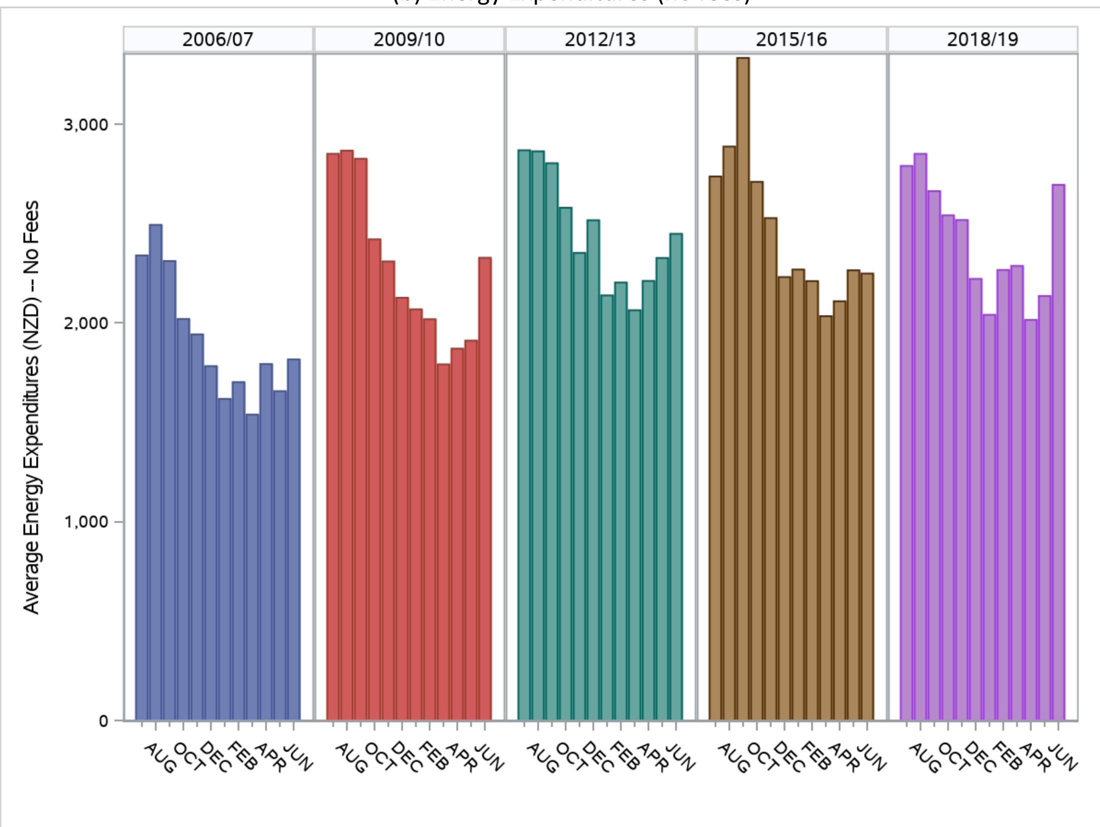
[28] Figure 6 shows total energy expenditures with no fees, but the same patterns are found using total energy expenditures with fees. Moreover, given that expenditures vary with prices and a large proportion of a household's energy bill is attributable to electricity, it is important to note the trends in electricity prices over our analysis period. Hence, more details about electricity prices are provided in Appendix B.

Figure 8. Average Annual Household Expenditures by Survey Year and Month (July to June)

(a) Electricity Expenditures



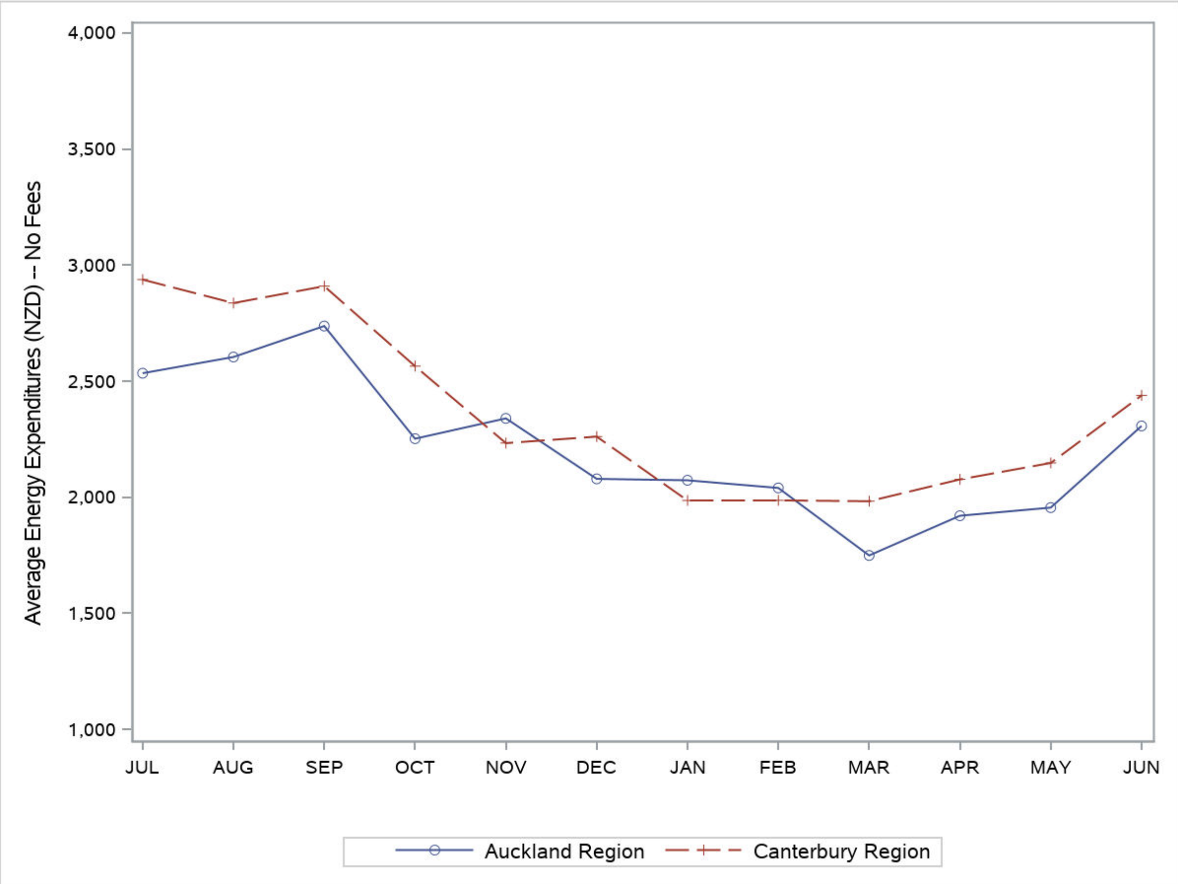
(b) Energy Expenditures (no fees)



Notes: Expenditures are in nominal NZD.

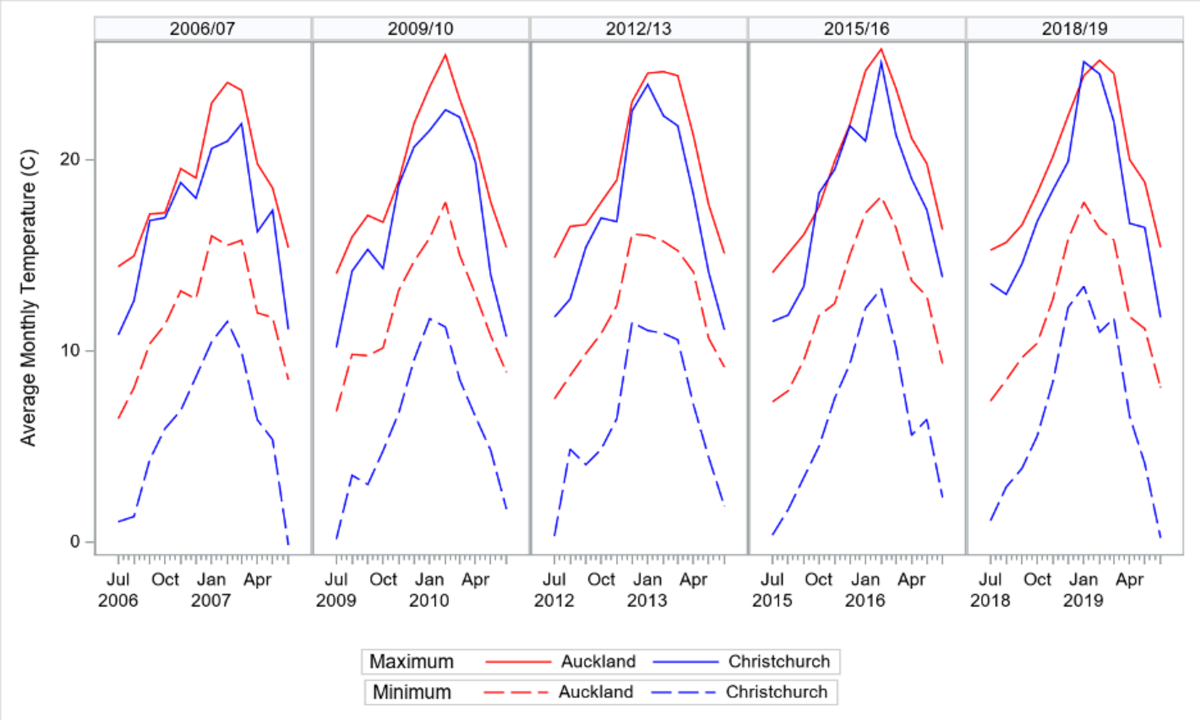
Figure 9 shows the difference in average annual energy expenditures, without fees, reported by interview month for households in the Auckland region compared to those in the Canterbury region. The Canterbury region generally has colder temperatures in the colder months compared to the Auckland region; hence, higher energy expenditures for Canterbury households are indicative of the higher heating costs associated with colder temperatures. As shown in Figure 10, the average monthly minimum temperature in Christchurch is around 0˚C in the colder months, whereas in Auckland, the minimum temperatures generally do not go below 8˚C. We do not see a lot of variation across years in the minimum or maximum temperatures in either region indicating that heating needs should be relatively stable over the time period given that housing thermal performance also stays relatively stable.

Figure 9: Average Household Energy Expenditures in Auckland and Canterbury Regions by Interview Month



Notes: All survey years were used to calculate average energy expenditures in each region using nominal NZD to show the monthly variations.

Figure 10. Average Monthly Temperatures in Auckland and Christchurch



Source: Ministry for the Environment Daily Temperature Data[29]
Notes: Average monthly maximum and minimum temperatures are derived from daily data.

The vast majority of households in our HES samples reported electricity expenditures, with many reporting electricity as their only source of energy expenditure. This is further evidenced by average annual household expenditures for electricity being about 85% of total energy expenditures. Approximately 3% of households (unweighted) had no associated household energy expenditures – including no electricity – even though they reported other non-energy expenditures (e.g., food, clothing). It is unclear if the information was simply not reported or if these households, in fact, had no expenditures. We excluded these households from our analysis given their small number.

6. Results – Regression Analysis

For our main analysis, the dependent variable is total household energy expenditures with fees excluded.[30] Although we do not present the results here, we ran the same analysis using only electricity expenditures, and the pattern of results was similar.

We used a generalised linear model for the regression analysis, weighted by the household survey weights.[31] Table 4 shows our results across a variety of different specifications with the coefficients displayed above the corresponding t-statistics. The first column shows the results for our full sample

[29] Available from https://data.mfe.govt.nz/table/105056-daily-temperature-1909-2019/.

[30] Fees (i.e., generally connection and disconnection fees) are classified separately from customers' main energy expenditures and include items charged on an ad hoc basis. Given the ad hoc nature of these fees and the small window of time captured by the survey, we have excluded these fees from the main measure used as the dependent variable as they are not likely to be captured consistently across customers. Lines or supply charges, on the other hand, are not classified separately from the main energy expenditures and are charged on a regular basis. Hence, these charges are included in the main analyses.

[31] We also ran the regressions without weights and found similar results. These results are shown in the appendix (Table C1).

(all households with positive energy expenditures and positive household income), which we call the all-months sample. Column 2 of Table 4 presents the results for the cold-months subsample (households interviewed from June to November). Column 4 presents results for the low-income sample, and Column 5 presents results for the small-homes sample. The other columns are variations of these samples.

For the all-months sample, 2006/07 is the only survey year in which household energy expenditures were significantly different from those in 2018/19. However, looking across the table at all specifications, the coefficient for the 2006/07 survey year is always highly significant, negative, and around the same magnitude (ranging between -$300 and -$400). Moreover, the significance and magnitudes of the coefficients for each of the survey years are largely similar across the different specifications. Given that expenditures in 2006/07 were so significantly different from the other years, we also ran specifications which excluded households from this survey year (columns 3, 7, and 9 in Table 4), but dropping the 2006/07 survey year did not substantially change the overall pattern of results.

Regardless of the sample used, we found that interview month[32] is a statistically significant predictor of annual household energy expenditures and that households surveyed in July, August, and September were estimated to have substantially and significantly higher annual expenditures than households surveyed in December (omitted category). In the all-months sample, this difference is generally between $500 to $650, which means that households interviewed between July and August appear to spend between $500 and $650 annually compared to households surveyed in December. However, if converted back to a monthly expenditure, then the difference in monthly expenditure is between $40 and $60. Hence, the average household appears to spend between $40 and $60 more on energy between July and September than they do in December. Similarly, respondents interviewed in January, February, March, and April reported between $100-$200 dollars less in annual energy expenditures than households interviewed in December (all else equal). On a monthly basis, this is between $8 and $16. These coefficients are plotted in the top panel of Figure 11, clearly showing the difference in annualised energy expenditures reported by survey month. Hence, these annualised expenditures may be misleading when analysing data at the household level.

The results for the cold-months sample (households interviewed from June to November inclusive) are shown in Column 2 of Table 4. We can see that households interviewed in July, August, and September still had substantially and significantly higher expenditures than those interviewed in November (November is the omitted category for this sample rather than December as is used for the all-months sample). The coefficient for October is positive but insignificant (though close to significance at the 5-percent level),[33] and it is much smaller in magnitude than the July-September coefficients for this sample. These coefficients are plotted in the bottom panel of Figure 11 -- the solid line shows the actual coefficients relative to November, and the dashed line shows the adjusted coefficients relative to December. These lines show that the seasonal patterns persist in both samples and the differences are similar in terms of magnitude after adjusting for the base month differences.

[32] As discussed earlier, HES asks respondents about their last energy bill, which covered a one-month period for most respondents. For example, respondents interviewed in July tend to be reporting their June energy expenditures.

[33] The coefficient is significant at the 10-percent confidence level.

The monthly patterns are also generally consistent across the different specifications. However, for households interviewed in all months, we start to lose significance for January-April when we limit the sample and hence reduce the number of observations. This is especially true for the low-income sample where we limit the sample to households with total income in the bottom six deciles of the income distribution. While these coefficients tend to remain negative, they lose their significance, which is possibly due to fewer observations. The coefficients for the months July-October, however, are positive and generally significant across all specifications. The coefficient for June is positive and significant across the "all-months" specifications but not in the "colder months" specifications indicating similar energy expenditures for June and November but not for June and December.

The dwelling characteristics in our regressions are generally statistically significant predictors of household energy expenditures. Across all specifications, households in stand-alone homes tended to spend significantly more on energy – around $200 or more annually – than households in attached homes. This is consistent with the physics. A stand-alone house will have more surface area exposed to the exterior with more heat loss than a similarly sized, attached house. In our low-income sample (results shown in Columns 4, 8, and 9 of Table 4), the coefficients were on the higher end of the range which could indicate that stand-alone homes are more costly in terms of additional energy expenditures for lower income households than for the average household.

The number of rooms in a home is also a statistically significant predictor of energy expenditures in all specifications.[34] In the first four columns of Table 4, our sample includes households with any dwelling size (9+ rooms were an omitted category) while the last four columns limit the sample to households living in dwellings with 8 or fewer rooms.[35] (results shown in columns 5-9 in Table 4). In these regressions, the omitted category is dwellings with 8 rooms. Overall, we see very similar patterns and magnitudes to the results from both samples.

In our all-months sample (shown in Column 1 of Table 4), we can see that all room-size coefficients are negative and significant, indicating that households in smaller homes spend significantly less on energy than those in larger homes. For example, households in dwellings with 1-2 rooms spent approximately $1400 less annually on energy than households in dwellings with 9 or more rooms. Figure 12 plots these coefficients (solid red line) and shows the positive relationship between the number of rooms in the dwelling and energy expenditures.

Comparing the all-months sample (Column 1, Table 4) to the cold-months sample (Column 2, Table 4), we can also see an additional reduction in energy expenditures for smaller dwellings in winter months. In colder months, the coefficient on dwellings with 1-2 rooms compared to dwellings with 9 or more rooms is $1640 compared to $1380 using the all-months sample. Hence, smaller dwellings' comparatively lower energy expenditures, particularly in winter months, indicates reduced heating requirements for smaller dwellings in addition to generally lower annual energy use. The coefficients for the cold-months sample are also plotted in Figure 12 as the solid blue line. The gap between these lines represents the additional energy expenditures of larger homes in colder months (i.e., the cost of heating). In our example of 1-2 room dwellings, households in these homes spent $250 less annually on heating than households in dwellings with 9 or more rooms.

[34] We ran robustness checks using the number of bedrooms as well as the number of people in the household in place of the number of rooms, and these regressions resulted in similar findings (results not shown). Since these measures are highly correlated with the number of rooms, we chose to include number of rooms as our proxy for size of the dwelling.

[35] We create this sample in order to better control for the overall size of the dwelling. The smaller homes sample is approximately 90% of the all-months sample.

Table 4: Regression results using a General Linear Model, Weighted

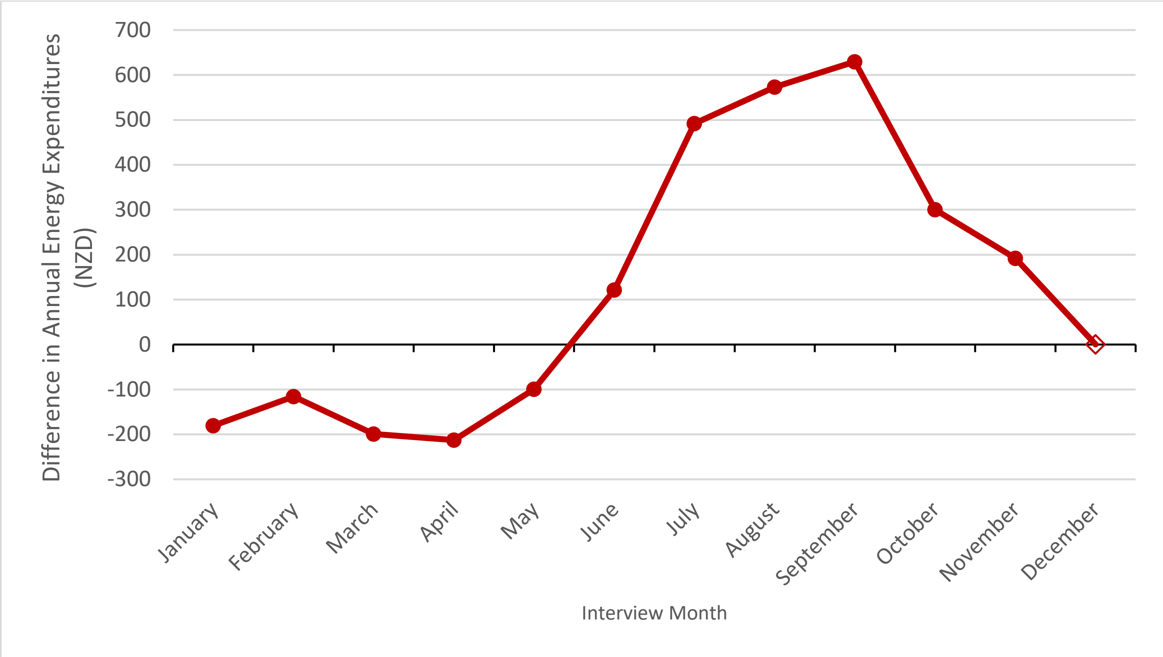
Dependent Variable: Total HH Energy Expenditures (No Fees)		(1) All Months	(2) Cold Months	(3) All Months Drop 06/07	(4) Low Income	(5) Small Homes	(6) Cold months, Small Homes	(7) Small Homes, Drop 06/07	(8) Small Homes, Low Income	(9) Small Homes, Low Income, Drop 06/07
		β *(t-value)*	β *(t-value)*	β *(t-value)*	β *(t-value)*	β *(t-value)*	β *(t-value)*	β *(t-value)*	β *(t-value)*	β *(t-value)*
Intercept		**-1168.39**	**-1790.47**	**-1390.83**	297.21	**-1024.65**	**-1754.16**	**-1242.52**	243.09	72.64
		-7.06	-6.75	-7.37	1.38	-6.27	-6.79	-6.67	1.13	0.30
Year	**2006/07**	**-373.21**	**-365.92**		**-358.97**	**-353.89**	**-347.47**		**-345.65**	
		-11.34	-6.80		-9.49	-10.79	-6.53		-9.05	
	2009/10	-53.43	42.62	-50.01	**-130.75**	**-66.37**	28.54	-62.43	**-117.87**	**-114.50**
		-1.64	0.80	-1.49	-3.54	-2.05	0.55	-1.87	-3.16	-3.00
	2012/13	48.80	-4.61	49.79	-27.78	52.31	28.41	53.23	-1.70	0.64
		1.52	-0.09	1.50	-0.75	1.63	0.55	1.61	-0.05	0.02
	2015/16	14.51	32.86	11.31	-35.89	15.42	41.43	13.13	-28.27	-29.18
		0.45	0.63	0.34	-0.96	0.48	0.79	0.40	-0.75	-0.76
Interview Month	**January**	**-180.42**		**-181.06**	-64.09	**-146.60**		**-123.93**	-74.70	-26.63
		-3.52		-3.09	-1.08	-2.85		-2.11	-1.25	-0.39
	February	**-115.60**		**-116.36**	-78.36	**-107.29**		-102.77	-101.14	-103.44
		-2.27		-1.98	-1.34	-2.11		-1.75	-1.71	-1.53
	March	**-199.36**		**-196.17**	-107.94	**-185.81**		**-166.33**	**-116.34**	-92.52
		-3.84		-3.29	-1.83	-3.59		-2.80	-1.96	-1.36
	April	**-212.69**		**-238.54**	-105.08	**-223.04**		**-222.89**	**-137.21**	**-132.76**
		-4.20		-4.11	-1.82	-4.40		-3.84	-2.36	-2.01
	May	**-99.67**		-98.56	-43.56	**-98.83**		-78.23	-58.41	-20.00
		-1.98		-1.72	-0.76	-1.98		-1.37	-1.01	-0.31
	June	**121.32**	-79.44	**132.12**	**146.55**	**128.15**	-26.44	**135.93**	97.00	119.30
		2.40	-1.46	2.28	2.53	2.54	-0.49	2.36	1.66	1.80
	July	**492.15**	**289.52**	**507.17**	**344.63**	**465.98**	**311.41**	**492.85**	**336.91**	**337.35**
		9.47	5.14	8.48	5.85	8.95	5.60	8.24	5.66	5.01
	August	**572.96**	**366.92**	**561.55**	**628.20**	**568.67**	**409.08**	**593.71**	**573.73**	**608.99**
		11.02	6.51	9.38	10.55	10.87	7.33	9.87	9.52	8.89
	September	**629.62**	**436.00**	**658.33**	**478.80**	**585.95**	**438.23**	**639.36**	**451.44**	**500.29**
		12.35	7.91	11.26	8.16	11.52	8.10	10.94	7.66	7.43
	October	**300.32**	110.03	**308.52**	**258.53**	**287.69**	**141.87**	**336.96**	**236.13**	**293.17**
		5.68	1.92	5.06	4.32	5.47	2.53	5.54	3.92	4.24
	November	**192.02**	Omitted Category	**190.73**	**206.63**	**147.54**	Omitted Category	**160.85**	**168.01**	**196.72**
		3.85		3.33	3.63	2.98		2.83	2.95	3.04

Dependent Variable: Total HH Energy Expenditures (No Fees)		(1) All Months	(2) Cold Months	(3) All Months Drop 06/07	(4) Low Income	(5) Small Homes	(6) Cold months, Small Homes	(7) Small Homes, Drop 06/07	(8) Small Homes, Low Income	(9) Small Homes, Low Income, Drop 06/07
		β *(t-value)*	*β* *(t-value)*	*β* *(t-value)*	*β* *(t-value)*	*β* *(t-value)*	*β* *(t-value)*	*β* *(t-value)*	*β* *(t-value)*	*β* *(t-value)*
Dwelling Characteristics	**Stand-alone Home**	**237.46**	**193.34**	**236.48**	**262.39**	**233.33**	**188.80**	**231.75**	**258.55**	**261.81**
		7.14	3.54	6.24	7.57	7.35	3.66	6.38	7.57	6.80
	Social Housing	**162.64**	94.34	**210.48**	**207.67**	**169.89**	103.29	**221.06**	**211.36**	**259.22**
		3.82	1.35	4.34	4.94	4.16	1.55	4.73	5.10	5.53
	Private Rental	19.54	15.11	40.07	**110.30**	38.34	34.69	**60.90**	**121.30**	**145.13**
		0.76	0.36	1.37	3.86	1.54	0.87	2.15	4.28	4.53
Number of Rooms	**1-2**	**-1384.28**	**-1637.25**	**-1429.01**	**-1294.70**	**-1240.56**	**-1475.08**	**-1280.44**	**-1176.83**	**-1194.25**
		-10.43	-7.45	-9.31	-10.36	-9.96	-7.23	-8.88	-9.85	-8.69
	3	**-1290.11**	**-1533.39**	**-1380.93**	**-1185.33**	**-1134.50**	**-1349.53**	**-1224.67**	**-1067.30**	**-1136.03**
		-16.50	-12.06	-15.47	-14.11	-15.57	-11.55	-14.72	-13.72	-12.86
	4	**-1004.09**	**-1093.88**	**-1064.47**	**-838.86**	**-842.94**	**-908.53**	**-902.78**	**-720.04**	**-765.35**
		-18.39	-12.20	-16.98	-12.84	-16.75	-11.19	-15.67	-12.36	-11.59
	5	**-900.01**	**-1047.56**	**-946.71**	**-711.27**	**-728.68**	**-849.90**	**-773.36**	**-588.95**	**-615.43**
		-21.03	-15.15	-19.21	-12.47	-18.75	-13.85	-17.39	-12.00	-11.09
	6	**-719.57**	**-820.67**	**-762.83**	**-535.80**	**-537.54**	**-615.38**	**-577.67**	**-410.92**	**-434.68**
		-19.42	-13.64	-18.01	-10.01	-16.15	-11.69	-15.35	-9.10	-8.56
	7	**-470.97**	**-546.67**	**-512.74**	**-315.52**	**-281.06**	**-333.55**	**-320.76**	**-190.05**	**-222.33**
		-12.17	-8.68	-11.61	-5.55	-8.03	-5.99	-8.11	-3.89	-4.07
	8	**-197.39**	**-218.88**	**-199.90**	**-127.45**	Omitted Category	Omitted Category	Omitted Category	Omitted Category	Omitted Category
		-4.65	-3.21	-4.17	-2.00					
	9+	Omitted Category	Omitted Category	Omitted Category	Omitted Category					
Auckland Region		**-203.77**	**-270.57**	**-203.12**	**-151.00**	**-200.86**	**-276.70**	**-207.83**	**-160.01**	**-169.86**
		-9.03	-7.31	-7.88	-5.55	-8.88	-7.52	-8.01	-5.83	-5.44
HH Income (log)		**349.63**	**435.69**	**371.92**	**189.87**	**320.33**	**410.71**	**341.00**	**184.61**	**199.70**
		26.16	20.11	24.38	10.07	23.88	19.09	22.25	9.70	9.20
N		7,700,000	3,829,000	6,233,000	4,434,000	6,858,000	3,414,000	5,550,000	4,115,000	3,330,000
Adjusted-R^2		0.2112	0.1937	0.1983	0.1481	0.1950	0.1806	0.1815	0.1423	0.1287

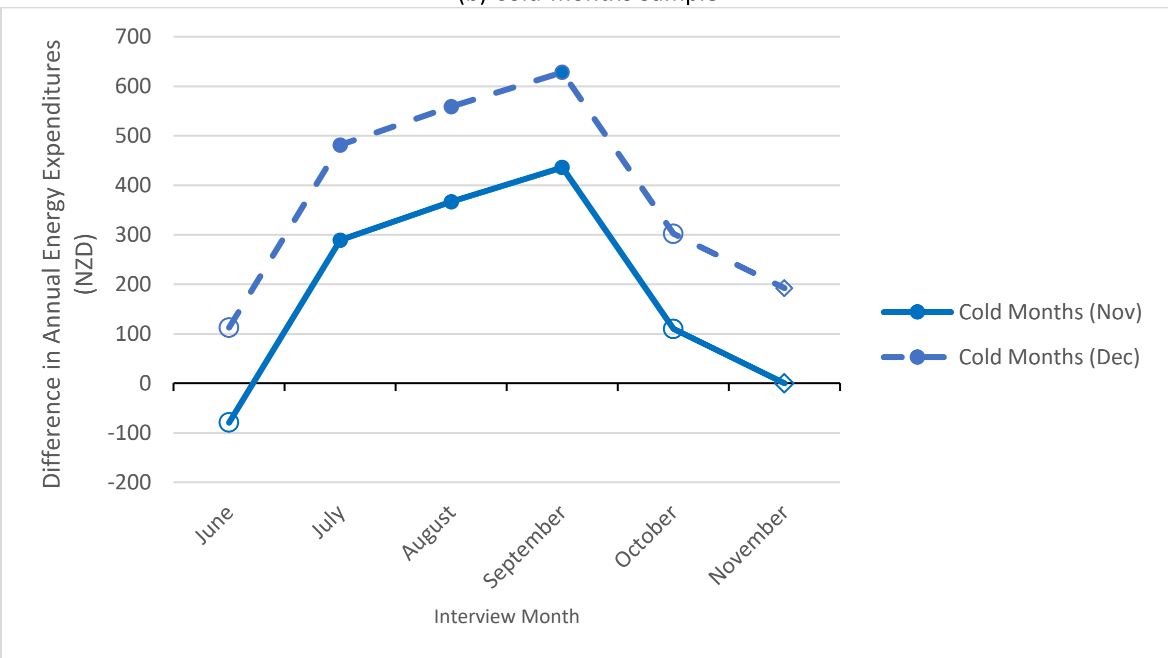
Notes: For the survey year results, the omitted category was the 2018/19 HES year. For the interview month, the omitted category is December when all months are used and November when only the cold-months sample is used. The omitted category for social housing and private rentals is owned dwellings. For number of rooms, the omitted category is 9-or-more rooms (9+). For the Auckland Region, the omitted category is the rest of New Zealand. The number of observations (N) have been rounded to the nearest thousand. Statistically significant results at the 5-percent level are bolded. Results are weighted using household survey weights.

Figure 11. Monthly Coefficients Representing Difference in Estimated Annual Energy Expenditures Relative to the Base Interview Month

(a) All-months Sample



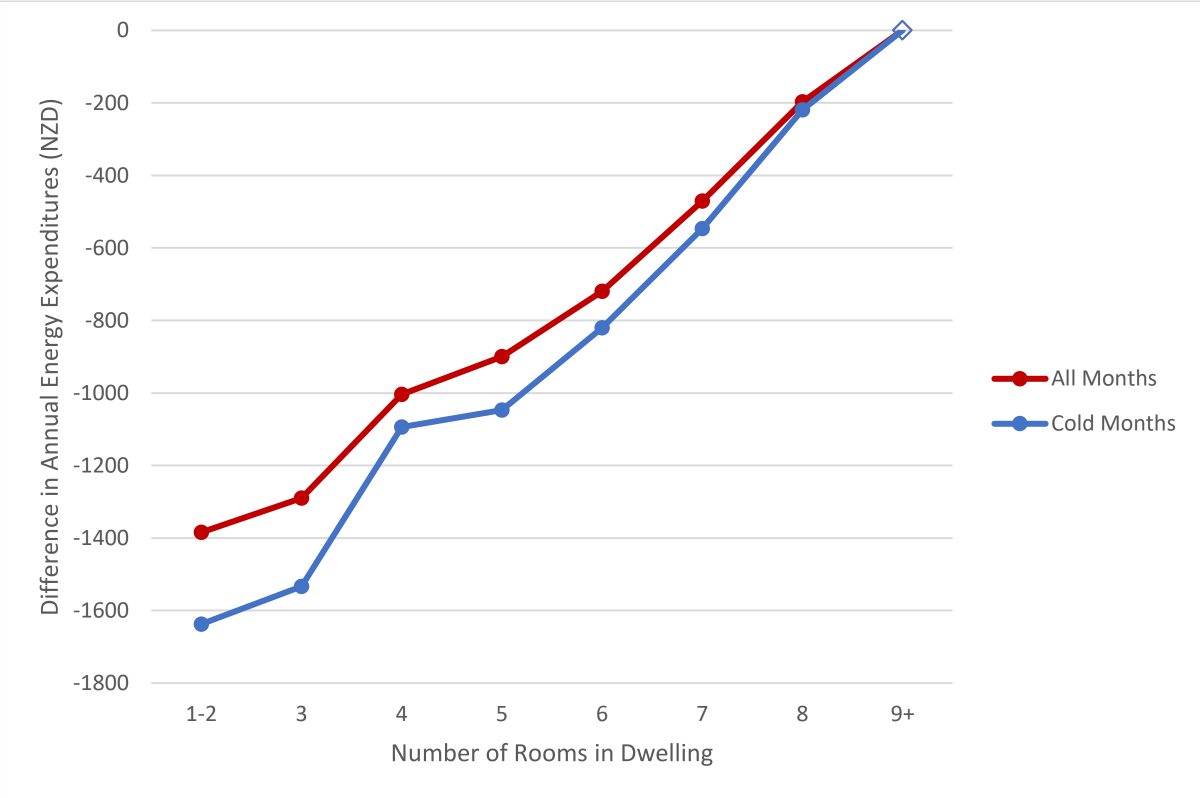
(b) Cold-months Sample



Notes: This figure plots the coefficients for each interview month in our main two samples (all-months and cold-months). These coefficients represent the additional annual energy expenditures for households interviewed in each survey month relative to the base month which is the omitted category in the regression (represented using an open diamond) – this month is December for the all-months sample and November for the cold-months sample. For our all-months sample, households interviewed between January and April were estimated to spend between $100 and $200 less on energy than households interviewed in December, and households interviewed between July and September were estimated to spend $500 to $600 more, controlling for various dwelling and household characteristics. The bottom panel shows the coefficients from the cold-months sample, with the solid line using the actual coefficients relative to November and the dashed line using the coefficients relative to December (estimated by adding the coefficient for November in the all-months sample to each coefficient). Statistically insignificant coefficients are represented using an open circle.

For the low-income sample (Column 2, Table 4), the room coefficients are always smaller in absolute magnitude than those for the all-months sample (column 1, Table 4) indicating that lower-income households spend less on energy (all else equal) on a per room basis. For example, in dwellings with 1-2 rooms, low-income households spent about $90 less annually, (about $7.50 per month) on energy expenditures compared to households in the full sample. However, the average low-income household in a 5- or 6-room dwelling spent between $180 and $190 less annually (about $15 per month) compared to the average household in the same size dwelling in the full sample.

Figure 12. Coefficients for Number of Rooms in Dwelling Representing the Difference in Annual Energy Expenditures Relative to the Base Category



Notes: This figure plots the coefficients for the number of rooms in the dwelling for our main two samples (all-months and cold-months). All coefficients are statistically significant. These coefficients represent the difference in annual energy expenditures for dwellings with fewer rooms relative to the base category which is the omitted category in the regression (represented using an open diamond) – in both samples, the base category is 9+ rooms in the dwelling. All coefficients are statistically significant. The lines for both samples are upward sloping indicating the positive relationship between dwelling size and energy expenditure – larger dwellings generally require more energy. Moreover, the line for the cold-months sample is always below the all-months sample line which indicates an additional reduction in expenditures attributable to smaller dwellings. Moreover, the gap between the two lines closes as the number of rooms in the dwelling increases. These results control for various dwelling and household characteristics.

Given the warmer climate found in the Auckland region,[36] we also controlled for households living in this region and found that these households spent approximately $150 to $300 less per year than households in other areas of the country. The largest coefficients in absolute terms were for our

[36] We also ran the analysis combining households in the Auckland and Northland regions and found very similar results (sample results shown in Table C2 in Appendix C). This is largely due to the relative size of the two regions – with Auckland households tending to dominate the results. For brevity, we only report the results using the binary variable for the Auckland region in the main text.

cold-months sample (Columns 2 and 6 in Table 4), indicating that heating requirements are generally lower in Auckland than in other areas of the country.

Controlling for household income showed the coefficient on income to be positive and significant across every specification. Using our all-months sample in Column 1 of Table 4, we see that a 1-percent increase in income increased household energy expenditures annually by about $3.50. For our cold-months sample (Column 2, Table 4), the same 1-percent increase in income increased annual energy expenditures by about $4.36, indicating that the income effect is greater in colder months (i.e., increased income increases heating expenditures). Using our low-income sample, we see that this increase in annual energy expenditures is between $1.85 and $2 for each 1% increase in income depending on the specification used (Columns 4, 8, and 9 in Table 4). The income effect is not linear.

We also included housing tenure in the analysis, including a variable for those living in social housing and for those living in private rentals, with the omitted category being households living in owner-occupied dwellings. In our main samples, the coefficient on private rentals tends to be positive but insignificant (and relatively small ranging between $15 and $40. This indicates that for the overall sample, even in colder months, households in private rentals spend about the same on energy as households in owner-occupied dwellings. However, when we limit the sample to low-income households (Columns 4, 8, and 9 in Table 4), the coefficient is both positive and significant and is generally larger than the coefficients found in the other specifications (ranging between $60 and $150). These results indicate that low-income households in private rentals spend more on energy than similar households who own their homes.

In contrast to the results for private rentals, the coefficient on the social housing variable is positive and statistically significant in all specifications except those using the cold-months sample (columns 2 and 6 in Table 4); however, even in the cold-months sample, the results are still positive.[37] In the other samples where the social housing coefficient is significant, the coefficient ranges from $160 to $260 annually (or from $13 to $22 monthly). Overall, these results indicate that households in social housing generally had higher energy expenditures than owner-occupiers all else equal. These results combined with those for low-income private rentals indicate that low-income renters, whether public or private, spent more on energy than similar households who owned their homes. However, when using the logged dependent variable, the coefficients on both rental variables lose significance (results shown in Column 4 of Table C2 in Appendix C), so these results should be interpreted with caution. More work is needed to determine the relationship between housing tenure and energy expenditures.

It is plausible that low-income renters could spend significantly more on energy than similar low-income homeowners (i.e., all else equal). Some possible explanations for this include the following:

- social housing and low-income rentals are less energy efficient (e.g., less well-insulated dwellings, less efficient heating, less efficient appliances) than owner-occupied dwellings,
- owner-occupiers may practice different energy- or expenditure-saving behaviours (e.g., using high-energy appliances in off-peak hours, switching providers), or
- households in social housing may have more income to spend on energy due to lower housing costs compared to a similar household paying a mortgage.

[37] In the unweighted regressions shown in Table C1 in Appendix C, the coefficient on the social housing variable is positive and significant in all specifications.

While we do not have information about the energy efficiency of the dwellings or about household behaviours to test the first two explanations, we do have information about housing costs in the 2015/16 and 2018/19 HES to test the last explanation. Hence, we added housing costs to the regression equation using the small homes sample and found that the coefficient on housing costs was positive and significant (results shown in Table C2 in Appendix C) and that the coefficient on the social housing variable remained significant and positive as well.[38] This suggests that the third possible explanation set out above is less plausible than the previous two.

The HES also collects some information about problems with the dwelling as well as information about households' ability to afford heating and other utilities. In Figure 13, we show these results split by housing tenure. Only 52% of social housing households and 60% of private renters reported no problem heating or keeping their house warm in winter compared to 84% of owner-occupiers (shown in panel a of Figure 13). This means that almost half of all households in social housing reported a problem keeping their accommodation warm in winter, with a fairly even split between those reporting this as a minor problem (24%) and a major problem (24%). Comparatively, only 15% of private renters and only 4% of owner-occupiers reported this as a major problem. Problems with dampness and mould showed similar results (shown in panel b of Figure 13) – only 57% of households in social housing reported no problem with damp or mould in their dwelling, whereas 84% of owner-occupiers reported no problem. Moreover, almost 17% of households in social housing reported a major problem with damp/mould, whereas only 2% of owner-occupiers reported the same.[39]

Part of the problem with heating or keeping a house warm could come down to cost and not necessarily be due to the energy efficiency of the home, though these are related. So, we also examined the questions related to households' ability to heat their homes. About 20% of households in social housing reported that they were unable to afford to keep their accommodation warm compared to 13% of private renters and 3% of owner-occupiers (shown in panel c of Figure 13).[40]

Moreover, about 30% of households in social housing reported putting up with feeling cold in the last 12 months in order to keep costs down (19% a little and 11% a lot) compared to 8% of owner-occupiers (6% a little and 2% a lot) as shown in panel d of Figure 13. Households in social housing were also more likely to report being unable to pay their utility bills in the last 12 months (20% more than once and 12% only once) compared to owner-occupiers (3% more than once and 3% only once).

These results indicate that social housing may be less energy efficient than owner-occupied dwellings but also that households in social housing may have more difficulties in affording to keep their dwellings warm. Households in private rentals generally fall in between those in social housing and those in owner-occupied dwellings.

---

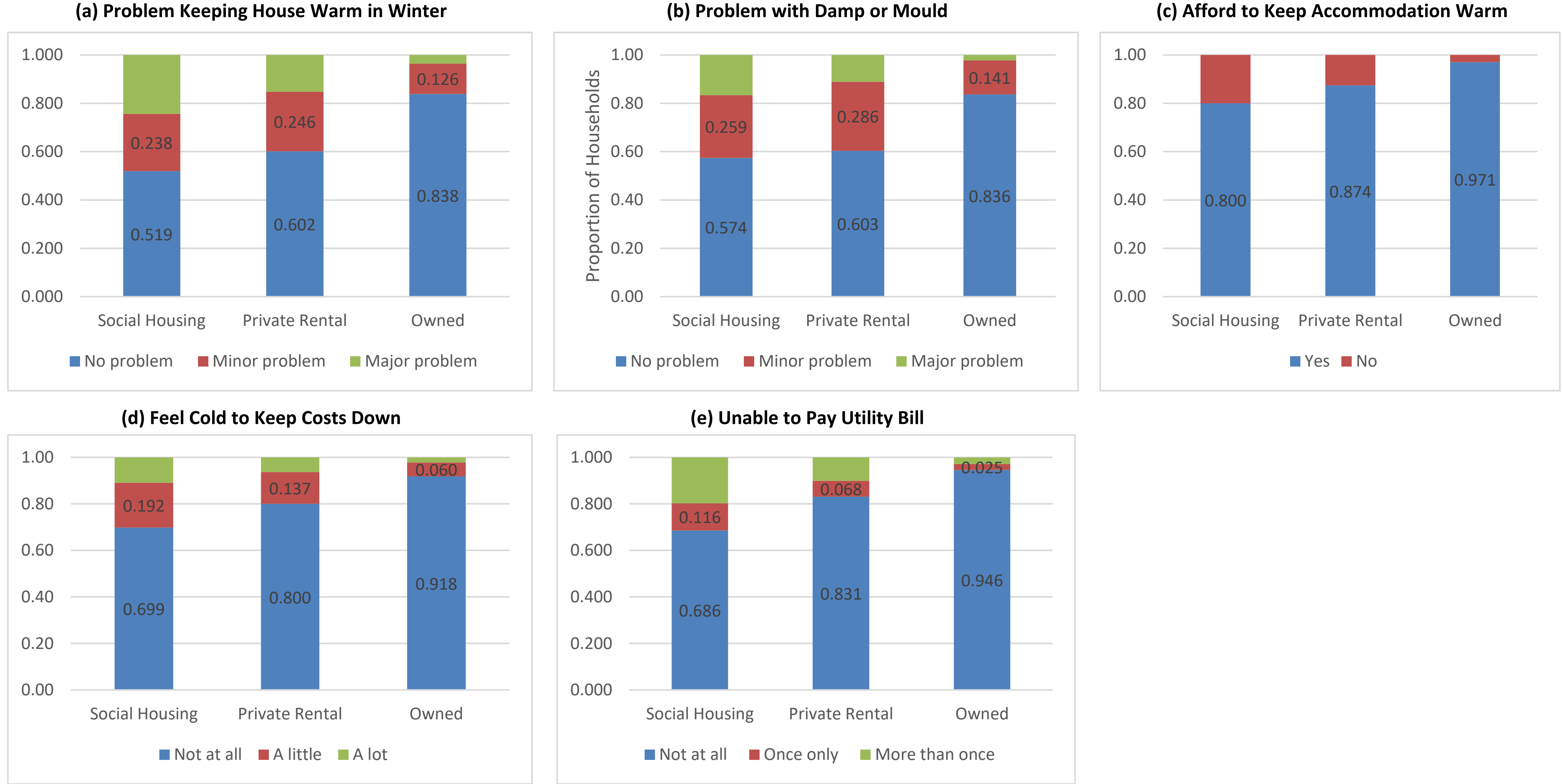
[38] Since homeowners have an asset against which they can borrow, we also included a measure of the property value of the dwelling (logged) which we set close to zero for renters because the property value was only available for homeowners (results shown in Column 3 of Table C2 in Appendix C). The coefficient on the property value variable was insignificant, and the pattern of results remained substantially the same. We also included the logged property value in a regression using the logged value of the dependent variable (column 3 of Table C2), and the coefficient on the property value variable remained insignificant.

[39] Dampness and mould can be a sign of underheating since colder air temperatures result in less moisture absorption into the air and often leads to increased condensation. (Plagmann et al., 2021; Pollard, 2018)

[40] This measure was only available in the 2018/19 HES survey year.

As part of this analysis, we also considered that households may have been misclassified as living in social housing when they were in fact receiving housing support such as the Accommodation Supplement (AS); however, we found very little overlap in households designated as living in social housing and households reporting AS receipt. For those households that did have overlap, it is plausible that the household had received AS for part of the previous year but was now living in social housing. However, the numbers were too small for any further meaningful analysis. We also considered the possibility that these households were more likely to use LPG for heating, which is known to be a more expensive way to heat a home on a per unit basis but also provides fixed-cost heating. If this were the case, the higher energy expenditures for public renters would not necessarily imply that the dwellings were less energy efficient but rather that the heating was more expensive. However, we did not find evidence that LPG heating was driving the results for higher energy expenditures for public renters.

Figure 13. Housing-related Material Wellbeing Measures by Housing Tenure



Notes: Results were calculated using HES survey weights. The question about the household's ability to afford to keep the accommodation warm was only asked in the HES 2018/19 year (shown in panel (c)). All the other questions were asked in all five HES years, and these results are based on the pooled observations.

7. Concluding Discussion

Over our time period (2006/07 to 2018/19), the fuel mix used across households has changed. The use of wood for heating declined from 40% to 30% between 2006 and 2018, bottled gas declined from 28% to 6%, and coal declined from 7% to 3%. Still, household expenditures remained relatively stable, with 2006/07 being the only year in which expenditures significantly differed from the other years in the regression analysis.

Our results indicate that a number of factors play a role in household energy expenditures. Outdoor temperatures – proxied using interview month and location of the dwelling in the warmer Auckland region – expectedly play a role. The regression results showed that households in the Auckland region reported lower energy expenditures in general (about $200 annually in the main sample) and substantially lower expenditures for those Auckland households surveyed in colder months (about $270 annually in the cold-months sample) compared to their counterparts in the rest of the country.[41] This indicates that milder temperatures in Auckland are correlated with lower energy expenditures for those who live there when compared to the average household in the rest of the country.

In general, households surveyed in colder months reported significantly higher energy expenditures relative to similar households surveyed in warmer months. These results are not just statistically significant but are also economically significant with expenditures in the coldest months about $50 higher (on a monthly basis) than expenditures in the warmest months. This result is exacerbated, however, by the method used to annualise these expenditures, with households surveyed in colder months appearing to spend $500-$600 more annually than their counterparts surveyed in warmer months. These results indicate that using the annualised household energy expenditures for analyses at the individual household level is likely to be problematic without some form of seasonal adjustment.

In addition to outdoor temperatures, the regression results indicate that stand-alone dwellings and larger dwellings are associated with higher energy expenditures, with the difference between a 1- or 2-room dwelling and a 9+-room dwelling ranging between $1200 and $1700 annually, depending on the sample used. The higher end of the range is based on the cold-months sample, which also provides an estimate of the additional annual cost of heating these larger dwellings (approximately $250 annually, $21 per month if spread across the entire year, or $50 per month if spread over the 5 months covered by the Winter Energy Payment[42]). In Appendix D, we provide graphs of the predicted energy expenditures from the regressions by number of rooms in the dwelling and housing tenure of the household.

The results for low-income renters indicate that these renters tended to have higher energy expenditures relative to similar households in owner-occupied dwellings. This may be due to households with higher incomes being able to afford more energy-efficient rental properties and

[41] Moreover, we examined the distribution of energy expenditures for households in different regions and in different seasons (results not shown). For households in the Auckland region, the distribution of energy expenditures for households surveyed in summer months were very similar to the distribution of households surveyed in winter months. This was not true for households outside of the Auckland region, whose winter and summer distributions looked very different.

[42] The Winter Energy Payment is paid to eligible recipients from 1 May to 1 October.

appliances. However, differing results across specifications means that these results should be treated with caution.

Household income was also a statistically significant predictor of household energy expenditures, where a 1% increase in income is associated with a $3-$4 increase in annual expenditures for our overall sample but with a $1.70-$2 increase for our low-income sample. These results indicate that the effect of income on energy expenditures is not linear, with lower income households increasing their energy expenditures more slowly than the average household. Moreover, this rate is higher in colder months.

As there is no indoor temperature data, this analysis cannot take into account variations in heating practice – whether internal temperatures or the proportion of the house heated. Nor can we account for differences in energy-saving behaviours. However, our results suggest that households in public and private rentals are more likely to report living in homes that are more difficult to keep warm and are more likely to be damp or mouldy. Previous literature has found similar results. Riggs et al., (2021) found not only that rental properties had a significantly higher likelihood of substandard housing conditions compared to owner-occupied homes but also that the likelihood of living in damp, mouldy, unheated, or crowded housing was substantially higher for children living in social housing compared to children living in private rentals, with odds ratios for social housing generally 1.5-2 times those of private rentals. The results from Riggs et al., (2021) also suggest that children in social housing were more likely to have worse housing-related health outcomes (e.g., chest illnesses, respiratory hospitalisations). Hence, more research to further examine the factors affecting energy expenditures for low-income renters, particularly those in social housing, is needed.

References

Alvarez, M. (2019). Distributional effects of environmental taxation: An approximation with a meta-regression analysis. *Economic Analysis and Policy*, *62*, 382–401. https://doi.org/10.1016/j.eap.2018.10.003

Awaworyi Churchill, S., & Smyth, R. (2020). Ethnic diversity, energy poverty and the mediating role of trust: Evidence from household panel data for Australia. *Energy Economics*, *86*, 104663. https://doi.org/10.1016/j.eneco.2020.104663

Bardazzi, R., Bortolotti, L., & Pazienza, M. G. (2021). To eat and not to heat? Energy poverty and income inequality in Italian regions. *Energy Research & Social Science*, *73*, 101946. https://doi.org/10.1016/j.erss.2021.101946

Boardman, B. (1991). *Fuel poverty: From cold homes to affordable warmth*. Pinter Pub Limited.

Brabo-Catala, L., Collins, E., & Barton, B. (2022). Fuel Poverty or Energy Hardship? Analysing the literature, the proposed official definition, and the views of experts in Aotearoa New Zealand. *Policy Quarterly*, *18*(4), 46–53.

Collins, M. J., Barnard, T., Bayne, K., Duignan, A., & Shayer, S. (2003). *Building green in New Zealand: Wood, a sustainable construction choice*. Forest Research.

Fuerst, F., Kavarnou, D., Singh, R., & Adan, H. (2020). Determinants of energy consumption and exposure to energy price risk: A UK study. *Zeitschrift Für Immobilienökonomie*, *6*(1), 65–80. https://doi.org/10.1365/s41056-019-00027-y

Grimes, A., Denne, T., Howden-Chapman, P., Arnold, R., Telfar-Barnard, L., & Young, C. (2011). *Cost Benefit Analysis of the Warm Up New Zealand: Heat Smart Programme* [Ministry of Economic Development Report].

Grimes, A., Young, C., Arnold, R., Denne, T., Howden-Chapman, P., Preval, N., & Telfar-Barnard, L. (2011). *Warming Up New Zealand: Impacts of the New Zealand Insulation Fund on Metered Household Energy Use* (p. 87) [Paper prepared for Ministry of Economic Development]. http://www.healthyhousing.org.nz/wp-content/uploads/2012/03/NZIF_Energy_report-Final.pdf

Halleck Vega, S., van Leeuwen, E., & van Twillert, N. (2022). Uptake of residential energy efficiency measures and renewable energy: Do spatial factors matter? *Energy Policy*, *160*, 112659. https://doi.org/10.1016/j.enpol.2021.112659

Hamilton, I. G., Summerfield, A. J., Shipworth, D., Steadman, J. P., Oreszczyn, T., & Lowe, R. J. (2016). Energy efficiency uptake and energy savings in English houses: A cohort study. *Energy and Buildings*, *118*, 259–276. https://doi.org/10.1016/j.enbuild.2016.02.024

Howden-Chapman, P., Crane, J., Matheson, A., Viggers, H., Cunningham, M., Blakely, T., O'Dea, D., Cunningham, C., Woodward, A., Saville-Smith, K., Baker, M., & Waipara, N. (2005). Retrofitting houses with insulation to reduce health inequalities: Aims and methods of a clustered, randomised community-based trial. *Social Science & Medicine (1982)*, *61*(12), 2600–2610. https://doi.org/10.1016/j.socscimed.2005.04.049

Howden-Chapman, P., Matheson, A., Crane, J., Viggers, H., Cunningham, M., Blakely, T., Cunningham, C., Woodward, A., Saville-Smith, K., O'Dea, D., Kennedy, M., Baker, M., Waipara, N., Chapman, R., & Davie, G. (2007). Effect of insulating existing houses on health inequality: Cluster randomised study in the community. *BMJ (Clinical Research Ed.)*, *334*(7591), 460. https://doi.org/10.1136/bmj.39070.573032.80

Howden-Chapman, P., Viggers, H., Chapman, R., O'Dea, D., Free, S., & O'Sullivan, K. (2009). Warm homes: Drivers of the demand for heating in the residential sector in New Zealand. *Energy Policy*, *37*(9), 3387–3399. https://doi.org/10.1016/j.enpol.2008.12.023

Howden-Chapman, P., Viggers, H., Chapman, R., O'Sullivan, K., Telfar Barnard, L., & Lloyd, B. (2012). Tackling cold housing and fuel poverty in New Zealand: A review of policies, research, and health impacts. *Energy Policy*, *49*, 134–142. https://doi.org/10.1016/j.enpol.2011.09.044

Hyslop, D., Riggs, L., & Maré, D. C. (2022). *The impact of the 2018 Families Package Winter Energy Payment policy* (No. 22–09; Motu Working Paper). Motu Economic and Public Policy Research. https://www.motu.nz/our-research/population-and-labour/individual-and-group-outcomes/impact-winter-energy-payment/

Isaacs, N., Camilleri, M., Burrough, L., Pollard, A., Saville-Smith, K., Fraser, R., Rossouw, P., & Jowett, J. (2010). *Energy Use in New Zealand Households: Final Report on the Household Energy End-use Project (HEEP)* (BRANZ Study Report No. 221; BRANZ Study Report, p. 366). BRANZ Ltd. https://www.branz.co.nz/cms_show_download.php?id=a9f5f2812c5d7d3d53fdaba15f2c14d591749353

Jones, R. V., Fuertes, A., & Lomas, K. J. (2015). The socio-economic, dwelling and appliance related factors affecting electricity consumption in domestic buildings. *Renewable and Sustainable Energy Reviews*, *43*, 901–917. https://doi.org/10.1016/j.rser.2014.11.084

Khan, I. (2019). Household factors and electrical peak demand: A review for further assessment. *Advances in Building Energy Research*, *15*(4). https://doi.org/10.1080/17512549.2019.1575770

Kriström, B. (2013). Residential Energy Demand. In J. F. Shogren (Ed.), *Encyclopedia of Energy, Natural Resource, and Environmental Economics* (pp. 218–224). Elsevier. https://doi.org/10.1016/B978-0-12-375067-9.00097-8

Legendre, B., & Ricci, O. (2015). Measuring fuel poverty in France: Which households are the most fuel vulnerable? *Energy Economics*, *49*, 620–628. https://doi.org/10.1016/j.eneco.2015.01.022

NZ Meteorological Service. (1983). *Summaries of climatological observations to 1980: Stations represented are in New Zealand, including its outlying islands, the Ross Dependency (Antarctica) and territories of the South-west Pacific, namely Kiribati, Tuvalu, Fiji, the Tokelau Islands, Western Samoa, Tonga, Niue, the Cook Islands and Pitcairn Island*. NZ Meteorological Service.

O'Neill, B. C., & Chen, B. S. (2002). Demographic Determinants of Household Energy Use in the United States. *Population and Development Review*, *28*, 53–88.

Plagmann, M., White, V., & McDowall, P. (2021). *Indoor climate and mould in New Zealand homes* (BRANZ Study Report No. SR452; BRANZ Study Report). BRANZ Ltd. https://www.branz.co.nz/pubs/research-reports/sr452/

Polkinghorne, J. D. (2011). *Factors Affecting Household Demand for Energy* [Bachelor of Commerce (Honours) in Economics]. University of Auckland.

Pollard, A. (2018). *Could damp homes be too cold/underheated?* (BRANZ Study Report No. SR389; BRANZ Study Report, p. 28). BRANZ Ltd. https://www.branz.co.nz/pubs/research-reports/sr389/

Riggs, L., Noy, S., Devlin, M., & Howden-Chapman, P. (2021). *Housing, Health, and the Well-Being of Children* (p. 87). Ministry of Social Development. https://www.msd.govt.nz/documents/about-msd-and-our-work/publications-resources/research/housing-health-wellbeing/housing-health-and-the-well-being-of-children.pdf

Riva, M., Kingunza Makasi, S., Dufresne, P., O'Sullivan, K., & Toth, M. (2021). Energy poverty in Canada: Prevalence, social and spatial distribution, and implications for research and policy. *Energy Research & Social Science*, *81*, 102237. https://doi.org/10.1016/j.erss.2021.102237

Siksnelyte-Butkiene, I., Streimikiene, D., Lekavicius, V., & Balezentis, T. (2021). Energy poverty indicators: A systematic literature review and comprehensive analysis of integrity. *Sustainable Cities and Society*, *67*, 102756. https://doi.org/10.1016/j.scs.2021.102756

Statistics New Zealand. (2019, June 26). *Wellbeing statistics: 2018 (housing quality and tenure security)*. https://www.stats.govt.nz/information-releases/wellbeing-statistics-2018

Statistics New Zealand. (2020). *Household income and housing cost statistics – HES (Income) data dictionary (version 249)*. Statistics New Zealand.

Stephenson, J. M. (2021). *All you can heat? Welfare implications of high fixed charge tariffs for electricity* [Master of Science]. University of Otago.

Szokolay, S. V. (2008). *Introduction to Architectural Science*. Taylor and Francis. https://doi.org/10.4324/9780080878942

Taneja, S., & Mandys, F. (2022). Drivers of UK household energy expenditure: Promoting efficiency and curbing emissions. *Energy Policy*, *167*, 113042. https://doi.org/10.1016/j.enpol.2022.113042

Trotta, G. (2018). Factors affecting energy-saving behaviours and energy efficiency investments in British households. *Energy Policy*, *114*, 529–539. https://doi.org/10.1016/j.enpol.2017.12.042

White, V. (2020). House condition and occupant wellbeing | BRANZ Build. *Build*, *181*, 50–52.

Williamson, A. G., & Clark, S. (2001). *Domestic Hot Water: Options and Solutions*. Centre for Advanced Engineering, University of Canterbury.

Appendix A

Energy is required to change the temperature of any material – whether air, water or concrete. Different materials require different amounts of energy to change their temperature, and this material property is termed "Specific Heat Capacity," (shortened to "Specific Heat") measured in Joules per degree Celsius per kilogram (J $°C^{-1}$ kg^{-1}). The other important property is the material's Density or the weight of material in a cubic metre.

Table A1 provides thermal properties for air, water, and a selection of building materials. Air is very much lighter than wood – a cubic metre of wood is 435 times as heavy as a cubic metre of air – yet has a similar specific heat (1120 compared to 1063 J $°C^{-1}$ kg^{-1}.). To look at this in a different way, while the same weight of air takes about the same amount of energy to raise its temperature by 1°C as wood, the same volume needs very much less as the density of air is only 0.1% of that of wood (1.15/500).

Table A1: Properties of Selected Materials

Material	Density (kg m^{-3})	Specific Heat (J $°C^{-1}$ kg^{-1})
Air (25°C, 50% RH)	1.15	1063
Water	1000	4187
Wood (Radiata pine)	500	1120
Structural steel	7830	480
Concrete (unreinforced)	2100	840

Sources: (Collins et al., 2003), (Szokolay, 2008, pp. 102–103)

Table A2 provides monthly and annual average air and ground temperatures for the Kelburn, Wellington, meteorological station. The average air temperature over the period 1909 to 1980 was 15.3°C, and the ground temperature at 1 m was 13.7°C. However, the monthly averages show strong seasonal variations – warmer in summer and cooler in winter. Assuming heating is only required in any month where the average temperature is less than 15°C (May-October) gives 184 heating days with an average temperature of 12.6°C.

Table A2: Air and Ground Temperature Normals

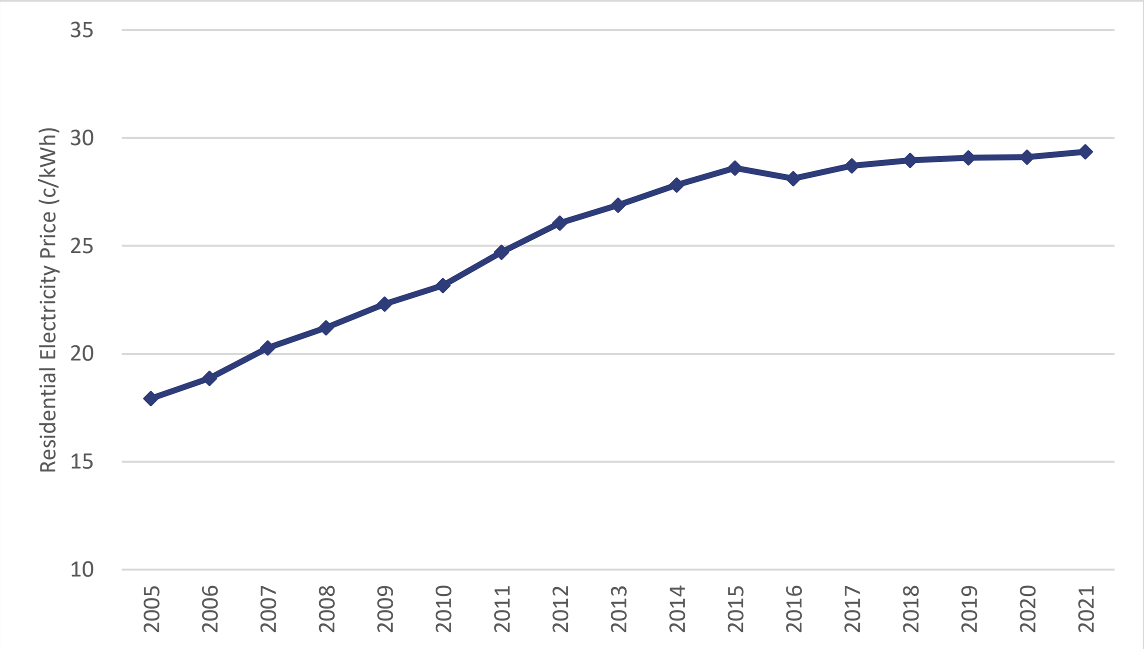
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean Air Temp (1909-80)	19.4	19.7	18.7	16.5	13.9	11.9	10.9	11.5	12.8	14.4	16.1	17.9	15.3
Lowest Grass Minimum Recorded (1928-80)	0.2	-0.3	-0.9	-1.7	-3.5	-5.3	-5.6	-6.1	-5.4	-3.6	-2.8	0.0	-6.1
Average Grass Minimum (1928-80)	10.9	11.1	10.1	8.2	5.7	3.8	3.1	3.7	5.0	6.5	8.0	9.9	7.2
Average At 10 cm Depth (1943-80)	17.4	16.9	15.1	12.2	9.4	7.0	6.2	6.9	8.8	11.4	13.9	16.1	11.8
Average At 30 cm Depth (1928-80)	18.8	18.6	17.1	14.4	11.3	8.8	7.6	8.4	10.3	12.8	15.2	17.4	13.4
Average At 1 m. Depth (1928-80)	17.7	18.1	17.4	15.7	13.2	10.9	9.3	9.3	10.4	12.3	14.3	16.2	13.7

Source: (NZ Meteorological Service, 1983)

Appendix B

Since a large proportion of a household's energy bill is attributable to electricity, it is important to note the trends in electricity prices over our analysis period. Figure B1 shows the average annual cost of residential electricity between 2005 and 2021 for all of New Zealand, and Figure B2 shows the quarterly price of residential electricity (on a given date) during the HES survey periods for all of New Zealand, Auckland, and Christchurch. Both Figure B1 and Figure B2 show the price of electricity increased steadily over the period – from an annual average of 19 c/kWh in 2006 to 29 c/kWh in 2021. However, while the increase in prices is fairly linear between 2005 and 2015 increasing on average one cent per year, the price flattens out between 2015 and 2021 increasing by less than one cent over the entire 6-year period. This indicates that there are no extreme price changes over the time period that could affect the results.

Figure B1. Average Annual Residential Electricity Price by Year (March)



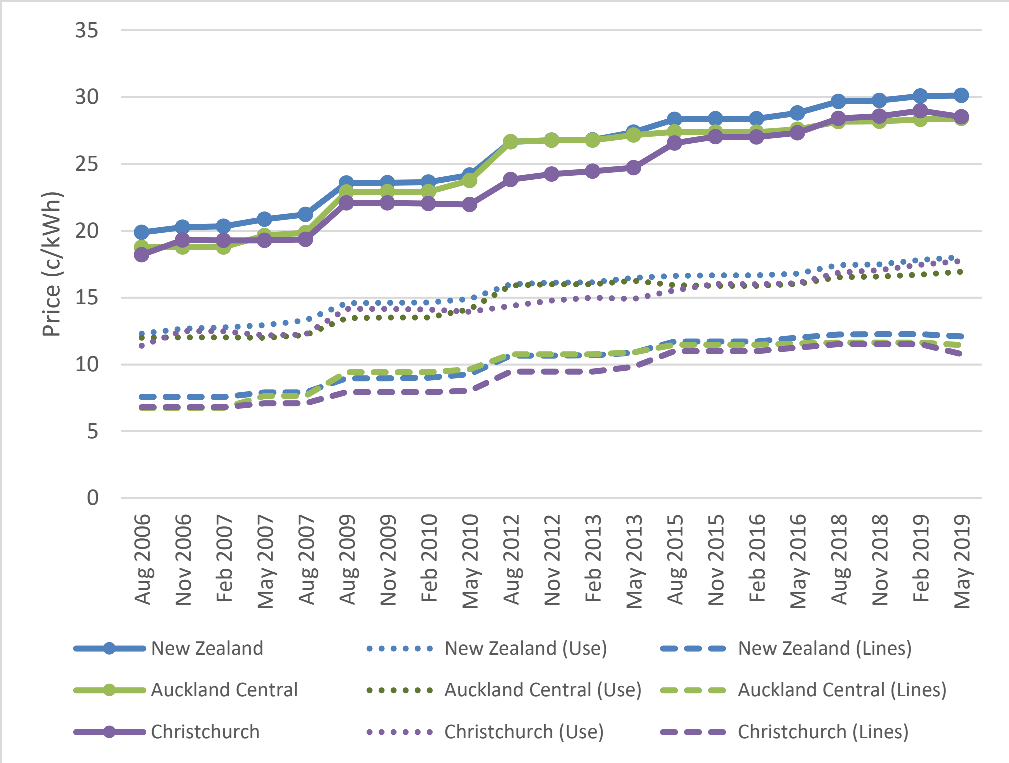
Source: Energy Prices produced by Markets team, Evidence and Insights Branch, Ministry of Business, Innovation & Employment.[43]

Since the price of electricity in Figure B1 is averaged over both fixed and variable costs, we also examined changes in both of these components. Figure B2 shows the price broken down into the variable cost (usage) and the fixed cost (lines). Overall, both the usage and the lines costs show similar patterns. The lines component of the price for Christchurch is generally less than the New Zealand average and is generally less than or equal to that for Auckland. The relative price of the usage component for Auckland and Christchurch varies quite a bit with Auckland having a higher price in some periods and a lower price in others. One notable period for Auckland is in usage prices in 2012/13, which appear to be higher than usual – even the usage prices in 2015/16 are lower than they are in 2012/13.

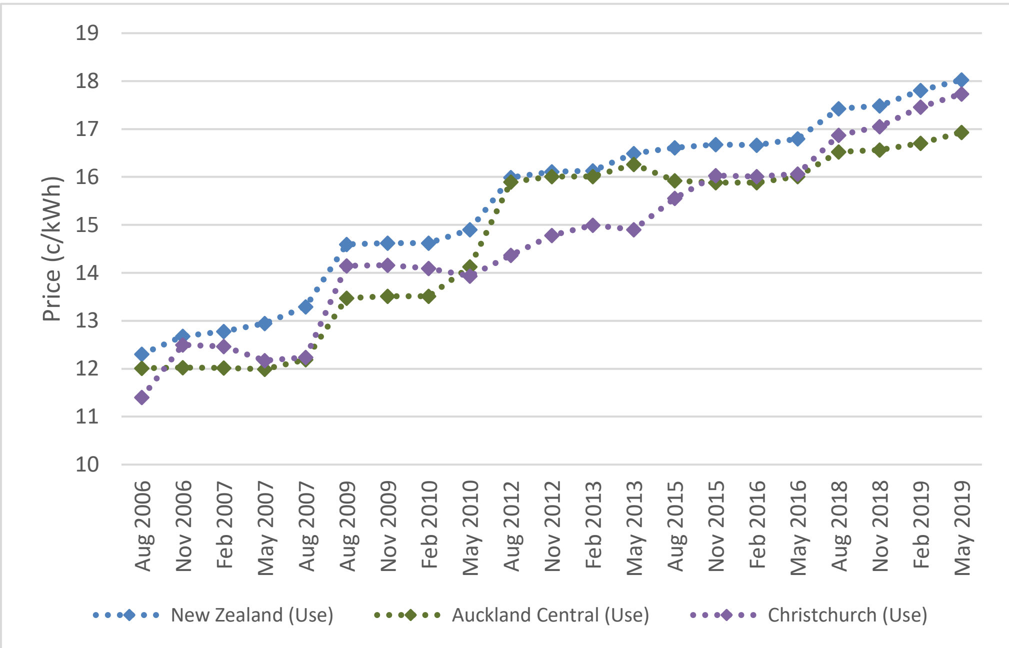
[43] More information about the energy prices collected by MBIE can be found on their website: https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/energy-prices/electricity-cost-and-price-monitoring/.

Figure B2. Average Quarterly Electricity Prices for New Zealand, Auckland, and Christchurch

(a) Total, Use, Lines



(b) Use



Source: Quarterly Survey of Domestic Electricity Prices from Ministry of Business, Innovation & Employment
Notes: The solid lines show the total retail electricity price in cents per kilowatt-hour, the dotted lines show the usage cost component, and the dashed lines show the lines component of the total cost. The top panel shows all three aspects of the price, and the bottom panel focuses on the usage component.

Appendix C

Table C1: Regression results using a General Linear Model, Unweighted

Dependent Variable: Total HH Energy Expenditures (No Fees)		(1) All Months	(2) Cold Months	(3) All Months Drop 06/07	(4) Low Income	(5) Small Homes	(6) Cold months, Small Homes	Small Homes, Drop 06/07	Small Homes, Low Income	Small Homes, Low Income, Drop 06/07
		β (*t-value*)	*β* (*t-value*)	*β* (*t-value*)	*β* (*t-value*)	*β* (*t-value*)	*β* (*t-value*)	*β* (*t-value*)	*β* (*t-value*)	*β* (*t-value*)
Intercept		**-1103.42**	**-1636.27**	**-1304.33**	**455.23**	**-1064.71**	**-1712.05**	**-1302.47**	289.69	37.22
		-6.89	-6.47	-7.18	2.20	-6.75	-6.97	-7.28	1.41	0.16
Year	**2006/07**	**-328.06**	**-337.68**		**-341.60**	**-308.16**	**-315.31**		**-320.24**	
		-10.43	-6.64		-9.46	-9.87	-6.27		-8.87	
	2009/10	2.72	67.17	5.24	**-73.59**	-7.38	46.02	-3.75	-54.74	-51.57
		0.09	1.36	0.17	-2.10	-0.24	0.94	-0.12	-1.57	-1.44
	2012/13	54.05	27.53	55.87	-43.35	56.67	51.33	58.69	-13.90	-11.26
		1.75	0.55	1.76	-1.23	1.85	1.03	1.86	-0.39	-0.31
	2015/16	50.28	37.67	49.38	12.67	52.48	36.67	52.16	23.16	23.86
		1.69	0.79	1.61	0.37	1.77	0.78	1.71	0.68	0.69
Interview Month	**January**	**-134.00**		**-142.24**	-37.99	**-110.20**		-107.66	-42.06	-25.01
		-2.66		-2.49	-0.66	-2.19		-1.88	-0.73	-0.38
	February	**-99.50**		-95.32	-44.67	-96.89		-91.88	-65.28	-50.21
		-1.99		-1.66	-0.78	-1.94		-1.61	-1.14	-0.77
	March	**-167.64**		**-166.23**	-68.16	**-160.36**		**-153.33**	-74.87	-59.97
		-3.32		-2.89	-1.19	-3.19		-2.67	-1.31	-0.93
	April	**-196.71**		**-201.46**	-83.78	**-212.67**		**-207.03**	**-111.93**	-99.26
		-4.00		-3.61	-1.51	-4.33		-3.71	-2.01	-1.58
	May	-75.36		-72.10	-7.19	-75.45		-65.48	-19.54	7.40
		-1.57		-1.32	-0.13	-1.58		-1.21	-0.36	0.12
	June	**169.85**	-77.67	**173.39**	**193.16**	**160.12**	-36.93	**160.36**	**146.84**	**162.92**
		3.45	-1.49	3.10	3.48	3.27	-0.72	2.88	2.65	2.60
	July	**558.19**	**311.92**	**587.91**	**412.80**	**536.24**	**342.62**	**560.14**	**407.56**	**414.53**
		11.03	5.79	10.17	7.26	10.60	6.44	9.72	7.15	6.46
	August	**605.93**	**356.64**	**594.32**	**615.70**	**573.05**	**374.16**	**578.02**	**558.98**	**577.18**
		11.83	6.53	10.19	10.59	11.17	6.93	9.92	9.56	8.79
	September	**606.85**	**369.79**	**629.32**	**533.84**	**562.90**	**375.28**	**596.23**	**503.28**	**554.03**
		12.19	6.98	11.06	9.48	11.35	7.21	10.51	8.94	8.67
	October	**356.25**	**115.21**	**376.16**	**300.87**	**335.15**	**142.23**	**373.89**	**285.18**	**333.75**
		6.92	2.10	6.41	5.20	6.55	2.64	6.40	4.94	5.09

	November	**238.42**	omitted	**251.47**	**252.84**	**190.48**	omitted	**204.19**	**212.49**	**243.99**
		4.83		4.47	4.52	3.89		3.66	3.82	3.88
Dependent Variable: Total HH Energy Expenditures (No Fees)		**All Months**	**Cold Months**	**All Months Drop 06/07**	**Low Income**	**Small Homes**	**Cold months, Small Homes**	**Small Homes, Drop 06/07**	**Small Homes, Low Income**	**Small Homes, Low Income, Drop 06/07**
		β (t-value)	*β (t-value)*	*β (t-value)*	*β (t-value)*	*β (t-value)*	*β (t-value)*	*β (t-value)*	*β (t-value)*	*β (t-value)*
Dwelling Characteristics	**Stand-alone Home**	**235.22**	**193.62**	**243.33**	**255.66**	**232.55**	**190.07**	**239.51**	**252.62**	**262.06**
		7.52	3.86	6.87	7.84	7.77	4.00	7.06	7.91	7.34
	Social Housing	**196.14**	**141.87**	**232.69**	**215.70**	**196.19**	**137.40**	**233.70**	**221.48**	**259.80**
		4.80	2.17	5.02	5.38	5.00	2.20	5.24	5.64	5.88
	Private Rental	13.97	-8.06	28.45	**95.84**	31.25	7.87	44.52	**107.59**	**119.38**
		0.55	-0.20	1.00	3.46	1.28	0.20	1.62	3.94	3.91
Number of Rooms	**1-2**	**-1408.27**	**-1674.13**	**-1422.83**	**-1327.40**	**-1172.89**	**-1394.67**	**-1164.93**	**-1094.57**	**-1064.19**
		-9.59	-6.93	-8.76	-9.64	-8.48	-6.17	-7.61	-8.34	-7.36
	3	**-1298.54**	**-1582.08**	**-1374.52**	**-1215.05**	**-1055.36**	**-1286.67**	**-1108.94**	**-983.55**	**-1010.18**
		-17.27	-12.88	-16.12	-14.88	-15.06	-11.40	-13.97	-13.19	-12.02
	4	**-1068.84**	**-1176.12**	**-1119.03**	**-928.37**	**-819.99**	**-881.38**	**-848.62**	**-694.79**	**-703.89**
		-20.24	-13.77	-18.69	-14.55	-16.92	-11.48	-15.48	-12.46	-11.27
	5	**-958.81**	**-1130.21**	**-999.12**	**-794.84**	**-702.27**	**-825.94**	**-720.32**	**-557.56**	**-553.45**
		-22.80	-16.74	-20.81	-14.16	-18.52	-13.94	-16.73	-11.81	-10.43
	6	**-782.13**	**-929.40**	**-826.95**	**-631.63**	**-515.66**	**-617.64**	**-538.73**	**-391.55**	**-389.66**
		-21.15	-15.54	-19.73	-11.86	-15.64	-11.95	-14.54	-8.91	-7.94
	7	**-525.61**	**-630.16**	**-564.60**	**-410.74**	**-252.05**	**-312.08**	**-270.98**	**-169.31**	**-170.58**
		-13.53	-10.07	-12.85	-7.27	-7.20	-5.70	-6.90	-3.55	-3.22
	8	**-279.80**	**-323.31**	**-299.59**	**-243.25**	Omitted Category	Omitted Category	Omitted Category	Omitted Category	Omitted Category
		-6.49	-4.69	-6.18	-3.82					
	9+	Omitted Category	Omitted Category	Omitted Category	Omitted Category					
Auckland Region		**-229.69**	**-318.94**	**-236.02**	**-173.11**	**-229.01**	**-331.49**	**-238.23**	**-179.47**	**-190.80**
		-9.87	-8.49	-8.94	-6.18	-9.81	-8.85	-8.98	-6.39	-6.03
HH Income (log)		**342.24**	**428.69**	**362.03**	**176.86**	**315.38**	**405.30**	**336.60**	**170.59**	**191.14**
		26.60	20.87	24.77	9.80	24.44	19.87	22.96	9.45	9.32
N		7,700,000	3,829,000	6,233,000	4,434,000	6,858,000	3,414,000	5,550,000	4,115,000	3,330,000
Adjusted-R^2		0.2164	0.2023	0.2059	0.1527	0.1964	0.1830	0.1849	0.1432	0.1315

Notes: For the survey year results, the omitted category was the 2018/19 HES year. For the interview month, the omitted category is December when all months are used and November when only the cold-months sample is used. The omitted category for social housing and private rentals is owned dwellings. For number of rooms, the omitted category is 9-or-more rooms (9+). For the Auckland Region, the omitted category is the rest of New Zealand. The number of observations (N) have been rounded to the nearest thousand. Statistically significant results at the 5-percent level are bolded.

Table C2: Regression results using a General Linear Model, Weighted

Dependent Variable: Total HH Energy Expenditures (No Fees)		(1) Small Homes 15/16 & 18/19	(2) Small Homes 15/16 & 18/19	(3) Small Homes 15/16 & 18/19	(4) Small Homes 15/16 & 18/19, Logged DV
		β *(t-value)*	*β* *(t-value)*	*β* *(t-value)*	*β* *(t-value)*
Intercept		**-1564.45**	**-1479.56**	**-1648.10**	**5.5106**
		-3.93	-3.73	-4.08	24.1000
Year	**2015/16**	11.61	10.56	11.09	**0.0391**
		0.33	0.30	0.32	1.9800
Interview Month	**January**	48.43	51.27	51.93	-0.0028
		0.57	0.60	0.61	-0.0600
	February	8.34	8.97	9.60	0.0022
		0.09	0.10	0.11	0.0400
	March	-14.75	-20.18	-11.30	-0.0388
		-0.16	-0.22	-0.13	-0.7600
	April	-100.37	-103.31	-97.69	-0.0457
		-1.19	-1.23	-1.16	-0.9600
	May	45.73	41.48	47.89	0.0160
		0.56	0.51	0.59	0.3500
	June	**216.68**	**217.42**	**220.01**	**0.1105**
		2.51	2.52	2.55	2.2600
	July	**415.84**	**419.37**	**419.48**	**0.1933**
		4.73	4.77	4.77	3.8800
	August	**532.01**	**534.55**	**533.95**	**0.2506**
		6.10	6.13	6.12	5.0700
	September	**563.71**	**562.91**	**565.91**	**0.2422**
		6.22	6.22	6.24	4.7200
	October	**368.48**	**368.44**	**369.55**	**0.1300**
		4.16	4.17	4.18	2.5900
	November	**214.87**	**224.08**	**216.91**	**0.1195**
		2.50	2.61	2.52	2.4500
Dwelling Characteristics	**Stand-alone Home**	**270.89**	**274.98**	**267.96**	**0.1018**
		5.73	5.82	5.66	3.7900
	Social Housing	**135.56**	**131.44**	**238.25**	0.0617
		2.22	2.16	2.36	1.0800
	Private Rental	-13.57	-8.28	91.40	-0.0216
		-0.29	-0.18	0.96	-0.4000
Number of Rooms	**1-2**	**-759.14**	**-765.20**	**-761.40**	**-0.4225**
		-3.75	-3.79	-3.76	-3.6900
	3	**-958.58**	**-951.88**	**-958.30**	**-0.5364**
		-8.89	-8.83	-8.89	-8.7800
	4	**-707.40**	**-706.02**	**-708.14**	**-0.3612**
		-8.45	-8.44	-8.46	-7.6200
	5	**-518.62**	**-516.60**	**-517.65**	**-0.2444**
		-7.62	-7.60	-7.61	-6.3400
	6	**-397.81**	**-397.95**	**-398.54**	**-0.1502**
		-6.33	-6.34	-6.35	-4.2200
	7	**-310.15**	**-309.23**	**-310.27**	**-0.1522**
		-4.62	-4.61	-4.62	-4.0000
Auckland Region		**-231.10**		**-235.37**	**-0.1244**
		-5.67		-5.75	-5.3700
Auckland/Northland Regions			**-245.00**		
			-6.37		
HH Income (log)		**252.15**	**246.41**	**252.35**	**0.1487**
		6.57	6.43	6.58	6.8400
HH Housing Costs (log)		**112.79**	**111.13**	**110.49**	**0.0458**
		4.34	4.30	4.24	3.1000
Property Value (log)				8.40	0.0026
				1.28	0.6900
Adjusted-R^2		0.1428	0.1448	0.1430	0.1221

Notes: For survey year, the omitted category is the 2018/19 HES year. For interview month, the omitted category is December. The omitted category for social housing and private rentals is owned dwellings. For number of rooms, the omitted category is 8 rooms. For region, the omitted category is the rest of New Zealand. The number of observations (N) have been rounded to the nearest thousand. Statistically significant results at the 5-percent level are bolded.

Appendix D

The following figures show the predicted energy expenditures from the regression analysis shown in Table 4 for different housing tenure types based on the number of rooms in the dwelling. The bars around the points on the line represent the 95% confidence interval for the prediction. So, even though the individual coefficients indicate the statistical significance and the magnitude of each individual effect, the predicted estimates show the combined effects. For example, despite the coefficient for the social housing variable being significant in column 1 of Table 4, we can see from Figure D1 that predicted energy expenditures for households in social housing are not significantly different from the other groups once all the factors are taken into account. However, in the low-income samples (Figure D3 and Figure D5), households in owner-occupied dwellings are predicted to have significantly lower energy expenditures regardless of dwelling size compared to those in social housing or in private rentals.

Figure D1. Predicted Annual Energy Expenditures, All-Months Sample

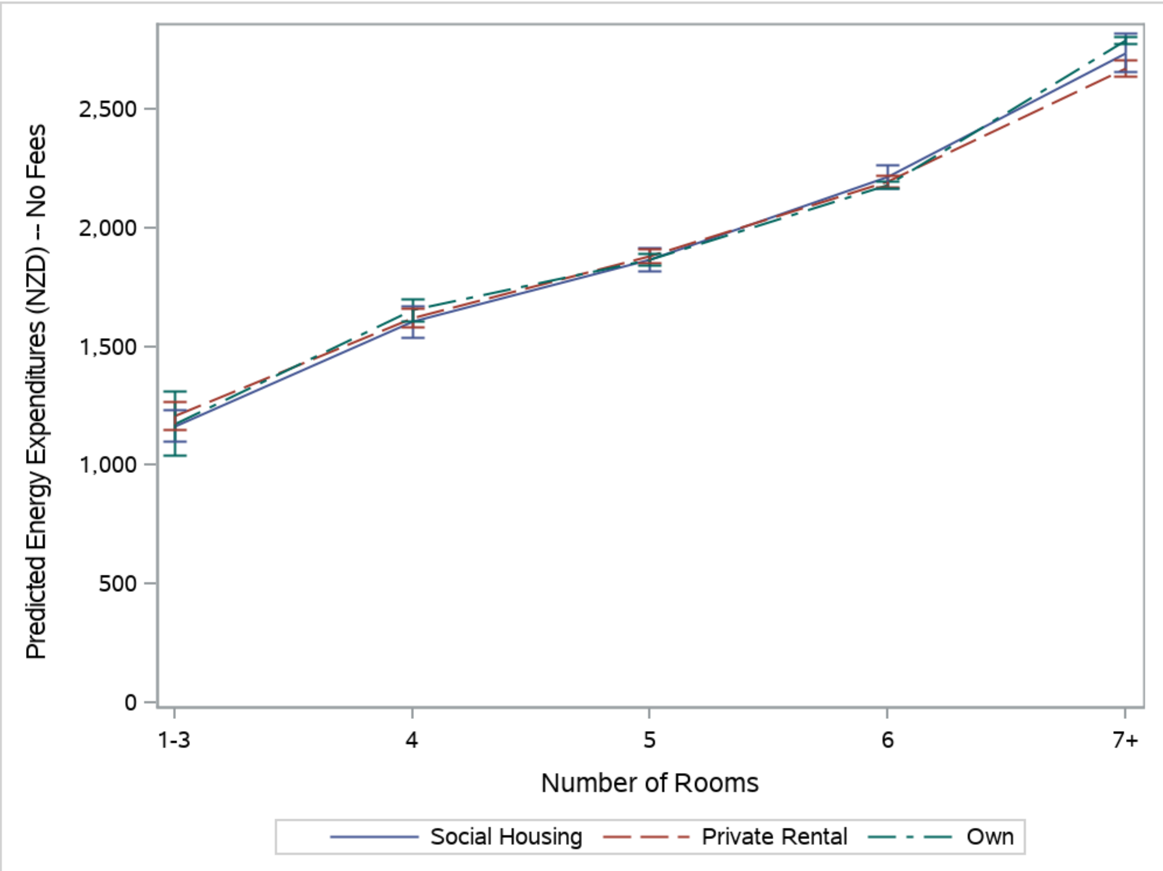


Figure D2. Predicted Annual Energy Expenditures, Cold-Months Sample

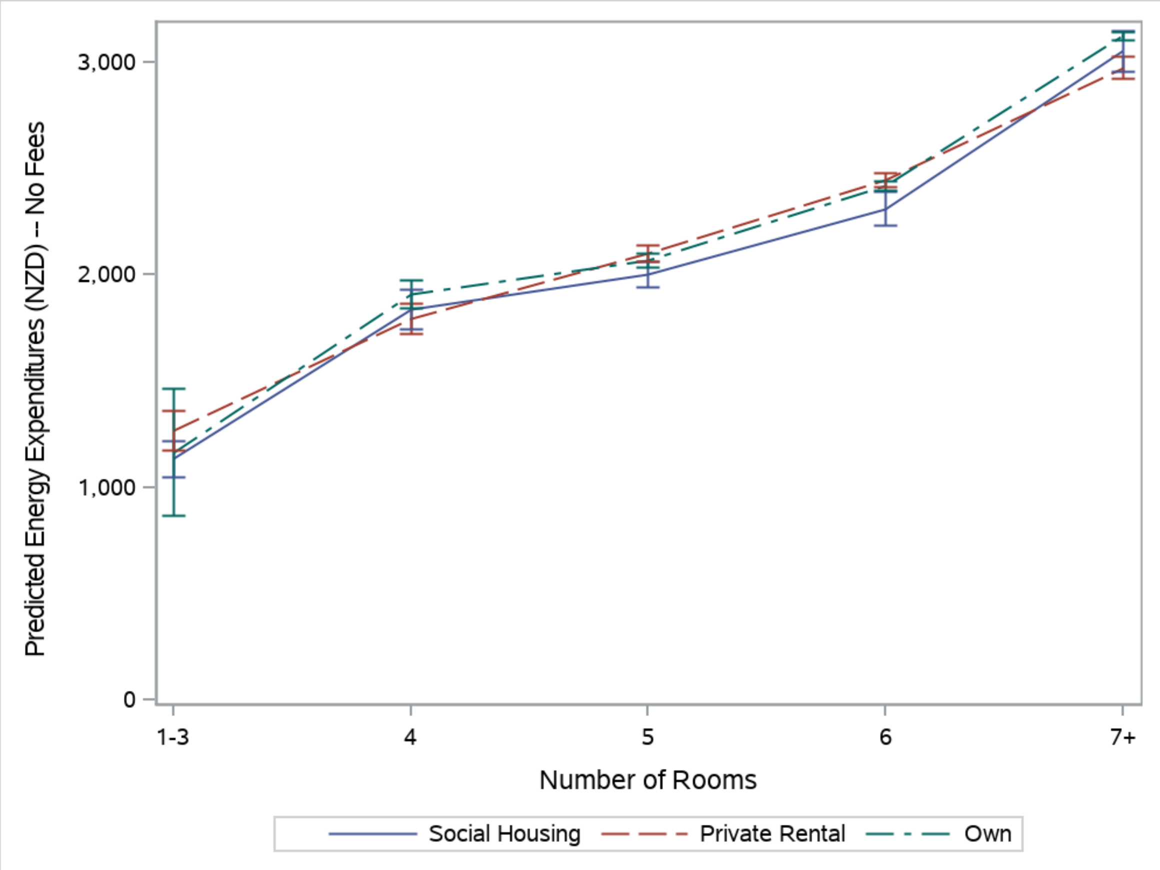


Figure D3. Predicted Annual Energy Expenditures, Low-Income Sample

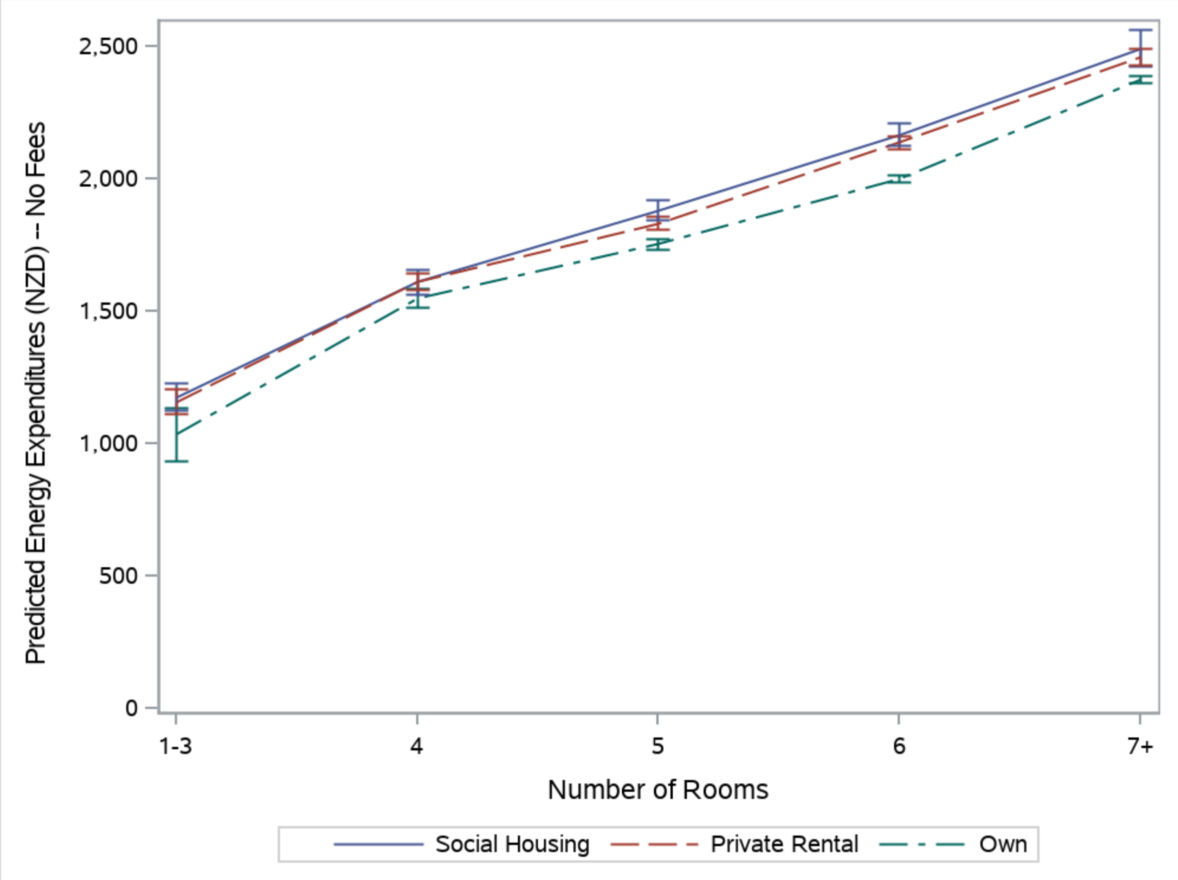


Figure D4. Predicted Annual Energy Expenditures, Cold-Months Small-Homes Sample

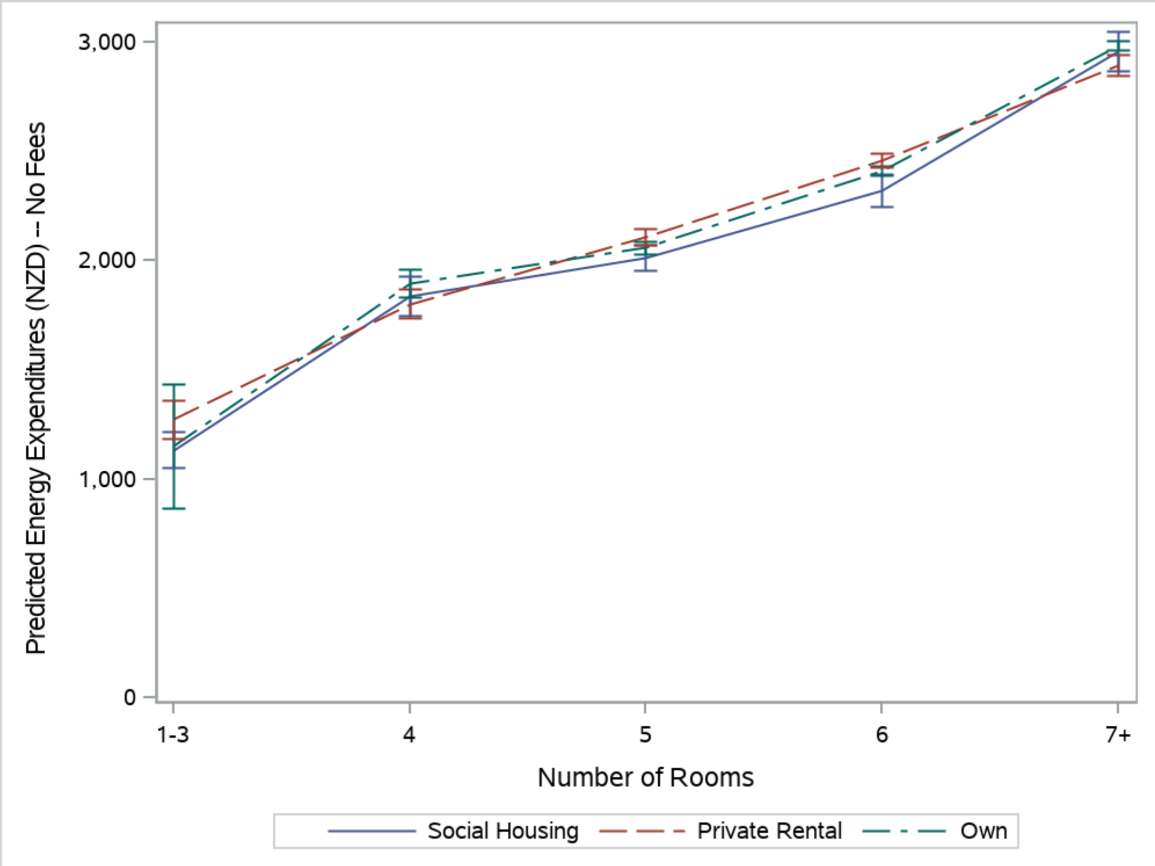
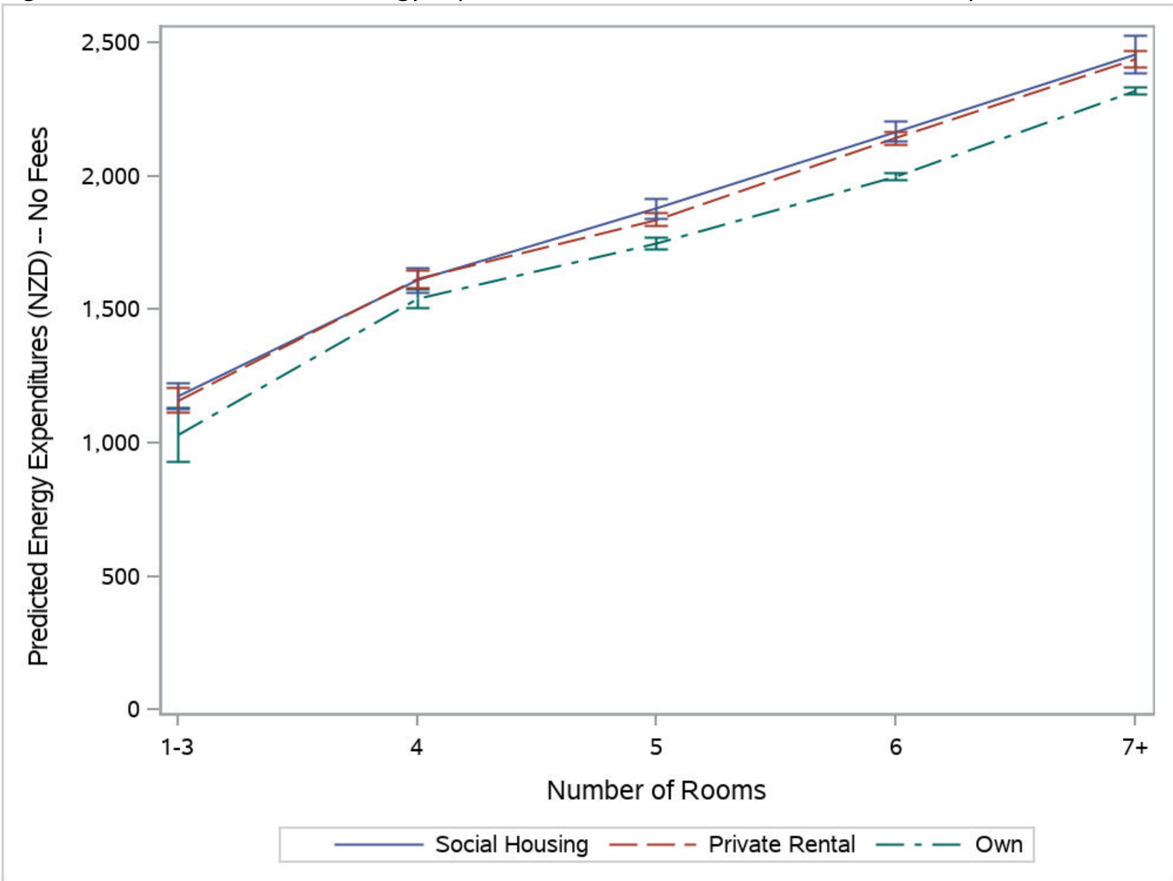


Figure D5. Predicted Annual Energy Expenditures, Small-Homes Low-Income Sample



The following figure shows the predicted energy expenditures from the regression analysis shown in Table C2 for different housing tenure types based on the number of rooms in the dwelling while controlling for housing costs.

Figure D6. Predicted Annual Energy Expenditures, Small-Homes Sample Controlling for Housing Costs