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Retrofit or behaviour change? Which has the greater impact on energy consumption in low income households?

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Abstract

What is the most effective way to help low income households use less energy? Is it best to target the building in which they live by upgrading its thermal envelope, its lighting, its heating and cooling system, or its hot water system? Or is it more effective to focus on educating the householder and facilitating energy efficiency through behaviour change? Or is a combination of the two required? This paper presents the results of a randomised control trial that compares changes in energy consumption in 320 low income Victorian households which underwent different combinations of retrofit and behaviour change interventions. The results show that households which underwent retrofit only interventions reduced total energy consumption by 7.1% and were 1°C warmer in winter; households which underwent a combination of retrofit and behaviour change interventions reduced gas consumption by 18.6% and total energy consumption by 11.4%; households which underwent behaviour change only interventions did not show a noticeable improvement.

Peer-review under responsibility of the organizing committee iHBE 2016.

Keywords: Energy efficiency; residential building energy; retrofit; behaviour change

1. Introduction

Low income households spend a larger proportion of their income on gas and electricity than any other household. A recent report into Australian household energy consumption found that the lowest income quintile spent 5.6% of their income on gas and electricity in 2012, up from 5.1% expenditure in 1994. This is more than double the average household expenditure of 2.7% of income [1]. The later part of this period also saw large increases in electricity prices. Government data shows that household electricity prices rose by around 50% from 2010 to 2013 [2]. Over the past ten years, the retail price of gas for households has increased by 8 per cent a year. This is significantly faster than the rate of inflation [2].

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The Council of Australian Governments (COAG) developed a 10 year national strategy on energy efficiency in 2010 which included proposals for new energy efficiency provisions for new residential buildings and increasing the stringency of minimum energy performance standards (MEPS) for appliances and equipment [3]. Improvements in energy efficiency provisions for new buildings and increased MEPS have resulted in more energy efficient new houses. Average energy consumption in Australian households has remained relatively constant for the last couple of decades [4], but is projected to decline by about 6% by 2020 compared to 1990 levels. This expected decline is primarily being driven by the energy efficiency programmes that have been introduced to increase the efficiency of the building shell and appliances.

Whilst changed regulations have led to new houses and household appliances and equipment becoming more energy efficient, low income households are less likely to benefit from this. Low income households have greater exposure to poor quality housing stock and have limited access to more efficient appliances. This, combined with rising electricity and gas prices over the last decade, has put pressure on Australian low income households.

The Australian Government's commitment to a target of improving Australia's energy productivity by 40 per cent by 2030 includes a focus on reducing energy costs and carbon emissions for households [5]. It aims towards "energy consumers that are able to effectively manage their energy costs and are engaged in improving the productivity of their energy use" [5, p13], and includes working with stakeholders to support vulnerable consumers.

The Australian Government established the Low Income Energy Efficiency Program (LIEEP) in 2011, providing $55.3M in grants to twenty different consortia, to trial approaches to improve the energy efficiency of low income households and enable them to better manage their energy use [6]. One of the grant recipients was the South East Councils Climate Change Alliance (SECCCA) who coordinated a consortium of local government, researchers, and businesses to implement the Energy Saver Study (ESS). This three-year project involved the recruitment of 320 households to participate in the implementation and evaluation of three pilot household energy efficiency programmes, designed to help low income households become more energy efficient. The programmes involved different combinations of retrofit and behaviour change interventions. This paper describes the project and the three programmes trialed, outlines the method used to evaluate them, and gives the results of the evaluation.

2. Methodology

2.1. Recruitment of households

Volunteer households were recruited from a pool of low income clients that receive direct care services through Home and Community Care (HACC), a Victorian state government service deployed by local councils. The 320 households that participated in the study were recruited using an online random number selection tool. Each of the randomly selected clients was assessed for eligibility to participate in the study. Those invited to participate needed to have the physical and cognitive capacity to enable them to participate in the three-year study. They needed to be able to receive numerous visits from a wide range of staff and contractors and to answer a series of survey questions.

2.2. Allocation of households to study groups

The 320 recruited households were allocated to one of four study groups involving different combinations of retrofit and behaviour change interventions:

- Retrofit – households received energy efficiency upgrades to the house itself, such as insulation, weather sealing, appliance repair and replacement, and lighting upgrades
- Behaviour change – householders were provided with information and house operation strategies to encourage behaviour change in order to reduce energy consumption
- Retrofit and behaviour change – occupants received both the behaviour change programme and retrofits
- Control group – these households only partook in the surveys and monitoring and received no other intervention

Households were allocated to a study group using a random number selection tool. Exceptions to this process occurred to maximise the participation of households until the end of the study so that as much data as possible could be collected. For example, households which were judged as most capable of receiving high numbers of visits and contact were placed in the retrofit and behaviour change study group, and/or the group that received the installation of onsite energy monitoring equipment. Those householders that appeared to be less inclined to receive a high number of visits and contact were allocated to either the control group or to a study group that did not receive energy monitoring equipment. This process recognised that all householders were not comfortable to receive high numbers of visits and contact, and if they did, they would be less likely to complete the study.

2.3. Surveys

In order to understand the characteristics of the houses and householders participating in the study, and what interventions might be possible, a number of different surveys were conducted. Data collected included: the dwelling characteristics and energy characteristics of the house including building type, age and size and the appliances installed in the house including heating/cooling systems, hot water systems, lighting and major appliances; household characteristics including number of people in the house, age, occupancy profile and income; householder energy use behaviour and attitudes towards energy efficiency pre- and post- intervention; and for a subset of 60 houses a detailed survey included thermography inspection, weather sealing inspection and a Nationwide House Energy Rating Scheme (NatHERS) energy assessment.

Some of the characteristics of the 320 households include: 55% were single person households and 39% were two person households; 78% of the participants were more than 70 years old; 84% of households had someone home all day; 69% of households had a weekly income less than $A600 (average Australian income is $A998 [7]); 71% of houses were brick veneer construction; 54% of houses had 3 bedrooms; and 80% of houses were separate houses.

2.4. Interventions

Of the 320 households recruited to the study, 230 underwent one or more interventions designed to reduce energy consumption. 75 houses received retrofit interventions only, 74 received behaviour change interventions only, and 81 received both retrofit and behaviour change interventions. 80 houses did not receive any intervention and were used as a control group. 10 houses withdrew from the study before interventions were implemented.

Houses which received retrofit interventions received one or more of eleven different retrofit intervention subtypes: appliance upgrade, draught sealing, heater/cooler maintenance, heater/cooler upgrade, hot water service insulation, hot water service maintenance, hot water service upgrade, insulation, LED lighting, window treatment, and zoning. Households which received behaviour change interventions received one or more of five different behaviour change intervention subtypes: one-on-one meeting to discuss motivations and choice of energy actions; follow-up meeting to discuss motivations and choice of energy actions; group meeting to discuss energy actions taken, challenges, and to share learnings; installation of a Watts Clever EW4500 in-home-display; installation of an EMS Ecofront energy monitor in-home-display. Houses received a tailored package of interventions and so each house received a different combination of intervention subtypes.

Intervention costs varied from house to house, depending on what combination of interventions the house underwent. Retrofit interventions varied from $469 to $4,450 with a mean of $2,348. Behaviour change only interventions varied from $85 to $2,586 with a mean of $711. And retrofit combined with behaviour change interventions cost between $1,086 and $6,840 with a mean of $2,885. The interventions were provided at no cost to the household.

2.5. Measurements

Several different measures were used to assess the impact of the interventions on households. These measures fall broadly into four main categories: savings in energy consumption, savings in energy bills, savings in greenhouse gas emissions, and increased thermal comfort in households.

Energy consumption in households was measured using two main methods: using data obtained from electricity and gas monitoring equipment installed in 120 of the houses; or using data obtained from electricity and gas distributors. The electricity and gas monitoring equipment recorded thirty minutely consumption. Data from the electricity distributors was mainly smart meter data and was thirty minutely consumption. Data from the gas distributors was billing data and usually in three monthly blocks. Billing data was converted to a daily consumption value by calculating the days in each billing cycle and evenly distributing the total consumption over the period. The results presented in this paper are based on the distributor data only. A separate paper presents the analysis of the monitoring equipment data [8].

House daily energy consumption values were used to calculate for each house an average daily value for each month pre-intervention and an average daily value for each month post-intervention. The average daily value post-intervention was compared against the average daily value pre-intervention for equivalent months. The difference between these two gives the change in consumption for a house for a month. For control houses, daily averages were calculated for months in 2014 and compared against equivalent months in 2015. The same range of months was used for control houses as for houses which underwent an active intervention. Although differences in weather from one year to the next may have impacted measured monthly changes in energy consumption, the analysis compares intervention group changes against control group changes (whose households are subject to the same weather), thus nullifying the impact of weather.

Bill savings were calculated by applying a 29 cents/kWh and 1.8 cents/MJ rate to daily electricity and gas savings respectively. Greenhouse gas emissions savings were calculated by applying a 1.26 kgCO2-e/kWh and 0.0039 kgCO2-e/MJ rate to electricity and gas savings respectively [9]. Changes in household comfort levels were calculated using monitored thirty minutely indoor temperatures.

2.6. Data limitations

Ideally we would have a full year's worth of data pre-intervention and another full year's worth of data post-intervention. There were a number of reasons why this was not possible: later recruitment of volunteers than expected; following on from this, later timing of interventions than originally planned; withdrawal of some volunteers before the end of the study period; and finally, an earlier final reporting deadline for the project than initially expected.

Because we did not have a full year's worth of data pre and post intervention, we were unable to calculate household average daily consumption over an entire year prior to intervention and then compare it against the household average daily consumption for an entire year after the intervention. Instead, we have used the available data to calculate average daily consumption for each month prior to intervention and again for each month after intervention. Only months where there was at least twenty days' worth of data were used. Where a house had pre and post intervention data for the same month (different year), the difference between the daily averages was calculated.

Although households received multiple interventions over a range of dates, the date of the first intervention was used as the dividing line between the pre-intervention period and the post-intervention period for each household. This was done in order to maximise the amount of data we could use for analysis. This may result in the impact of interventions being greater in the later post-intervention months.

Some households had data covering more months than others. Because of this, the study group averages are weighted towards the houses and months where there was more data. There is no change data for January or February for any households, and there is data for only one household for March (Figure 1). This data limitation means that the impact of interventions on summer energy use is not properly gauged by this study.

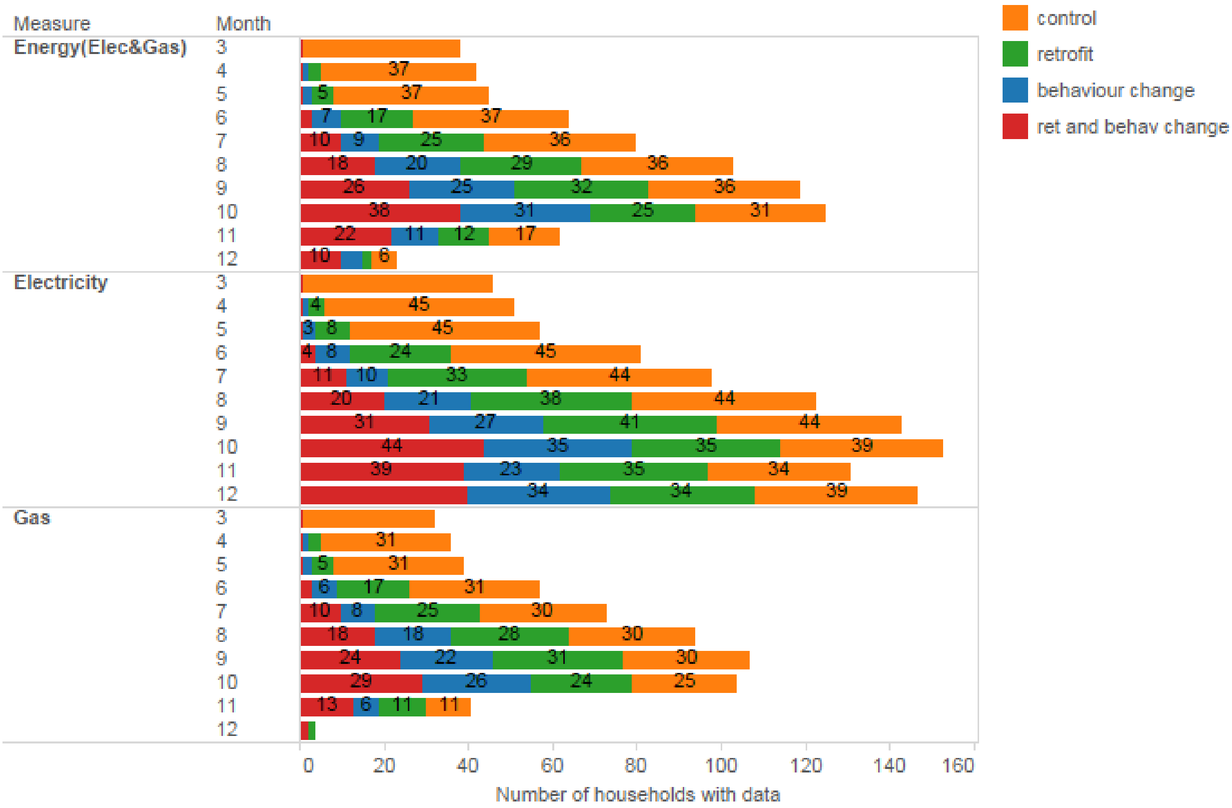

Fig. 1. Number of households for which change data was available for each month, for households with distributor data.

2.7. Analysis

Collected data was analysed using a combination of the following tools: PostgreSQL for aggregation of data; Microsoft Access for aggregation and manipulation of data; Tableau for visualisation of the data; and R for statistical analysis.

For each dwelling, the electricity and gas usage data was first aggregated (or in the case of distributor billing data, disaggregated) to a daily total, and then to an average daily total for each month so that the comparison pre- and post- intervention could be based on similar weather conditions. To calculate total energy use, gas use was converted from megajoules (MJ) to kilowatt hours (kWh) (using 1 MJ = 0.278 kWh), and then added to electricity use (in kWh).

For each study group for each month, the changes in electricity, gas, and total energy daily averages for the dwellings in the group were averaged (mean). Each study group's mean was compared against the control group mean using a t-test. Statistical significance at the 0.05 level and 95% confidence intervals were calculated.

3. Results and discussion

3.1. Energy consumption, energy costs, greenhouse gas emissions, and temperature pre-intervention

For the period prior to carrying out the interventions, but using only those months of the year for which post-intervention data also existed, mean daily measure values were calculated for houses in each study group (Table 1). Energy consumption in the cohort of households in this study is lower than for the Victorian population in general. Average daily consumption in the general Victorian population over the months March to December is 15.2 kWh for electricity and 187 MJ for gas [10].

Table 1. Mean household energy consumption, energy costs, greenhouse gas emissions, and temperature prior to interventions

Measure	Control	Retrofit	Behaviour change	Ret & behav change
Average daily electricity consumption (kWh)	12.61	11.95	12.32	10.48
Average daily gas consumption (MJ)	159.6	152.8	159.2	136.0
Average daily total energy (elec & gas) consumption (kWh)	50.38	53.51	50.49	42.02
Average daily cost of electricity consumption ($)	3.657	3.465	3.572	3.040
Average daily cost of gas consumption ($)	2.873	2.750	2.865	2.448
Average daily cost of total energy (elec & gas) consumption ($)	6.068	6.143	6.185	5.089
Average daily GHG emissions due to electricity consumption (kgCO_2e)	15.89	15.06	15.52	13.21
Average daily GHG emissions due to gas consumption (kgCO_2e)	8.83	8.45	8.8	7.52
Average daily GHG emissions due to total energy (elec & gas) consumption (kgCO_2e)	23.24	23.27	23.79	19.52
Average daily temperature in living room during winter (°C)	18.27	18.69	19.26	18.71

3.2. Impact of interventions on energy consumption

When comparing the post-intervention period against the pre-intervention period, the change in average daily energy consumption varied considerably from house month to house month (Figure 2). For example, in the control group: the change in total energy consumption (electricity and gas) varied from -63.86 kWh to +74.23 kWh with a median of +1.76 kWh and a mean of +1.17 kWh, the change in electricity consumption varied from -39.12 kWh to +30.97 kWh with a median of -0.31 kWh and a mean of -1.13 kWh, the change in gas consumption varied from -48.14 kWh to +86.61 kWh with a median of +3.35 kWh and a mean of +4.07 kWh. (Note that gas consumption contributes more to the total energy consumption than electricity consumption does.)

The mean change in average daily energy consumption varies between study groups. For total energy, the mean change in average daily consumption was +1.17 kWh for houses in the control group, -2.61 kWh for houses which underwent retrofit, -1.52 kWh for houses which underwent behaviour change, and -3.63 kWh for houses which underwent a combination of retrofit and behaviour change.

Thus, relative to the control group, retrofit houses had a mean change of -3.78 kWh, behaviour change houses had a mean change of -2.69 kWh, and retrofit & behaviour change houses had a mean change of -4.80 kWh (Figure 3). For electricity only, relative to the control group, retrofit houses had a mean change of -1.05 kWh, behaviour change houses had a mean change of -0.77 kWh, and retrofit & behaviour change houses had a mean change of -0.15 kWh. For gas only, relative to the control group, retrofit houses had a mean change of -2.54 kWh, behaviour change houses had a mean change of -3.25 kWh, and retrofit & behaviour change houses had a mean change of -7.01 kWh.

The differences between the study group means and the control group means were tested for statistical significance (at the 0.05 level) using t-tests, and 95% confidence intervals were calculated (Table 2, first three rows). The retrofit group showed a change in total energy consumption which was statistically significant (-3.78±3.46 kWh). The retrofit & behaviour change group showed changes in both gas consumption (-25.22±14.03

MJ) and total energy consumption (-4.8±3.27 kWh) which were statistically significant. None of the intervention groups showed a statistically significant change in electricity consumption by itself. Comparing these statistically significant changes against values pre-intervention (Table 1) enables a percentage change value to be calculated. The retrofit group showed a change in total energy consumption of 7.1±6.5%. The retrofit and behaviour change group showed a change in total energy consumption of 11.4±7.8% and a change in gas consumption of 18.5±10.3%.

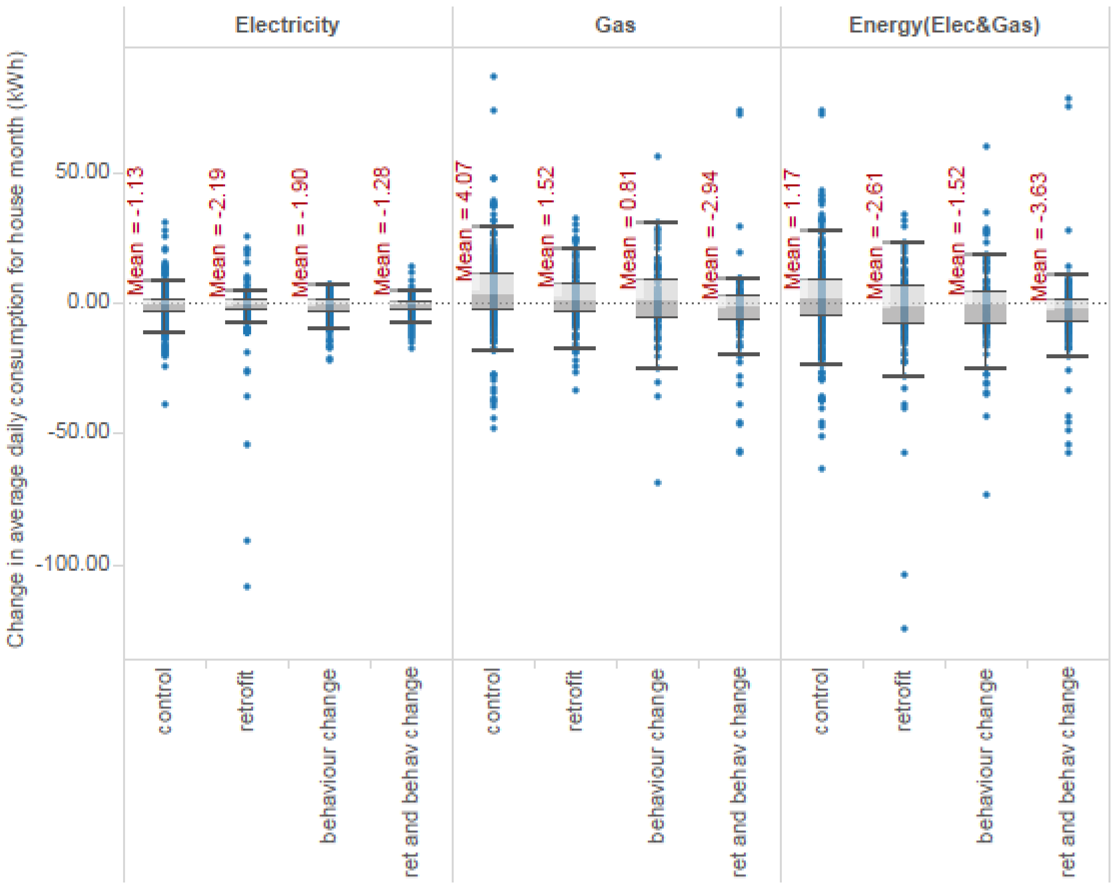

Fig. 2. Change in average daily energy consumption for house months (using distributor data). Each dot represents one house month; box shows median and interquartile range; whiskers show 1.5 times interquartile.

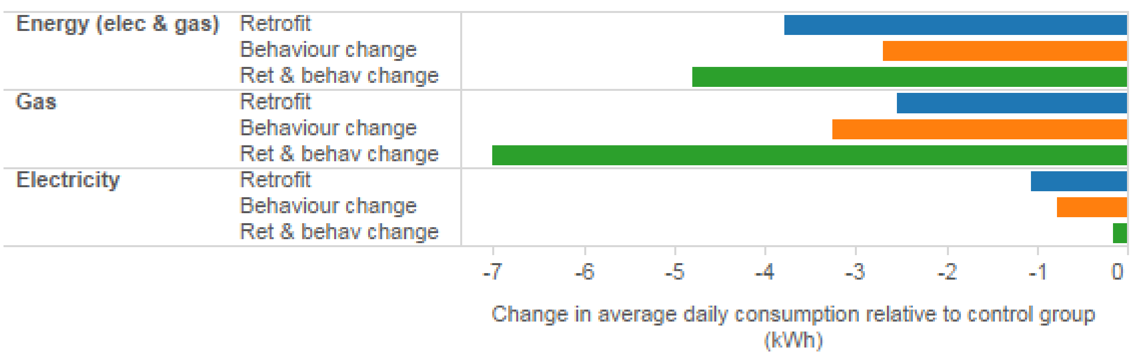

Fig. 3. Mean change in average daily energy consumption for intervention group, relative to the control group (kWh).

Table 2. Study group mean change in measure value since intervention for house months (with 95% confidence interval). Entries marked with an asterisk (*) indicate that the result was statistically significant at a 0.05 threshold. Data from distributors was used for this analysis.

Measure	Retrofit	Behaviour change	Ret & behav change
Change in average daily electricity consumption (kWh)	-1.05±1.49	-0.77±1.00	-0.15±0.82
Change in Average daily gas consumption (MJ)	-9.14±9.64	-11.69±13.88	-25.22±14.03 (*)
Change in average daily total energy (elec & gas) consumption (kWh)	-3.78±3.46 (*)	-2.69±3.55	-4.8±3.27 (*)
Change in average daily cost of electricity consumption ($)	-0.306±0.431	-0.223±0.29	-0.044±0.237
Change in average daily cost of gas consumption ($)	-0.165±0.174	-0.211±0.25	-0.454±0.253 (*)
Change in average daily cost of total energy (elec & gas) consumption ($)	-0.866±0.679 (*)	-0.367±0.428	-0.311±0.340
Change in average daily GHG emissions due to electricity consumption (kgCO2e)	-1.33±1.87	-0.97±1.26	-0.19±1.03
Change in average daily GHG emissions due to gas consumption (kgCO2e)	-0.51±0.54	-0.65±0.77	-1.39±0.78 (*)
Change in average daily GHG emissions due to total energy (elec & gas) consumption (kgCO2e)	-3.84±2.89 (*)	-1.60±1.71	-1.11±1.34
Change in average daily temperature in living room during winter (°C)	0.96±0.73 (*)	-0.02±0.72	0.66±0.82

3.3. Impact of interventions on energy bills

The savings (or additional expenditure) on daily energy bills associated with the change in energy consumption varied from house month to house month. The mean change in total daily energy bills was -22 cents for the control group, -109 cents for the retrofit group, -59 cents for the behaviour change group, and -53 cents for the combined retrofit/behaviour change group. Thus, relative to the control group, the retrofit group had a mean daily change of -87 cents, the behaviour change group had a mean change of -37 cents, and the combined retrofit/behaviour change group had a mean change of -31 cents (Figure 4, Table 2). Changes in costs associated with electricity and gas consumption separately are also shown in Figure 4 and Table 2. Only the change in costs for total energy consumption for the retrofit group (-87±68 cents) and costs for gas consumption for the combined retrofit/behaviour change group (-45±25 cents) were statistically significant (Table 2). These changes are equivalent to savings of 14.1±11.1% and 18.6±10.2% respectively.

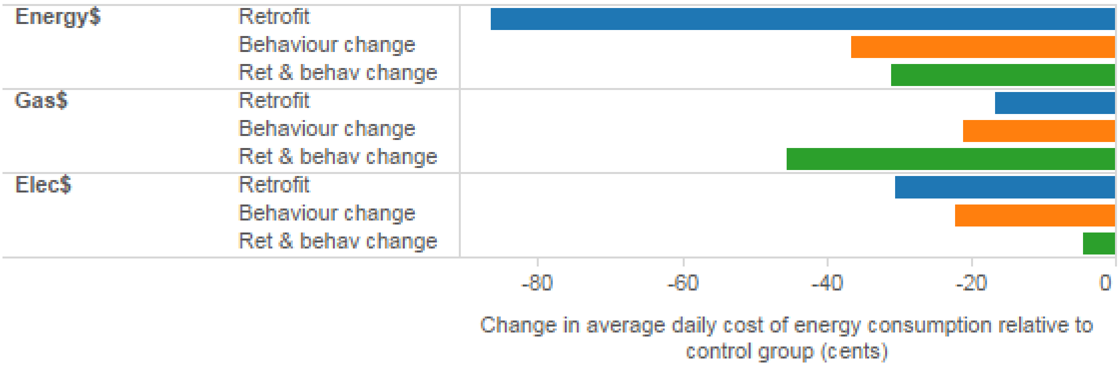

Fig. 4. Mean change in average daily cost of energy consumption for intervention groups, relative to the control group (cents).

3.4. Impact of interventions on greenhouse gas emissions

The change in greenhouse gas (GHG) emissions due to total energy consumption for the retrofit group was statistically significant, with a mean daily savings of 3.84±2.89 kgCO2e (16.5% ± 12.4%), when compared against the control group (Table 2). The change in greenhouse gas (GHG) emissions due to gas consumption for the combined retrofit/behaviour change group was also statistically significant, with a mean daily savings of 1.39±0.78 kgCO2e (18.5% ± 10.4%), when compared against the control group (Table 2). No other statistically significant results were obtained relating to GHG emissions.

3.5. Impact of interventions on householder comfort

Changes in household comfort as measured by average daily temperature in the living room during the winter months varied from house to house. The mean change in temperature was statistically significant for the retrofit only group (0.96±0.73 °C), when compared against the control group (Table 2). The other groups showed no statistically significant change in temperature.

There was insufficient summer data to be able to determine whether the interventions had an impact on indoor temperatures over the summer months.

3.6. Intervention cost effectiveness

Using the mean intervention impacts (which were statistically significant) together with the cost of the interventions, the cost effectiveness of the interventions was calculated (Table 3). For example, it costs a household undergoing a combination of retrofit and behaviour change interventions $1.65 to save 1 kWh of total energy (electricity and gas) per year. It costs a household undergoing only retrofit interventions $2,451 to make their house 1°C warmer in winter.

Table 3. Cost effectiveness of interventions which had statistically significant impact

Intervention	**Impact measure**	**Cost effectiveness**
Retrofit and behaviour change	Total energy consumption	$1.65 per kWh saved per year
Retrofit and behaviour change	Gas consumption	$1.13 per kWh saved per year
Retrofit	Total energy consumption	$1.70 per kWh saved per year
Retrofit and behaviour change	Gas bills	$17.42 per $ saved in annual gas bill
Retrofit	Energy bills	$7.43 per $ saved in annual gas bill
Retrofit and behaviour change	GHG emissions from gas consumption	$5.67 per kg$CO_2$e saved over a year
Retrofit	GHG emissions from total energy consumption	$1.68 per kg$CO_2$e saved over a year
Retrofit	Temperature in living room in winter	$2451 per °C warmer in winter

4. Conclusion

This study evaluated the efficacy of three programmes designed to help low income households become more energy efficient. It found that:

- Households which underwent a combination of retrofit and behaviour change interventions made on average the following improvements: a saving in their total daily energy consumption (electricity and gas) of 4.80 ± 3.27 kWh (11.4 ± 7.8%); a saving in their daily gas consumption of 25.2 ± 14.04 MJ (18.5 ± 10.3%); a saving in their daily gas bill of 45 ± 25 cents (18.6 ± 10.2%); a saving in their daily greenhouse gas emissions due to gas consumption of 1.39 ± 0.78 kg CO_2-e (18.5% ± 10.4%).
- Households which underwent retrofit only interventions made on average the following improvements: a saving in their total daily energy consumption (electricity and gas) of 3.78 ± 3.46 kWh (7.1 ± 6.5%); a saving in their

daily energy bills of 87 ± 68 cents (14.1 ± 11.1%); a saving in their daily greenhouse gas emissions due to total energy consumption of 3.84 ± 2.89 kg CO_2-e (16.5% ± 12.4%); an increase in the average temperature in the living room during the winter months of 0.96 ± 0.73 °C.
- Households which underwent behaviour change only interventions did not show a noticeable improvement in any of the measures.
- In dollar terms, the households which underwent a combination of retrofit and behaviour change interventions have a payback period of 17.42 years (in terms of savings on gas bills), and households which underwent retrofit only interventions have a payback period of 7.43 years (in terms of savings on energy bills). Households which underwent retrofit only interventions have the added benefit of an additional 0.96 °C of warmth in the winter months.

This analysis did not include data from January or February and is therefore skewed to the autumn, winter, and spring seasons. It must also be noted that the retrofit and behaviour change study group was more likely to contain households judged as being more able to cope with a high level of interaction. This has the potential to introduce bias into the randomised control process.

Ideas for future research include the collection of a full year's worth of data both pre-intervention and post-intervention to give a more complete assessment of intervention impacts across a whole year. A focus on summer months in particular is needed. It would also be of value to conduct randomised control trials to test the efficacy of different retrofit subtypes. For example, insulation, draught sealing, appliance upgrade, etc. Further exploration of behaviour change subtypes would also be warranted.

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