SDRC 8.3

LED TRIAL REPORT

SAVE
Solent Achieving Value from Efficiency

Scottish & Southern Electricity Networks

Solent Achieving Value from Efficiency

Solent Achieving Value through Efficiency (SAVE) is an Ofgem funded project run by Scottish and Southern Electricity Networks (SSEN) and partnered by the University of Southampton (UoS), DNV GL and Neighbourhood Economics (NEL). The innovative programme evaluates the potential for domestic customers to actively participate in improving the resilience of electricity distribution networks and thereby defer the need for traditional reinforcement. The government has forecasted an increase in electricity demand of 60% by 2050 meaning peak demand is likely to grow to six times higher than what the network was designed for.

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EXECUTIVE SUMMARY

This report presents the design, implementation, analysis and results of the LED trials conducted in the Solent Achieving Value from Efficiency project. The LED trial ran from 2017 to 2018 in two distinct trial periods and aimed to accelerate the adoption of LED lighting in over 1000 residential properties through (1) an offer of discounted LED bulbs and (2) free of charge LED bulb installation.

Trial period 1 (TP1) tested an opt-in approach, with customers receiving an offer for discounted LED light bulbs available for purchase through a project website.

Trial period 2 (TP2) tested an opt-out approach, in which the project offered to install up to 10 LED light bulbs in each participant's home free of charge. Project staff called and made in-person visits to attempt to install the bulbs. Project staff removed old bulbs to ensure they were not re-installed.

In TP1 whilst 19% of the trial group visited the projects website selling bulbs, less than 1% of the trial group actually purchased bulbs. While this did not have an impact on the network, it was useful to determine which engagement methods are (or in this case, are not) successful with customers.

TP2 built on TP1 and was significantly more successful, as nudge theory[1] would suggest, adopting an opt-out approach saw 76% of participants accepting the project's offer to install LED bulbs in their house. Bulbs were installed across the Autumn and early Winter of 2017 with the final installations occurring in January 2018. The maximum observed change in energy consumption during the peak period was 47 Watts per household. These impacts were statistically significant at the 90% confidence level. Across a 500-customer secondary substation, that equates to approximately 24 kW of peak load reduction or the demand of approximately 3.5 electric cars. If, for example, this LED programme was rolled out to the entire population of Hampshire County (including Southampton)[2], the average peak reduction would be approximately 64 MW.

Average annual savings per household were 90 kWh, resulting in financial savings of approximately £15.82 per year. The project produced savings of 97,470 kWh annually. This results in a reduction of 37,181 kq of CO_2 annually. If the LED programme was extended to all 3.7 million of SSEN's customers, savings would be 333,000 MWh per year and 127,000 metric tons of CO_2 a year. This is similar to taking approximately 28,000 petrol cars off the road.[3] Through the acceleration of the adoption of energy efficient light bulbs approximately 1 additional 7kw EV charger can be added to the network per 212 households assuming charging is at peak times and that constraints are at the higher voltage level.

While traditional reinforcement generally is more cost effective than LEDs, there are additional, non-reinforcement benefits of LED engagement that should be considered. Engagement with customers to promote the installation of LEDs can identify Priority Services Register customers; DNO's are directly incentivised to do this under RIIO. Alternatively, future revenue streams to support energy efficiency could be considered to support social benefits of initiatives (whether to the DNO or a third party). In future iterations of energy efficiency rollout, the DNO should look to stack engagement benefits by partnering with third parties to devise cost-efficient programmes. Success of such initiatives will be site dependant based upon the cost of reinforcement and of other smart and market based solutions in an area.

1 Thaler and Sunstein, 2009, Nudge: Improving Decisions About Health, Wealth and Happiness
2 Using 2017 population data from https://www.nomisweb.co.uk/reports/lmp/la/1941962884/report.aspx#tabrespop
3 Using CO2 emission data from https://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle.

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INTRODUCTION

This Successful Delivery Reward Criteria (SDRC) Report presents the design, implementation, analysis and results of the LED trials conducted in the Solent Achieving Value from Efficiency (SAVE) project. The LED trial ran from 2017 to 2018 in two distinct trial periods. It aimed to accelerate adoption of LED lighting in residential properties through (1) an offer of discounted LED bulbs and (2) free of charge LED bulb installation and analyse the associated network impact.

1.1 Background

Energy efficiency has been proven as a cost-effective method for reducing consumption in residential properties, and initial studies in the UK show it is a promising alternative to traditional network reinforcement. A National Energy Action and Northern Powergrid study states that "a small but nonetheless meaningful opportunity may exist" in energy efficiency.[4]

The initial SAVE project bid looked at winter energy demand by end-use in the UK and determined the two energy efficiency demand groups most interesting to a DNO are lighting and white goods/consumer electronics.[5] These reports show lighting is responsible for 11.5% of domestic energy consumption and 19% of evening peak demand. For this reason, SAVE focused on LED lightbulbs.

While LED bulbs have been available in the UK for some time, uptake has been slow; Energy Savings Trust estimate that at the time of drafting the SAVE bid documents there were still 651 million filament bulbs in use in the UK. Even compared to the compact fluorescent bulbs, LEDs are at least 50% more efficient. The bid calculated that LED deployment is a viable alternative for all demand driven thermal and voltage constraint network reinforcement scenarios except high-voltage minor works, where the number of customers and budget available do not make it financially viable.

Energy efficiency and demand reduction has benefits for both consumers and DNOs. Ofgem has calculated that a 5% reduction in energy use at peak will result in energy market cost reductions of £219m per annum, some of which would benefit customers in the form of lower energy bills. At the same time, a 5% reduction at peak will result in infrastructure cost savings of between £143m and £275m. This directly correlates to savings for the customer, in addition to the direct savings from lower household energy consumption.

The SAVE project builds on these ideas to robustly test energy efficiency and customer engagement using a randomised control trial of over 4,000 households.

At point of submission, the SAVE project identified seven key knowledge gaps and four learning outcomes to be addressed by project activities. The project objectives considered in this SDRC (LED lighting) are detailed below:

Learning Outcomes:

- To gain insight into the drivers of energy efficient behaviour for specific types of customers.
- To gauge the effectiveness of different measures in eliciting energy efficient behaviour with customers.

Knowledge gaps:

- What engagement approaches are available to DNOs to facilitate uptake of energy efficiency measures by domestic customers?
- What do DNO led energy efficiency campaigns look like and how can they be run successfully?
- Can energy efficiency make an effective and economic contribution to network management?
- How enduring are the impacts of each measure and what costs if any are associated with sustaining the impacts?

4 AgilityEco for National Energy Action and Northern Powergrid. "Supporting Local Energy Efficiency as an Alternative to Network Reinforcement." 2015.
5 Based on 'Assessing the Impacts of Low Carbon Technologies on Great Britain Distribution Networks' by Ofgem and 'GB Energy Demand – 2010 and 2025' from Initial Brattle Electricity Demand-side Model. Confirmed by 'Household Electricity Survey: A study of domestic electrical product usage' by Intertek, reference R66141.

1.2 Method definition

The SAVE project bid document (SSET206) outlines four main methods of intervention that will be tested within the project. These were originally named as follows:

- Method 1 (M1)- LED engagement
- Method 2 (M2)- Data informed engagement
- Method 3 (M3)- Data informed engagement and price signals
- Method 4 (M4)- Community Energy Coaching

This, however, did not provide a reference number to the project's control group population. Throughout delivery of the project to ease identification of the methods being trialled each was re-named as follows:

- Trial Group 1 (TG1)- Control Group
- Trial Group 2 (TG2)- LED Lighting
- Trial Group 3 (TG3)- Data informed engagement and price signals
- Trial Group 4 (TG4)- Data informed engagement
- Community Energy Coaching Trials (CEC or M4)

To avoid confusion and the risk of mismatch between delivery and reporting the project came to the conclusion that the methods were better referred to by these names. Within this document all interventions will be referred to under these revised names.

1.3 Trial goals

Both trial periods attempted to persuade participants to adopt LED lighting in order to lower the energy consumption of their homes. The trials were structured to determine the most effective way of engaging with customers by testing both an opt-in and an opt-out approach.

TP1 tested if customers would proactively engage with an offer of discounted LED bulbs while in TP2 project staff visited households with an offer of free LED bulbs that the customer needed to reject if they were not interested.

Ultimately, participation in TP1 was low, and TP2 sought to build on the learning around limited engagement by requiring participants to opt-out if they were not interested. Initial research into best practices around energy efficiency and behaviour change (see SDRC 1, 'Lessons learnt on Energy Efficiency and Behaviour Change'[6]) confirmed that opt-out campaigns are generally more effective than opt-in, and should be used where possible to maximise participation. The LED trial aimed to test both approaches to gauge the effectiveness of each.

While the main focus was to determine the impact energy efficiency measures can have on the network, the trial also aims to gain insight into the drivers of energy efficient behaviour and technology and how results (energy, carbon and bill savings) vary for different types of customers.

It is hoped that the results from this trial can inform future government energy efficiency schemes, such as future versions of Green Deal and Energy Company Obligation (ECO). The UK Government's Carbon Plan states that all buildings will need to have close to zero emissions in order to meet Government targets by 2050. Homes will need better insulation and more efficient lighting and devices. SAVE actively worked towards this goal by providing low-cost and no-cost LED bulbs to households, laying a blueprint for the role of future energy efficiency initiatives in network management.

6 Available at https://www.ssen.co.uk/save/

1.4 Trial design and approach

Trials ran over two periods; Trial Period 1 (TP1) ran from 1 January to 31 March 2017 while Trial Period 2 (TP2) ran from 1 October 2017 to 31 March 2018.

DNV GL used the Cabinet Office's '6Es – MINDSPACE' framework as a guideline when developing the LED trials. The 6Es refer to the actions needed to be undertaken by an organisation implementing a strategy to drive behaviour change. These are: Explore, Enable, Encourage, Engage, Exemplify and Evaluate. DNV GL used this framework as a structure to analyse lessons learned from past research (such as previous LCNF projects). A number of key findings came from this work (see SDRC 1, for full results and details on literature reviewed), but the main findings relevant to the LED campaigns are:

- Customers need to understand how they can reduce their energy usage and be educated appropriately. The trial provided free of charge information on how much energy and money LEDs can save through postal mailers.
- Parties delivering messages to customers need to be seen and recognised as both trustworthy and authorities in the subject matter. All contact with trial participants was done under the SAVE project name. Where outside suppliers were used, the project introduced them as trusted partners to avoid trust issues.
- Financial incentives can be effective but potentially need to be relatively large and impacts are often not sustainable over time; non-financial incentives should also be considered. The LED trial tested both small incentives in TP1 and larger ones in TP2 to determine how these can impact uptake.
- Opt-out designs should be applied where possible as they are typically more effective than opt-in approaches. The LED trials tested both an opt-in approach and an opt-out approach to determine how much difference recruitment approaches can make.
- There is a delicate balance to be struck between using negative connotations such as 'waste' or 'loss' while also making customers feel positive. The outreach kept messages positive and focused on how much more efficient LED lights are instead of how wasteful halogen and other older bulbs types are.

TP1 tested an opt-in approach, with customers receiving an offer for discounted LED light bulbs available for purchase through a project website.

As outlined in the initial bid document, after the first trial, SAVE analysed the effect and attempted to improve in the second iteration. While TP1 did not provide learnings on energy impacts of LEDs, it did provide valuable learning on the rate of receptiveness and uptake.

TP2 tested an opt-out approach, in which the project offered to install up to 10 LED light bulbs in each participant's home free of charge. Project staff called and made in-person visits to attempt to install the bulbs. Project staff removed the old bulbs to ensure they were not re-installed.

At the conclusion of TP2, the project investigated other energy efficiency measures that could be installed directly in to customers' homes in Trial Period 3 (TP3). The project specifically looked at measures that could reduce consumption of white goods/consumer electronics and those that had been successfully trialled in other markets. Measures assessed included:

- Low flow showerheads and faucet aerators
- Smart or programmable thermostats
- Pipe insulation
- Smart power strips
- Air sealing
- Refrigerator coil cleaning
- Slow cookers
- Appliance recycling (exchange of old, low efficiency appliance for a discount on a new, highly efficient appliance)

The applicability of each of these measures was scored using a red-amber-green scale. Many of the possible measures received a low applicability score as they would only reduce electricity consumption if the household had electric heating (low flow showerheads, smart thermostats, pipe insulation, air sealing) or electric hobs (slow cooker). Because the majority of the trial group had gas heating, these were not pursued further. Smart power strips and refrigerator coil cleaning both received medium scores, as they could be applied to almost all homes in the trial group. However, the energy savings were likely to be very small and therefore invisible in the resulting data. Appliance recycling has high potential; however, it would be almost impossible to market the programme, gain participants and see results within TP3 (three months).

Therefore, in TP3 this group did not receive additional energy efficiency measures, but rather participated in 'event days' where they were asked to reduce their consumption during a specific day and time. More details can be found in SDRC 8.4 and SDRC 8.7[7].

Additional details on trial design can be found in Section 2 (for TP1) and Section 3 (TP2).

1.5 Project outcomes

In TP1, 5 households participated by purchasing bulbs discounted by 20%. While 19% of the trial group visited the website selling bulbs, less than 1% of the trial group actually purchased bulbs. While this did not have an impact on the network, it was useful to determine which approaches are (or in this case, are not) successful with customers.

In TP2, 76% of participants accepted the project's offer to install LED bulbs in their house. The offer of free bulbs and installation coupled with an opt-out trial design was a winning approach that led to statistically significant energy reductions (at the 90% confidence level) for 2 weeks in the analysis period - weeks commencing 1st and 8th January 2018. The maximum peak-hours reduction 8% and was seen in the week commencing 1 January 2018. Full results are available in Section 5.2.

7 Available at https://www.ssen.co.uk/save/

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TRIAL PERIOD 1 DESIGN

Trial Period 1 ran from 1 January to 31 March 2017.

2.1 Approach

In the first trial period, the LED trial group was offered discounted LED products for sale via a voucher (sent by post) that linked to a project specific retail website. This engagement aimed to promote LEDs as an easy way to reduce electricity use and explain the benefits of LED lighting technologies.

After speaking with a number of SSEN approved suppliers, the project team elected to partner with RS Components as the LED technology provider. RS Components recommended six different bulb types and offered a 20% discount to SAVE trial participants. The bulbs were chosen to match the bulbs and fixtures most commonly found in residential properties.

Figure 1: LED bulb types available on saveled.co.uk in TP1

Customers were directed to the project-specific retail website via two postal mailings developed by project partners DNV GL and Behaviour Change. The first mailing was a four page A6 booklet that explained the advantages of LED bulbs over traditional technologies: lower operational costs, longer lifespan, average payback period and warm colour light. The booklet also introduced RS Components as a partner of the University of Southampton and SSEN to show to customers that they were a trusted supplier. The second postal mailer was a post card with a reminder, or 'nudge' of the discounted offer and a call to action. Each mailer was addressed to the participant by name and branded with the SAVE logo to give the promotion legitimacy and avoid it being dismissed as a junk mail promotion. The mailers were delivered in a bright pink envelope to further distinguish it from other post.

Figure 2: LED mailer

RS Components hosted the website and tracked the number of views and the take up (order) rate of LEDs. Billing addresses were matched to participant addresses to ensure the LED orders were made by project participants and not passed along to family or friends.

2.2 Uptake

The website allowed participants to purchase discounted LEDs from a selection of common bulb types. Over the length of the trial, the website had 225 unique page views. This represents about 19% of the participants who received the leaflet/postcard in the post.[8] Of these visits, 69% progressed to a product page while 31% left the website before viewing a product. Of those that visited the site, 5 participants made a purchase. This translates to 0.4% of participant take up of the discounted LED offer.

This uptake is not entirely unexpected, as direct mail has average response rates of somewhere between 1% and 3.7% depending on the type of mailing list and product.[9] However, the hypothesis was that take-up may be higher as the offer came from the SAVE project and was not an advertisement. Similar past energy efficiency campaigns have reported open rates as high as 41%.[10] The web conversion rate of 19% is higher than expected, although the actual buy rate is lower than expected.

One participant thought the costs of the bulbs high, as they did not realise the prices listed were for multipacks. Future trials should ensure that websites are targeted to domestic customers. Sales websites should be simple to understand while still remaining aesthetically pleasing and retaining project branding. RS Components is not a household name; they usually sell to commercial and industrial organisations and may not have the same 'brand recognition' as high street brands. Previous project communication with this group was minimal, and so the SAVE brand also may not be easily recognised. If possible, partnering with a known retailer may also increase uptake.

Because of the low take up, energy impacts of LEDs purchased in TP1 were negligible.

8 1,137 household received mailers about the benefits of LED lighting.

9 Haskel, D. 2015 DMA Response Rate Report: Direct Mail Outperforms All Digital Channels Combined by Nearly 600%. https://www.iwco.com/blog/2015/04/14/dma-response-rate-report-and-direct-mail/

10 Mazur-Stommen, S. and K. Farley. ACEEE Field Guide to Utility-Run Behavior Programs. http://kms.energyefficiencycentre.org/sites/default/files/b132.pdf

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TRIAL PERIOD 2 DESIGN

TP2 ran from 1 October 2017 to 31 March 2018 and offered to install LED light bulbs in customers' households free of charge.

3.1 Approach

In TP2, SAVE offered to install LED bulbs in participants' homes at no cost to the customer. While the first trial period sought to test an 'opt-in' approach through direct mailers offering discounted LED bulbs, TP2 tested an 'opt-out' approach and participants' willingness to accept or reject this free service.

The SAVE project did not attempt to send free LED bulbs to customers through the post, as there is no way to guarantee the bulbs are actually installed and not placed in storage, resold or given away. As reported in previous SDRC's, the U.S. Project Porchlight campaign offered free high efficiency light bulbs but let customers install them themselves and reported installation rates between 39% and 57%. Early participants in Project Porchlight reported that they were saving their bulbs until old ones burned out.[11]

All TG2 participants were sent a letter to inform them of the offer. Project staff followed up with phone calls and site visits to schedule an appointment when bulbs could be installed. While on site, staff installed the new LED bulbs in the most used areas of the home and aimed to replace the least efficient bulbs. The project allowed for up to 10 bulbs per household. Project staff removed the old bulbs from each property to prevent them from being reused. Project staff recorded the number of bulbs installed, installation location, previous bulb type and wattage for each house visited.

All bulbs were procured from RS Components. Project staff had weekly calls with RS Components to discuss current stock levels and place orders as needed. The project opted to acquire bulbs in many smaller orders (as opposed to one or two bulk orders) to minimise wastage and costs. The bulk buying of bulbs also meant they were procured at lower costs than homeowners would have paid if they purchased the bulbs themselves. Install rates of each bulb type informed subsequent orders.

3.1.1 Safety

Before LED installations commenced, all project staff completed a safety training class that addressed risks associated with home visits, bulb removal and installation. This training was provided by Proactive Technical Training, a company specialising in electrical training courses. The course included: a brief overview of electrical circuits and domestic lighting circuits, the effects of electricity on the human body and the types of injury detailed (shock, burns, secondary injuries), the framework of current UK legislation, including the Health & Safety at Work Act and The Electricity at Work Regulations, and understanding the correct procedures to inspect fittings and replace standard lamps in dwellings including not to touch or interact with any suspect fixtures or electrical work and to only change bulbs in fittings that were in good working order. Staff were also trained to only work on fixtures when they were turned off or otherwise isolated from the power connection. Staff also performed risk assessments on site to identify any other site-specific risks or unusual hazards such as pets, high ceilings or uneven floor surfaces. As part of the risk assessment staff were instructed to not climb beyond the top two rungs of the work platform.

RS Components also advised on which kinds of bulbs would be the safest and easiest to install. The project did not use any dimmer bulbs or install bulbs in areas with dimmer switches, as these sometimes require replacement of the dimmer switch with a switch compatible with LED bulbs. Field staff did not have the skills required to replace or rewire switches and therefore were instructed to avoid circuits with dimmer switches.

3.1.2 Pilot

TP1 had limited engagement from the LED group, and so the team could not predict interest in the LED installations. The SAVE team conducted a pilot to better understand possible uptake rates and approximate quantity and types of LED bulbs required. The project chose 100 households to contact. All households had actively communicating electricity monitoring devices (called 'Loop devices', for more information see Section 4.1.3). Any households where electricity data was not correctly being transmitted were excluded from the pilot. The pilot took place over 4 weeks in August 2017.

11 See findings from SDRC 1, available at https://www.ssen.co.uk/save/

3.1.3 Main rollout

Fieldwork for the main rollout of LED installations in TG2 commenced in September 2017 and ended in January 2018. The procedure followed a similar approach as the pilot, with trial participants receiving a letter in the post notifying them of the offer and project staff following up with phone calls or household visits to schedule the LED installation. The main roll out included participants that had non-communicating Loop devices; this provided an opportunity to remedy any issues with the Loop equipment.

3.2 Take up

3.2.1 Pilot

Project staff contacted all 100 households with the goal to install LED bulbs at as many of these households as possible. Overall, the SAVE project installed 580 LED bulbs at 80 households. This equates to an average of 7.25 bulbs per house. Details are available in the table below.

Table 1: LED pilot call response rates

Call outcomes	Total
Respondent Agrees to LED installation	80
No reply	13
Refusal	7

3.2.2 Main rollout

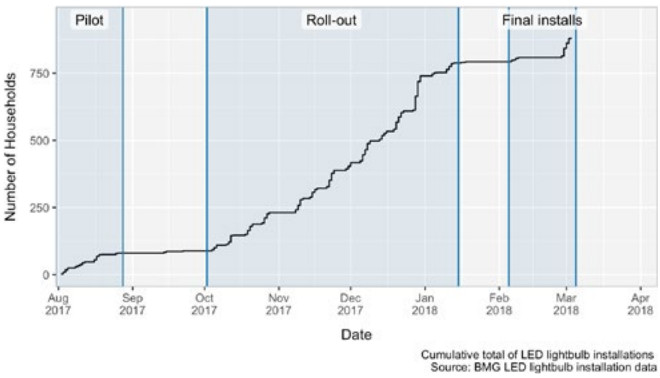
Full take up was expected to be slightly lower as this group included those with non-communicating Loop devices (which may indicate a lack of engagement with the SAVE project). However, final uptake of the main rollout was similar to the pilot, with 76% accepting the LED bulbs (as compared to 80% in the pilot). The main rollout occurred between October 2017 and February 2018.

In total, the project installed 6,135 bulbs across 882 properties for an average of 7 bulbs per household. Table 2 shows the final response rates and Figure 3 shows the cumulative number of installations over time.

Table 2: Overall response rates

Call outcomes	Total
Respondent Agrees to LED installation	882
No reply	101
Refusal	177

Figure 3: Cumulative LED lightbulb installations within treatment group (number of households)



Due to data loss from the Loop electricity monitoring, not all of the households receiving LED upgrades have corresponding electricity consumption data.[12] The final sample of upgraded households (with LED upgrades and Loop consumption data for the analysis period) was 706 households.

The fieldwork contractor captured installation details during the roll-out of LED upgrades. For each bulb installed, the power rating of the replaced bulb was captured, together with the new power rating.

The field work also included a short survey with households that had LED bulbs installed. The survey asked if the household had LED bulbs (before the project-led installation) and if no, asked why. The majority (60%) already had at least one LED bulb installed in their house. The kitchen was the most common location for LEDs.

Table 3: Pre-project LED presence

Percent of households with LEDs installed	
Yes	60%
No	40%

Of those that did not have any LEDs, the survey asked why. The most common reason cited was that they 'hadn't thought about it' (74%) while the second most common reason was they 'don't know enough about them' (28%).[13] This shows the main barrier to LED adoption is simply awareness. Breaking established habits and encouraging people to consider new technologies about which they may not be aware should be a focus of future LED projects.

Table 4: Reasons for absence of LEDs (pre-project)

Reasons stated for not using LEDs	
Haven't thought about it before now	74%
Don't know enough about them	28%
Too expensive	10%
I have tried them and do not like them – colour is off	1%
I don't need one, a bulb is a bulb	1%
Other (please specify)	1%

12 The SAVE project assumed there would be attrition over time as not all households would be engaged over the entire length of the project. Data loss generally occurs when households disconnect or unplug their Loop device.

13 The survey allows respondents to choose multiple reasons, so the sum of responses will be over 100%.

4

DATA AND METHODS

4.1 SAVE project data

4.1.1 Household survey data

Household survey data was collected by the fieldwork contractor (BMG Research). This data file contains socio-economic and demographic data for the households participating in the fieldwork. Update surveys are conducted where data is over 12 months old to ensure that basic household attributes such as number of occupants were accurate.

4.1.2 LED installation data

RS Components provided shipping addresses (to match with project records) of all customers that purchased LED bulbs in TP1.

The fieldwork contractor (BMG Research) collected data on all LED lightbulb installations completed during TP2. Data included the original bulb rating, the replacement (new) bulb rating and the location of the bulb. BMG also asked participants if they had LED bulbs in their house before their participation in TP2 and if not, why not.

4.1.3 15-minute household electricity consumption data

The analysis in this report is based on the electricity consumption data collected via internet-connected 'Loop' electricity monitoring kit (hitherto referred to as 'Loop data'). The Loop data used in the analysis consists of watt-hour (Wh) readings observed at 15-minute intervals for each participating household. This data provides the measure of electricity consumed by individual households within the treatment and control groups during the analysis period.

Before analysis, the Loop electricity consumption data is processed and summarised over a number of time periods and intervals: for example, producing hourly and weekly mean consumption values for each household. Inadequate or missing data (less than 3 of 4 readings in any hour), along with erroneous observations are excluded from the analysis (see Rushby and Harper, 2018 for details).

The metric of measurement used in the analysis presented is mean 15-minute consumption in watt-hours (Wh). Due to the requirement for the use of a normally distributed dependent variable within the statistical modelling, the (summarised) mean household consumption values have been log-transformed.[14]

4.2 Third-party data

4.2.1 Daylight data

This report uses sun-path simulation data produced by the Transient System Simulation Tool (TRNSYS) software[15] to estimate local sunrise and sunset times. The simulation used Southampton as the location.

4.3 Methods

4.3.1 Experimental design

Given the randomised control trial (RCT) design of the SAVE trials, intervention effects have been analysed by comparing the difference between control and intervention groups. Given the successful randomisation and allocation of participants to treatment and control groups, the assumption is that prior to treatment, the groups would be equal in terms of both the outcome variable and household characteristics. Any difference in consumption between the control and intervention groups is therefore assumed to be a result of the intervention alone.[16] It is assumed that all households in the study experienced the same environmental conditions during the trial weeks and therefore there is no need to correct for any differences in environmental conditions. This means the results should be replicable and scalable to the wider population. Using a RCT approach limits biases that may be present in the trial groups by comparing results to a similar control group, instead of past behaviour of the treatment group.

The analysis in this report (along with previous analysis presented in SDRC 2.2) indicates that the LED treatment group shows a small but consistent difference in consumption to that of the control group. For this reason, the analysis also employs the difference-in-differences statistical technique for analysis (see Section 4.3.3.2 for more information).

Due to the design of the study, it is not necessary to control for potential confounding characteristics of the households in each treatment group. However, a selection of household attributes is included in the analysis to examine characteristics that are associated with the variability in treatment effect.

14 This removes the positive skew in the distribution of consumption values. For additional details and equations used, see Section 4.3.

15 TRNSYS is a graphical software tool used to simulate the behaviour of transient systems such as energy, or in this case, sun-path. The SAVE project used the TRNSYS software to model sunrise and sunset times to estimate daylight hours in Southampton during the trials. More information available here: http://www.trnsys.com/

16 Frederiks, E.R., Stenner, K., Hobman, E.V., Fischle, M., 2016. Evaluating energy behavior change programs using randomized controlled trials: Best practice guidelines for policymakers. Energy Research & Social Science 22, 147–164. https://doi.org/10.1016/j.erss.2016.08.020

4.3.2 Assumptions and limitations

4.3.2.1 Experimental design and analysis

As with any experimental study, a number of limitations apply to the findings of the LED trial. General limitations apply to the analysis of the LED intervention arising from both sampling and statistical analysis. In summary, limitations of this study are related to the following:

- Recruitment of trial participants: the analysis assumes the sample was randomly assigned to treatment groups and therefore the groups are representative of the sampled population with respect to both the mix of household socio-demographic and electricity consumption characteristics (see SDRC 2.217).
- Statistical power: the achieved sample size and variability of household electricity consumption limit the size of the effect that can be robustly detected (see Anderson and Rushby, 201818). In general, the larger the sample size, the smaller the effect that can be observed with confidence.
- Experimental conditions: it is assumed that all households experienced the same environmental conditions during the trial negating the need to correct for any differences despite local variation in environmental conditions (such as weather).
- Analytical assumptions: for example, parallel trend assumption of the difference-in-differences technique may not hold (see Statistical models, Section 4.3.3);

4.3.2.2 Measurement

The Loop electricity monitors used in SAVE project measure current (amps) only without voltage measurement. Equivalent power (presented as Watts) is estimated based on the fixed voltage value of 240 Volts without voltage phase reference. In effect, the Loop estimates are closer to apparent power (VA), not real power (W).

As a consequence, the wattage reduction as seen by the Loop data is slightly underestimated, although it does accurately represent the intervention thermal impact on the distribution network. This means that actual wattage reductions due to LED bulb installation is likely higher than reported by Loop device.

4.3.3 Statistical models

In this analysis, two statistical techniques are used to investigate the change in consumption attributable to the interventions tested in TP2:

- 'Treatment-only' models: single-variable linear regression modelling to investigate the differences in mean consumption between the LED treatment group and control group;
- 'Difference-in-differences' (DiD) models: to investigate the change in the differences in mean consumption between treatment group and the control group, and the relationship of these differences to household characteristics.

4.3.3.1 Treatment only model

To examine and compare the differences in consumption between treatment and control groups, linear regression models were run using the treatment group as independent variable, the equation is as follows:

$$log(y_i)=\alpha+\beta_1\ TreatmentGroup+\epsilon_i$$

Where y_i is mean 15-minute consumption (Wh), α is the intercept (mean control group consumption), β_1 is the coefficient for the treatment group (estimate of the difference between treatment and control) and ϵ_i is the random error term.

Interpretation of the model results is provided by exponentiating the intercept (α) and coefficient β_1:

- exp(α) gives the geometric mean[19] of the control group (intercept) in Wh;
- exp(β_1) gives the ratio of the geometric means: treatment group over control group, this is the measurement of group differences reported in the model results.

The treatment only models were run to examine the differences between the treatment and control groups at a number of temporal scales:

- Weekly: to understand how the treatment effect varies across longer timescale, for example with the reduction in daylight availability during winter;
- Hourly: to understand how the treatment effect varied by hour of the day and/or day of the week, for example according to active occupancy.

17 Available at https://www.ssen.co.uk/save/

18 Anderson, B., Rushby, T., 2018. We Got the Power: Statistical Significance, Power, Study Design and Decision Making with A Worked Example. University of Southampton, Southampton, UK.

19 Not to be confused with the arithmetic mean.

4.3.3.2 Difference in difference model

Difference-in-difference is a commonly used statistical technique used to compare two groups that have been shown to be unequal in terms of the variable of interest (outcome or dependent variable) prior to the intervention; in this case, electricity consumption (log(mean Wh)) of TG1 and TG2 (see Section 5.2.4 for more details). The technique relies upon the assumption that although the treatment and control groups are not equal, the trend of the dependent variable over time is the same for both groups (i.e. the parallel trend assumption).

For simple difference-in-difference models, dummy variables were used for time (where *Time* = 0 for the measurement prior to treatment, and *Time* = 1 for the measurement after treatment[20]) and for Treatment (*Treated* = 0 for the control group, *Treated* = 1 for the treatment group), giving the following equation for the model:

$$\log(y_i)=\alpha+\beta_1\,Time+\beta_2\,Treated+\gamma_1\,(Time\times Treated)+\epsilon_i$$

Where:

y_i = mean 15-minute consumption in Watt-hours (Wh)

α = intercept (mean control group consumption at Time = 0, t0)

β_1= coefficient for difference in mean t0 to t1 (trend estimate)

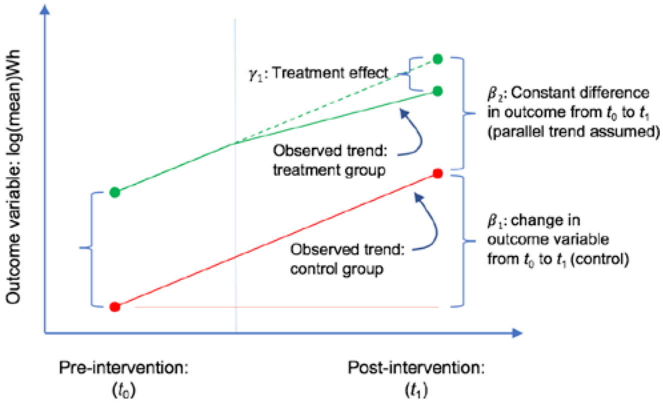
β_2= coefficient for treatment group (group difference estimate)

γ_1= coefficient for treatment effect (difference-in-difference estimate)

ϵ_i = random error

Separate regression models were run for each of the groups receiving treatment. An estimate of the trend in the control group (the difference mean from the week prior to the challenge to the challenge week) is given by β_1, and the estimate of the difference between the control and treatment groups is given by β_2. γ_1 is the difference-in-differences estimate of the treatment effect. The coefficients are shown in Figure 4 below.

Figure 4: Illustration of the 'difference-in-difference' linear regression model coefficients



Interpretation of the difference-in-difference coefficient is the ratio of the expected log-mean consumption of the treatment group (given by $\alpha+\beta_1 + \beta_2$) and the log-mean measured consumption of the treatment group (given by $\alpha + \beta_1 + \beta_2 + \gamma_1$), both at *Time* = 1. These estimates are shown in the presentation of the model results in Section 5.2.4. For ease of interpretation, the difference-in-difference estimates are also converted to give estimated treatment effects expressed as Watt-hours per hour (Wh/h) and presented in Section 5.2.5.

To estimate the effect on the outcome of another independent variable, the following equation applies:

$$\log(y_i)=\alpha+\beta_1\,Time+\beta_2\,Treated+\beta_3\,Group+\gamma_1\,(Time\times Treated)+\gamma_2\,(Time\times Group)+\gamma_3\,(Treated\times Group)+\Delta_1\,(Time\times Treated\times Group)+\epsilon_i$$

20 In this analysis, multiple DiD models were run using a common pre-treatment baseline (reference) measurement (Time = 0, household mean consumption for the week prior to treatment at the beginning of August 2017). Models are run for each week following the start of the LED installations (in each case, the time dummy variables are set as post-treatment - Time = 1). To test the parallel trend assumption and assess the impact on the estimated treatment effect of the variation in consumption between the trial groups prior to the intervention, the regression models were run using a number of consecutive reference weeks.

Estimates of the treatment effects observed in households belonging to subgroups of the independent variable in the model are as follows:

- For the contrast category, the treatment effect is given by γ_1;
- The interaction effect (the estimate of the difference-in-difference-in-difference (DDD) coefficient) is given by δ_1.
- For other categories of the grouping variable, the treatment effect is $\gamma_1 + \delta_1$;

Note: generally, the linear regression models consider the whole of the treatment group, despite not all of the households in this group receiving treatment. This analysis therefore gives an estimate of the treatment effect, given the sample population and uptake rate as achieved in this trial.

4.3.4 Statistical power and confidence intervals

The sample size for the SAVE trials was evaluated using commonly accepted values for statistical power of 0.8.[21] Confidence levels (p-values) of model results are reported where significant and, unless noted otherwise, confidence intervals shown on charts are at the 90% confidence level.

4.3.5 Vulnerable Customer analysis

The Energywise project, run by UK Power Networks, also looked at domestic demand side response (DSR) but focused on vulnerable customers only to understand how such customers can interact with domestic DSR and provide insight to ensure 'fairness' in business as usual approaches to customer engagement. For this reason, Energywise provides an interesting comparison project. SAVE has completed similar analysis of vulnerable customers in order to be comparable.

Energywise trialled both energy efficiency measures and price signals (much like SAVE). As a result, the SAVE project conducted additional analysis on how the SAVE trials effected vulnerable customers. SAVE looked to test if vulnerable customers interact with the SAVE interventions differently than the general population.

The selection of criteria adopted to identify vulnerable customer from SAVE's sample was built to be similar to that of Energywise.

Table 5 below shows the criteria for vulnerability identified on each project. Additional details on how these categories were defined are available in Appendix 1.4.

Table 5: Vulnerability criteria

Vulnerability identified	SAVE	Energywise
Rural Setting	X	
Lone Parent	X	
Age	X	X
Working status	X	X
Tenant	X	X
Pay Bills	X	X
Qualification	X	X
Long Term Sick	X	
Income	X	X

Within the SAVE project, customers with three or more of the criteria above were categorised as 'vulnerable' for the purposes of the analysis below.

In addition to using survey evidence to categorise vulnerability as above, SSEN also carried out a fresh cross-check of Priority Service Register customers against the project population to provide a subset of 'vulnerable'. No matches were found.

Having identified vulnerable customers, the analysis of the LED trials looked to compare:

- Average response rate (opted-in to LED trials) from different household types
- Average no. of bulbs installed in different household types
- Average load-reduction in different household types
- Variance in the type of bulb in different household types

The analysis evaluates the impact of SAVE on vulnerable customers as compared with the wider project population.

21 Statistical power indicates the probability of a Type II Error (false negative). This should not be confused with confidence interval, which indicates the probability of a Type I Error (false positive).

5

ANALYSIS

5.1 Trial Period 1

A total of 5 participants made a purchase through the website; this translates to 0.4% of participant take up of the discounted LED offer. Because of this low participation rate, energy impacts cannot be seen in the data and so no analysis or energy impacts are presented here. However, the learning on take-up of this approach were extremely valuable when designing Trial Period 2.

5.2 Trial Period 2 and beyond

In this section, the consumption of the LED treatment group is compared with that of the control group using the measures and statistical techniques set out in Section 3.

First, a comparison of weekly mean 15-minute consumption is provided for all-hours (i.e. considering consumption occurring during any hour of the day) and peak-hours only (only considering consumption occurring between 16:00 and 20:00 hours). LED lightbulbs were installed within a wide time period during the study (shown above in Figure 3). In the following figures, households which have and have not had LED bulbs installed are shown as a distinct group and indicated by colour.

Second, the distributions of household mean consumption within each group (treatment and control) are tested to determine if consistent differences exist using 'treatment only' regression modelling (described above). The results confirm earlier analysis showing small differences in average consumption between the control and LED treatment groups prior to the intervention. Estimation of the treatment effect therefore requires the use of 'difference-in-differences' statistical models.

Third, a more detailed analysis of consumption across the treatment and control groups is provided using an hour-by-hour approach. This analysis focuses on two selected comparison weeks, which are described within the weekly consumption trends (see full results in Appendix 2.3). This explores if there are any observable patterns in the group differences by hour-of-day and day-of week which should be incorporated into the final difference-in-difference statistical models.

Finally, treatment effects are estimated for all-hours and peak-hours consumption using 'difference-in-differences models' (described above).

5.2.1 Weekly consumption trends, year 1

Figure 5 shows the mean of the electricity demand per household averaged over all hours of the day, comparing the control group against the treatment group overall, and for those household where LEDs have been installed.

Figure 5: Weekly mean 15-minute consumption (Wh) by group, all hours: July 2017 to June 2018

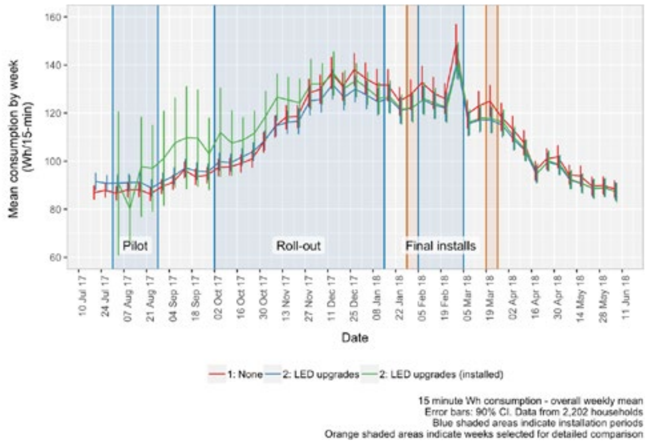
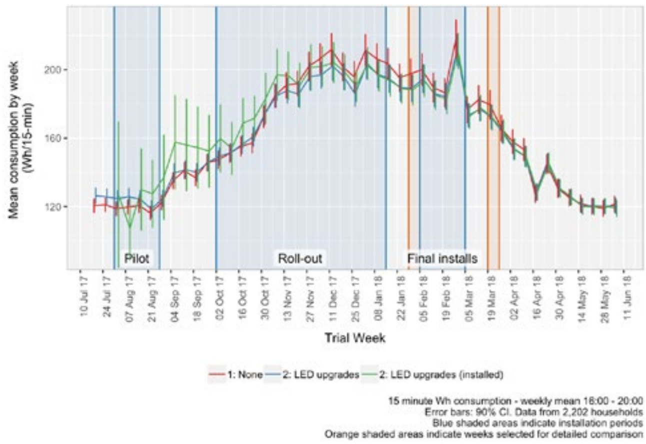


Figure 6 shows the mean of the mean electricity demand per household averaged over the peak hours only.

Figure 6: Weekly mean 15-minute consumption (Wh) by group, peak hours only: July 2017 to June 2018



In both figures above, the wide confidence intervals around the ‘LED upgrades (installed)’ group from July until November 2017 indicate the (initially) small number of households that had received LED upgrades. The figures also clearly show the increased consumption during the winter months. Although more difficult to observe, it can be seen that the treatment group does reduce consumption relative to the control group moving from marginally above during August to October, moving below the control group during November and remaining lower through to March. In the week commencing 26 February, we can see a spike in the mean consumption for all groups. This was due to a period of unusually cold weather (commonly referred to as the ‘Beast from the East’). Daylight saving time began on Sunday, 25 March; after this the additional daylight in the evenings likely resulted in the reducing consumption trend seen.

The figures above also show the two weeks selected for more detailed comparison between treatment and control. The two weeks selected are the week commencing 29th January 2018 (following the main roll-out of LEDs), and the week commencing 19th March 2018 (following the final installations).

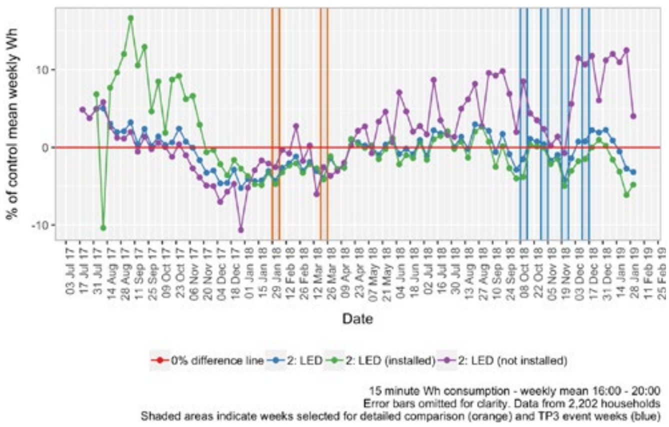
5.2.2 Weekly consumption trends, year 2

In Figure 7 below, the blue shaded bars highlight weeks during trial period three (TP3) - running from October to December 2018 - where households in the LED intervention group were exposed to additional data-informed behaviour-change treatment. The treatment consisted of postal, online and text messaging asking householders to reduce energy demand during periods ranging from a number of hours to a whole week (peak-hours only). Full details of these interventions can be found in SDRC 8.4/8.7.[22]

Figure 7 Weekly mean 15-minute consumption (Wh) by group, peak hours only: May 2018 to January 2019

Figure 8 shows the consumption of the LED treatment group (and subgroups) relative to the control group during peak hours. Points below the horizontal red line indicate mean (of household mean) consumption in the treatment group below the mean of the control group. This chart shows more clearly the movement of the treatment group compared to the control group. Note that from December 2017, the number of participants in the ‘LED not installed’ group (purple line) is small—so small that sample effects begin to contribute to the high variability of consumption shown.

Figure 8: Weekly mean consumption of treatment group (and subgroups) relative to the control group[23]



5.2.3 Weekly treatment-only models

To examine the significance of the differences between the treatment and control group with respect to the underlying variability in the consumption data, a series of ‘treatment only’ linear regression models were run using the weekly household mean consumption (summarised using 15-minute data) for all hours of the day, and peak hours only (16:00-20:00).

The models use the treatment group as one group and therefore contains households that received upgraded bulbs along with households that did not.

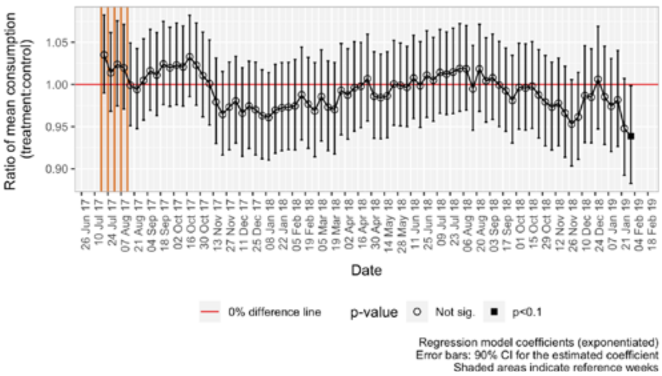
The results for the ‘all-hours’ models are shown in Figure 9 and confirm that consumption within the treatment group is generally above the control group from July to the end of October before dropping to below the control group. Consumption in the treatment group remains below the control group until the end of April. None of the differences between the groups are statistically significant (indicated by p-value in the figure). The shaded areas in the figure indicate the pre-treatment, or reference weeks adopted within the difference-in-difference models (refer to methods Section 4.3.3.2, results reported in Section 5.2.34.3.3.2).

22 Available at https://www.ssen.co.uk/save/

23 Due to chance, the consumption of the control group is slightly lower than the treatment group. The difference between groups is small (<5%) and variable. The confidence intervals overlap, which means these differences are not statistically significant.

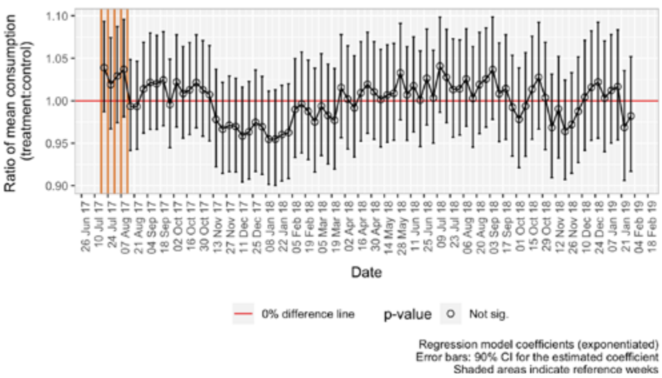
These results are consistent with the installation of LED upgrades, the majority of which took place between October and January. The increase in consumption of the treatment group relative to the control group in March and April suggest that the treatment effect (reduced electricity consumption) is seasonal and affected by the darker months of winter.

Figure 9: Weekly 'treatment only' model results, showing ratio of mean consumption (treatment group to control): all hours (peak and non-peak)



The results for the 'peak-hours' models are shown in Figure 10 and show a similar pattern to the all-hours models but with slightly larger differences between groups in January, due to darker evenings.

Figure 10: Weekly 'treatment only' model results, showing ratio of mean consumption (treatment group: control): peak-hours only



The results of the 'treatment only' models show that while statistically significant differences in consumption between the groups were not found, small but consistent differences between the groups were present before the roll-out of LED upgrades. Further analysis, using a differences-in-differences approach (Section 5.2.3), was conducted to account for these differences and estimate the treatment effect. Further analysis comparing day-to-day consumption can be found in Appendix 2.3.

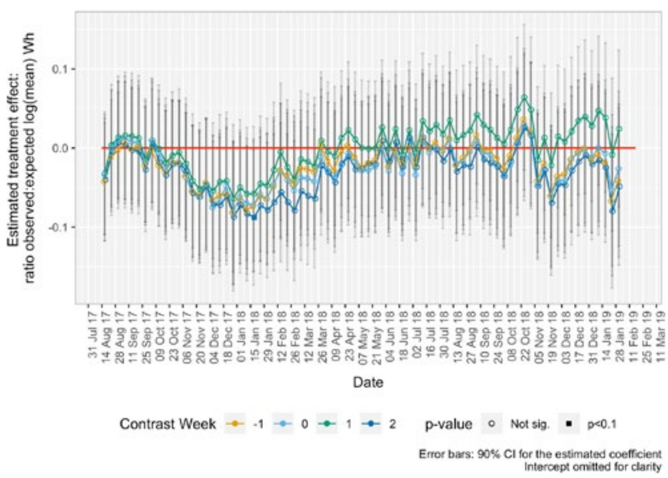
5.2.4 Difference-in-differences models

As described in Section 4.3.3.2, a difference-in-differences (DiD) model is useful to compare two groups that have been shown to be unequal in terms of the variable of interest prior to the intervention. Prior to the installation of LEDs, the consumption of the LED group was higher than the control group, indicating a difference between the groups.

This section contains the results of the linear regression models run to assess the difference between the expected and observed consumption in the LED treatment group: modelled using the difference-in-differences approach and the weekly summarised data. Two sets of models were run: using consumption from all hours of the day, and peak-hours only. Each set of models were run using multiple reference weeks to test the influence of between-group variability on the estimated treatment effect.

Figure 11 shows the differences between the expected and observed consumption in the LED treatment group: the estimated treatment effect. The coloured lines in the figure indicate each reference (contrast) week used as the pre-treatment baseline in the regression models. The chart shows the change due to the treatment effect as a proportion of the expected consumption of the LED treatment group weekly log(mean) 15-minute consumption during **peak-hours** only (16:00 - 20:00). Running the models for multiple reference (contrast) weeks reveals that the selected week influences the estimates of treatment effect. This is apparent from inspection of Figure 11 which shows the results for four contrast weeks overlaid. It can be seen that contrast week '2' generally provides the upper limit of effect estimates.

Figure 11: Estimated treatment effect in LED treatment group: weekly mean 15-minute consumption during peak-hours. Colours indicate 'contrast week' used as baseline.



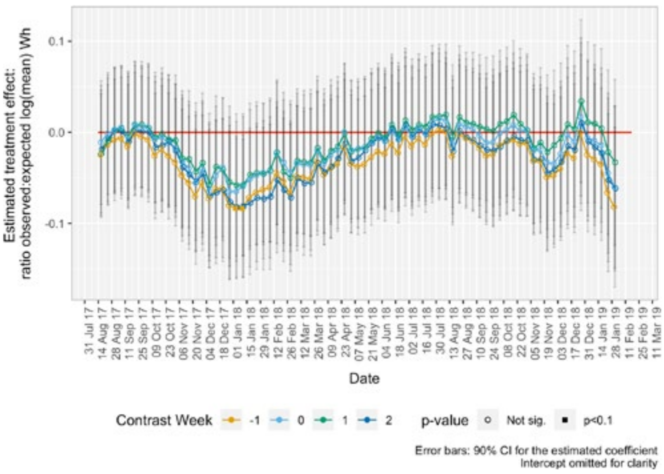
It is observed that using the DiD models, the differences in consumption between the treatment and control groups observed in the treatment only models during August and September 2017 are largely removed. The small changes shown for the weeks commencing 14th and 21st August, and 11th September 2017 are likely due to the week to week variation in consumption of the two groups relative to each other, rather than any treatment effect. At this time, few households had received LED lighting upgrades. Figure 11 confirms that the treatment effect appears to be seasonal in peak-hours, and that the maximum effect occurs in the week commencing 15th January.[24] Using alternative contrast weeks also reveals variation in the timing of the maximal effect. For example, contrast weeks '-1' and '0' show the maximal effect size at 3 weeks earlier, during the week commencing 25th December 2017.

The treatment effect observed is greatest during the winter months following the LED installations (October 2017 to April 2018) and reduced to a minimum over the summer months. While the model results indicate that the treatment effect increases again moving into September 2018, there is very large variability in the estimated effects during October, November and December 2018. There are a number of larger treatment effects during the second winter period, specifically during the weeks commencing 5th November, 19th November and 21st January, however the trend is less consistent than for the previous year. This may in part be caused by the attrition of the sample but also indicates that other confounding factors may be affecting consumption in the treatment group and thus the measurable treatment effect.

The DiD regression model results for the week commencing 15th January 2018 show the difference-in-differences estimate as a reduction of approximately 6% to 9% relative to the expected consumption of the treatment group, varying by approximately 3 percentage points with contrast week. Contrast week '2' produced statistically significant effect estimates at a 90 percent confidence level. For full regression results, please see Appendix 2.4.

Figure 12 shows the change in consumption in the LED treatment group relative to the control group for **all hours** of the day. The colours on the chart indicate reference weeks as before.

Figure 12: Estimated treatment effect in LED treatment group relative to control: weekly mean 15-minute consumption for all hours. Colours indicate 'contrast week' used as baseline.



The regression model results show statistically significant differences for the weeks commencing 1st and 8th January 2018 (at 90 percent confidence level). The full results for the week commencing 1st of January are shown in Appendix 2.4 and show the difference-in-differences model result as a reduction of approximately 6% to 8% relative to the expected consumption of the treatment group.

Comparing the LED upgrade installation data and with daylight availability shows that the installations were not completed until after the minimum daylight hours. The week commencing 18th December had the shortest daylight hours while the week commencing 11th December had the earliest sunset times. For visuals of sunset times and daylight hours, see Appendix 2.2.

5.2.5 Watt-hour reductions

Figure 13 and Figure 14 show the results of the difference-in-difference regression models as change in consumption (Wh). The lines represent the average change in the weekly mean 15-minute consumption (Wh) by treatment group.[25]

Using data for all hours of the day, Figure 13 shows that the maximum observed change relative to the control group occurred during the week commencing 1st January. During this maximal week, the mean change in the treatment group (relative to the control) was a reduction of 31 Watts per household (90% confidence interval = 2 to -61 Watts). Equivalent to 733 Watt-hours per household per day and 5.1 kWh per household per week.

24 Using alternative contrast weeks also reveals variation in the timing of the maximal effect. For example, Figure 10 reveals that contrast weeks '-1' and '0' show the maximal effect size at 3 weeks earlier, during the week commencing 25th December 2017.

25 To convert to hourly consumption, multiple by 4: thus a 10 Wh/15-minutes change during peak hours is shown as 40 Wh/hour (equivalent to 40 Watts continuous power) in the figures.

Figure 13: Mean change in hourly mean 15-minute household consumption, converted to constant power equivalent in Watts (peak hours)

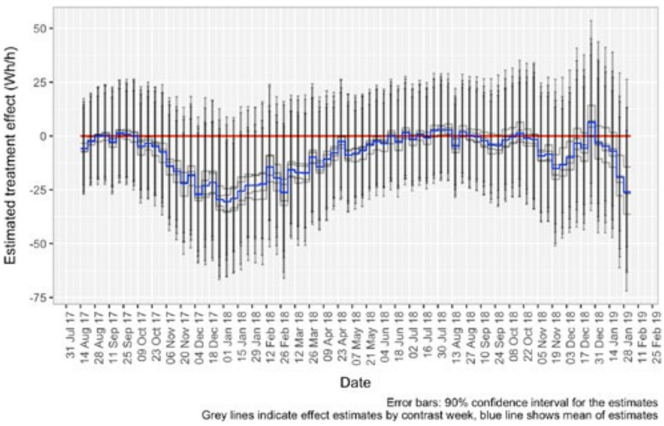
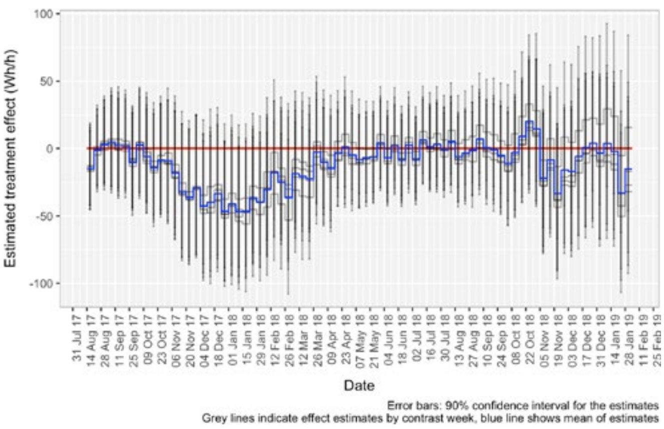


Figure 14 shows that during the targeted peak hours (16:00 to 20:00), the maximum observed change (relative to the control group) occurs during the weeks commencing 25th December 2017 to 15th January 2018.

Figure 14: Group median of change in hourly mean 15-minute household consumption, converted to constant power equivalent in Watts (peak hours)



During the maximal week, the median change in consumption in the treatment group over the peak hours (4 to 8 pm) was equivalent to a reduction of **47 Watts per household** (90% confidence interval between 8 and -97 Watts). This is equivalent to reduced consumption over the 4-hour peak period of 1**86 Watt-hours per household per day**.

5.2.6 Annual reductions

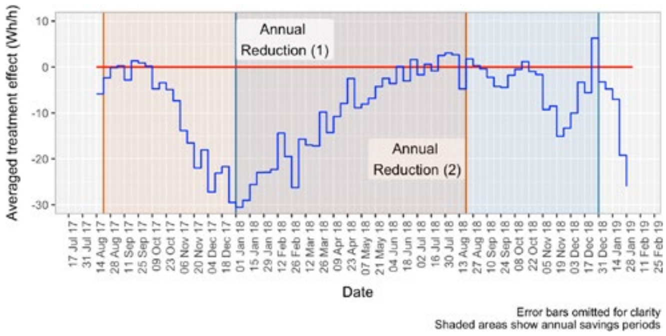
To calculate the average saving per household over 12 months, the totals of weekly Watt-hour reductions were calculated over two time periods using the averaged Watt-hour reductions shown above:

- Summer to summer: commencing 21st August 2017 ending 19th August 2018;
- Calendar year: commencing 1st January 2018 ending 30th January 2018.

Note that due to the weekly analysis, the annual reduction is calculated from 52 full weeks (364 days).

Figure 15 shows the average weekly Watt-hour treatment effect with the two annual intervals used to calculate the aggregated annual savings.

Figure 15: Mean weekly treatment effect for all-hours showing annual savings calculation periods



The annual savings calculated for each interval are as follows:

- Summer to summer: aggregated savings 90 kWh per household per year. Across the entire treatment group, this is approximately 97,470 kWh per year.
- Calendar year: aggregated savings 70 kWh per household per year. Across the entire treatment group, this is approximately 75,810 kWh per year.

Limitations: a year-to-year comparison is difficult due to the installation period stretching into the first annual measurement period (summer to summer). The second annual measurement period (calendar year) also does not span a full year following the completion of the LED installations, therefore both values for annual estimated savings may underestimate the annual savings that may be realised from an intervention rolled-out in a business-as-usual scenario.

The annual estimated savings suggest that there is a reduction in the treatment effect over time, however, due to the timing of the intervention and data collection period, direct comparison of equivalent periods is not possible.

5.2.7 Household characteristics and treatment effect

In this section, linear regression models are used to examine the interaction of a selection of household characteristics with variation in the effect of treatment. The models were run for the mean weekly household consumption during peak-hours from the week observed to give the largest change relative to control (i.e. the week commencing 15th January 2018). The baseline week is the week commencing 7th August 2017.

Results from the first of the two models repeats the result of the difference-in-differences model for peak hours (see Section 4.3.4). The second model adds the 'LED installed' field as an interaction term, to determine any difference between these households. Inspection of the results shows that consumption in the treatment group was approximately 4% higher than the control group in the baseline week (not statistically significant). However, within the treatment group, 'baseline' consumption in those households that did not receive the LED upgrades (the contrast category in the second model 'treated DiD') was approximately 3% lower, pre-treatment, than those that did receive upgrades ('LED install group').

For full regression results, please see Appendix 2.4.

Previous analysis (see SDRC 2.2) revealed the household characteristics most strongly associated with peak-hours consumption. In summary, none of the interaction terms were found to be statistically significant with large uncertainty around the estimated effects of the variables tested. Noting this uncertainty, the following observations were made for groups of households within the results for Customer Type interaction terms:

- Household size
  - the greatest treatment effect was observed in one-person households
  - the treatment effect reduces with household size

- Bedrooms
  - the greatest treatment effect is observed in the largest homes (5+ bedrooms)
  - the treatment effect increases with size of dwellings (no. of bedrooms)

- Heat source
  - greater effect is observed in electrically-heated households
  - greater effect is observed in households with 'other' primary heat source

- Employment
  - larger treatment effect where household representative person (HRP) is unemployed or retired
  - smaller treatment effect where HRP is in part-time employment

- Ethnicity
  - larger treatment effect where HRP is Asian/Asian British
  - smaller treatment effect where HRP is Black/Black British

- Tenure
  - smaller treatment effect where home is rented

- Built form
  - greater treatment effect where dwelling is terraced

- Presence of children
  - treatment effect is lower among households with children

The full results from the DiD regression models with interaction terms can be found in the Technical Annex to this analysis (Appendix 2.4).

5.2.8 Impact on Vulnerable Customers

As outlined in Section 4.3.5, the analysis of the LED trials compared the following for vulnerable and non-vulnerable customers:

- Average response rate (opted-in to LED trials) from different household types

- Average number of bulbs installed in different household types

- Average load-reduction in different household types

- Variance in the type of bulb in different household types

Table 6 summarises key findings from this analysis.

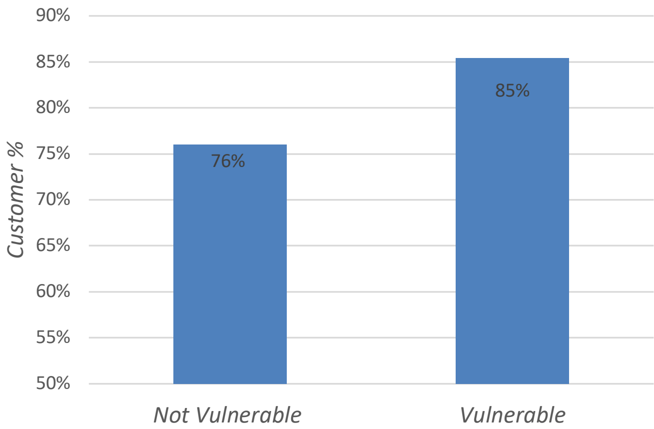
Table 6: Comparison of vulnerable and non-vulnerable SAVE participants

Customers				Average		
Vulnerable	All sample	LED Participant	N of bulbs	Participation rate	Bulbs per customer	Equipment wattage reduction
No	899	685	4,784	76%	7.0	170.7
Yes	230	197	1,351	85%	6.9	193.0
Total	1,129	882	6,135	78%	7.0	175.7

In TP2, 1,129 households were targeted for LED install, out of which 882 participated in the LED trial. Approximately 22% of these are considered vulnerable.

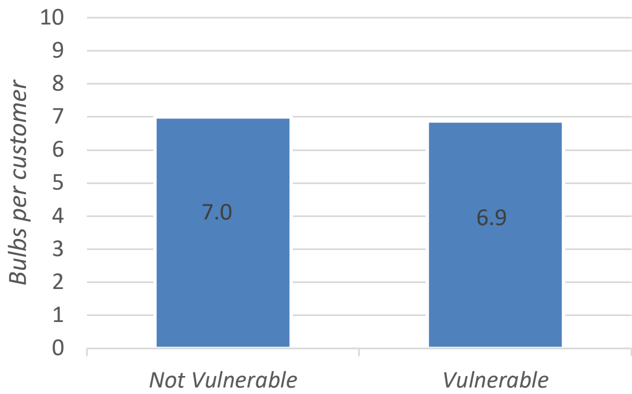
Figure 16 below shows the participation rate of vulnerable customers compared to 'non-vulnerable'. The participation rate of vulnerable customers, at 85%, was higher than non-vulnerable, at 76%. This suggests a vulnerable household is more likely to take-up an offer of LED lighting than the general population.

Figure 16: Participation rate of vulnerable customers



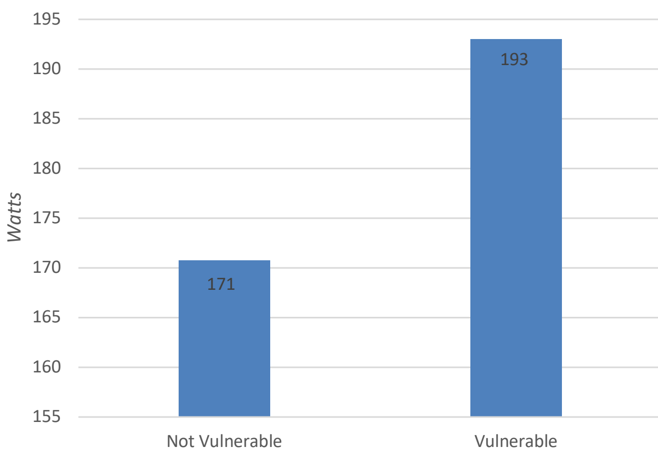
For non-vulnerable households, the project installed between two and ten LED bulbs, with an average of 6.9 bulbs per household. For vulnerable households only, this was slightly higher at 7.0, as shown in Figure 17.

Figure 17: Average bulbs replaced per household for vulnerable households



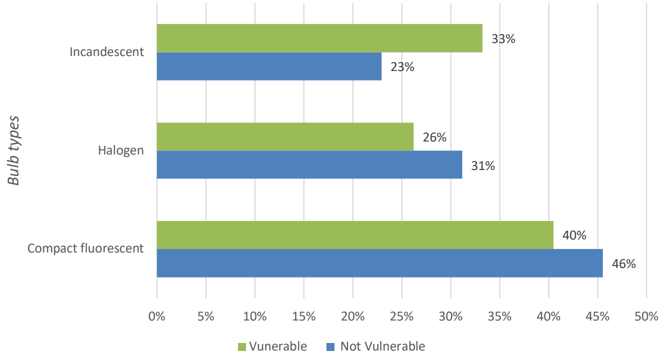
The project also recorded the wattage reduction for each household; this is the change in total rated wattage between the old and new bulbs. The average delta watts due to LED installation was higher for vulnerable customers. For vulnerable customers, the change was 193 W per household and for non-vulnerable the reduction was 171 W per household, as shown in Figure 18.

Figure 18: Average wattage reduction per vulnerable household



Overall, SAVE replaced 6,135bulbs. As seen in Figure 19, the removed bulbs in vulnerable households generally were less efficient (higher wattage) bulbs.

Figure 19: Bulb type replaced in vulnerable households



The SAVE project aimed to ensure fairness in delivering its interventions; for this reason, vulnerable customers were a unique group of interest. The analysis above shows some of the differences identified between vulnerable and non-vulnerable households. As shown, vulnerable customers have a 9% higher participation rate than that of non-vulnerable customers as well as greater theoretical wattage reductions. The average number of bulbs replaced is the same between the two categories.

Evaluation of the in-use energy demand within the LED treatment group included examination of households grouped by vulnerability for any differences in treatment effect. Vulnerable households have significantly lower consumption than non-vulnerable households. However, when controlling for household size, dwelling size and heating fuel the differences in consumption reduction are no longer statistically significant (at the 90% level). Households with none of the defined vulnerabilities had, on average, slightly higher peak-hours electricity consumption (<1% greater), households with 1-2 vulnerabilities had 4% higher consumption, and households with 3 or more vulnerabilities had approximately 2.5% lower consumption that the overall average.

The interaction between vulnerabilities and treatment effect was also modelled. No significant results were found, but the observed treatment effect was 5% higher for vulnerable households than the treatment group on average.

In conclusion, from the bulb installation data, a vulnerable customer can achieve a slightly greater wattage reduction than a non-vulnerable one and are more likely to respond to DNO led energy efficiency than non-vulnerable customers. However, when in-use, the difference in energy savings are not statistically significant.

6

ENERGY IMPACTS

6.1 Trial Period 1 impact

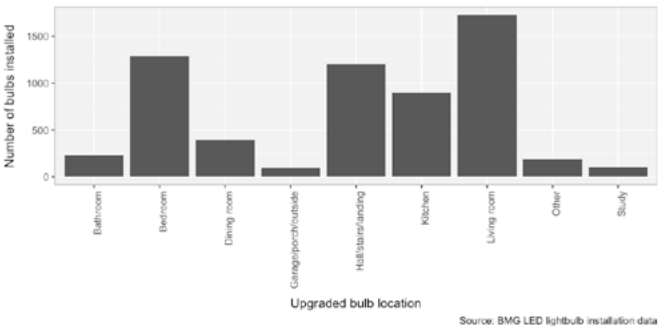
Due to the very limited take-up of the offer in TP1, there was minimal impact to energy consumption of the group.

6.2 Trial Period 2 impact

The fieldwork contractor captured installation details during the roll-out of LED upgrades. For each bulb installed, the location and rated wattage of the new and replaced bulbs were captured.

As seen in Figure 20, the rooms with the most bulbs replaced were the living room, halls and bedrooms.

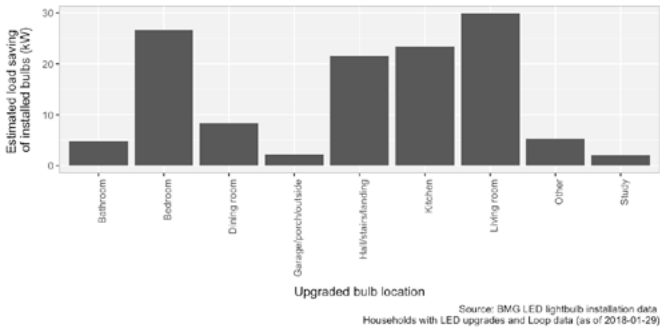
Figure 20: Number of lightbulbs installed in treatment group by bulb location



The location data, along with the wattages of the new and replaced bulbs were used to estimate the total theoretical demand reduction (in kW) for the installed households. This is the reduction in demand that would occur if all replaced bulbs were operating at the same time. In reality, most households do not have all their lights on at a single time. Therefore, Figure 21 shows the estimated theoretical maximum load reduction by bulb location (for households with Loop consumption data only).

The areas with the highest reductions are the living room, bedrooms and kitchen. Even though the kitchen was not one of the most common sites for bulb replacement, it does have one of the highest kW reductions. This is because the wattage of the old, replaced bulbs was higher in kitchens than in other rooms.

Figure 21: Estimated total load saving for the LED intervention by installed bulb location (households with Loop consumption data only)



The installed LED upgrades provide a maximum demand saving of 155 kW within the treatment group. For households with Loop data, the mean saving of the installed bulbs was 176 Watts per household, giving a total reduction of 124 kW.

6.2.1 Theoretical maximum

The analysis in Section 5 utilised the Loop data to determine the observed savings due to LED bulbs across the entire treatment group (including those that declined the LED offer). However, not all bulbs will be on concurrently, therefore the observed reduction will be less than the theoretical maximum load reduction.

The project replaced 6,135 bulbs at 882 properties. The project also recorded the wattage of all bulbs installed and removed. From this installation data, the SAVE project reduced the maximum load by 176 W per participating property. This is slightly higher than the impact seen by the Loop data as not all bulbs will be operational at the same time. The reduction of 176 W represents the theoretical maximum load reduction per household where LED bulbs were installed.

Table 7: Average maximum demand savings per participating household

Average per Household	
Number of Bulbs removed	6.9
Average wattage reduction	176 W

6.2.2 Network Impact

Based on the analysis above, the theoretical maximum network load reduction from those properties with LED bulbs installed would be 171 kW.

Table 8: Theoretical maximum network impact

Average per Household	
Number of Bulbs removed	6135
Wattage reduction	171,007 W – 171 kW

However, due to non-linear characteristics of the electronics in the LED power supply circuit, the power factor (the ratio of real power to apparent power) of LED bulbs is significantly below 1 resulting in reactive power requirements from the network.

Domestic customers in the UK are only charged for real power (in Watts) and are not penalised for reactive power consumptions (in reactive volt-amperes, or var). However, reactive power requires additional current flowing across the network, and thus creates distribution losses in transformers and power lines in the form of heat. Therefore, DNOs have great interest in minimizing apparent power in the grid.

To assess the power factor and impact of it on the distribution network, a sample of LEDs used in SAVE project were bench tested in a laboratory. Laboratory testing showed that non-dimmable LEDs have power factor between 0.47 – 0.49 and dimmable have slightly better power factor of around 0.61. Detailed results of the laboratory testing of LED power factor are available in Appendix 2.6. Applying these power factors to the theoretical maximum reductions shown in Table 8, maximum reductions in apparent power seen by the network are presented in Table 9.

Table 9: Real and apparent power consumption of LEDs tested

Network impact including Power Factor		
Power	Real	Apparent
Number of Bulbs removed	6135	6135
Wattage of removed bulbs	201 kW	254 kVA
Wattage of new LEDs installed	46 kW	98 kVA
Load reduction	155 kW	156 kVA
Wattage of new LEDs installed with PF=1	46 kW	46 kVA
Potential Load reduction with LED PF=1	155 kW	208 kVA

The poor power factor of the installed LEDs lowers the maximum load reduction from the LED intervention from 208 kW of potential reduction on the network to 156 kVA.

In order to maximise the network benefit, future projects should procure quality bulbs with higher power factors, being mindful that there needs to be an appropriate balance between the additional cost of higher quality bulbs and the additional savings that can be realised from them.

6.2.3 Realised Energy Savings

In contrast to the calculated theoretical maximum wattage reduction, analysis of the Loop electricity consumption data (see Sections 0 through 5.2.6) provides an estimate of the realised savings of the installed upgrades in-use. The maximum observed load reduction due to the LED bulbs installed during TP2[26] was 47 Watts per household during the peak hours[27] and was 31 Watts per household for all hours[28]. The load reduction reached a maximum in early January, reducing into spring as daylight hours increased. The results show that the observed load reduction effect varies across households of different characteristics, although the within-group variability in consumption provides low confidence in the estimates.

6.2.4 Customer Impact

Average savings from LED installation was 90 kWh per home, as shown in 5.2.5. Using Government data on average domestic electricity bills[29] this results in average bill savings of £15.82 per household per year.

6.2.4.1 Impact on vulnerable customers

Vulnerable customers are a key consideration for SSEN, and the SAVE project wanted to ensure its methods did not discriminate against them. As shown by the analysis in Section 5.2.7, vulnerable customers were not negatively affected by the SAVE LED trial. The wattage reductions from LED installations were similar for both vulnerable and non-vulnerable households, and the vulnerable customers were slightly more likely to participate in the programme.

26 Includes entire treatment group, both those that has LEDs installed and those that opted out.
27 90% confidence interval of between 1 and 62 Watts.
28 90% confidence interval of between 1 to 44 Watts.
29 Available at https://www.gov.uk/government/statistical-data-sets/annual-domestic-energy-price-statistics.

6.2.4.2 Power quality of bulbs

Due to non-linear characteristics of the electronics in the LED's power supply circuit, the power factor of LED is significantly below 1 (around 0.5) resulting in reactive power requirements. However, as domestic customers in the UK are only charged for real power (Watts) and are not penalised for reactive power consumptions (var), low power factor of LEDs does not affect customers' bills. Customers can fully benefit from wattage reduction of LED bulbs compared to other bulbs. Also, low power factor does not affect quality of light of LED nor start up time.

Low power factor does not have any impact and is not visible to the customers.

6.2.5 Carbon Impact (link to carbon plan)

The UK Government's Climate Change Act 2008 established a legally binding target for greenhouse gas emissions at 80% lower than 1990 levels by 2050. The Act introduced carbon budgets to meet this target. The Government published the Carbon Plan in 2011 (updated 2013)[30], which outlines proposals on how to meet the first four carbon budgets. The document points to energy efficiency as being a major factor in reducing demand and therefore carbon emissions. While the document focuses heavily on low carbon and efficient heating, energy efficiency in all areas is required. The SAVE LED lighting campaign aligns with this Government plan by providing highly efficient LED lighting free of cost to the customer.

Most of this report focuses on the energy savings associated with installing LED lighting, however in reducing energy consumption of homes, the SAVE project also provides savings in carbon emissions.

The UK Government publishes greenhouse gas conversion factors[31] for electricity generation and transmission and distribution losses. In 2017, the conversion factors were 0.34885 kg CO_2 per kWh for generation and 0.03261 kg CO_2 per kWh for transmission and distribution losses, for a total factor of 0.38146 kg CO_2/kWh.

As outlined previously, the maximum observed change relative to the control group was 559 Watt-hours per household per day and 3.9 kWh per household per week.

Using these factors, the maximum reduction in CO_2 per household was 0.213 kg per day and 1.488 kg per week. Over the entire year, the LED installations saved an average of 90 kWh per home, for a total of97,470 kWh and 37,181 kg CO_2.

30 UK Government. The Carbon Plan. https://www.gov.uk/government/publications/the-carbon-plan-reducing-greenhouse-gas-emissions--2

31 UK Government. Greenhouse Gas Reporting Factors https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2017

7

NETWORK APPLICATION

Given the success of TP2, SSEN and other DNOs may wish to roll out similar LED installation programmes in other areas.

7.1 Replicability and partnership with third parties

As outlined in the SAVE project Regulatory Report[32], when rolling out an LED installation programme as a business as usual activity, DNOs may wish to partner with external parties such as a charity or local organisation. This would provide a number of advantages, including:

- Enhanced customer trust. Many customers do not understand what a DNO is and may confuse them with an energy supplier. DNOs should look to partner with organisations that are well known in the area and brand the intervention and associated communication strategies accordingly.
- Reduced costs. A partner may be able to provide an additional or lower cost funding stream.
- Benefit stacking. Partners may be able to claim benefits that the DNO cannot, such as reduced carbon emissions.
  - Future SAVE-like interventions should also explore how participants can claim funding from multiple schemes, such as ECO, Green Deal or other Government funding schemes (if not DNO led[33]). Not all schemes will allow this, of course, but where possible it could allow DNO funding to act as 'gap-funding' to enable projects to move forward that may not be cost effective with Government funding alone.

SAVE's Community Energy Coaching (CEC) trial (see SDRC 8.8[34]) explored community partnerships in more detail. The CEC trial established a multi-agency stakeholder group to design and oversee the delivery of energy related interventions. These partnerships involved experts, local leaders and community members to design a programme that was fit for purpose to the area it served. A similar approach could be used in implementing SAVE or SAVE-like programmes into business as usual.

A DNO may also wish to procure the entire service from a third party, such as an aggregator, at a fixed cost and not be directly involved in the intervention. Competition between third parties may help lower costs to provide the service and maximise value for money for DNOs and consumers. Additionally, aggregators may be able to utilise other funding sources, such as Government energy efficiency schemes or Capacity Market[35] payments.

7.2 Scalability

7.2.1 Business case (financial benefits)

Table 10 below shows the LED deployment costs per 100 customers and the price for kW of peak reduction. This assumes take-up rates and costs similar to the TP2 deployment.

Table 10: LED deployment costs

Deployment costs per 100 customers	Average peak load reduction per customer (kW)	Load reduction per 100 customers (kW)	Price per kW of peak reduction
£12,000	0.047	4.70	£2,600

7.2.1.1 Influence on DNO's

Distribution network costs vary greatly based upon the area covered and nature of network issues within those distinct areas. Factors such as number of customers, location (urban/rural), length of feeders, ground conditions, overhead/underground lines and potential for upstream/downstream benefits (i.e. if LED's are deployed to address an LV overload energy saving benefits will accrue at HV and transmission levels) may all affect the cost of reinforcement and subsequent business case for any smart interventions.

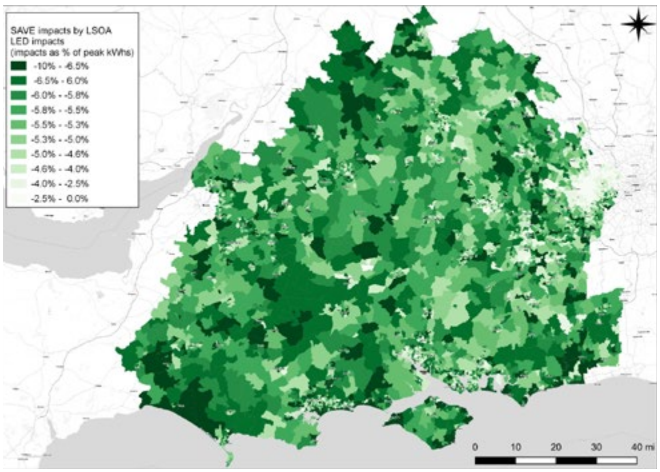
32 Available at https://www.ssen.co.uk/save/
33 Since Government energy efficiency schemes are generally not open to DNOs.
34 SDRC 8.8, 'TM4 (Community Energy Coaching Trial) - Final Reporting', available at https://www.ssen.co.uk/save/
35 It should be noted that at the time of drafting, the Capacity Market was in a forced standstill following judgment of the General Court of the Court of Justice of the European Union in Case T-793/14. It is unclear how the Capacity Market will be structured in the future. Updates can be found here: https://www.gov.uk/government/collections/electricity-market-reform-capacity-market

Given the analysis highlighted in Section 6.2, single-person households, homes with a large number of bedrooms[36], and elderly households may have a greater impact on peak demand through an LED based initiative than other household types. However, because the size of each of these sub-groups is small, these findings are not statistically robust and are subject to high errors. Further research is needed to robustly determine the characteristics of homes where the impact of LEDs is greatest.

Resultantly, the SAVE project is able to use this information and scale it across customers using regional census data. By matching census data with an interface developed on the project, the SAVE project's Network Investment Tool can tell its user the demographics of customers deployed on a given substation/feeder (see SDRC 8.2, Network Investment Tool[37]). This provides DNO's an understanding of how customer demographics will affect the network in question. Should similar energy and household data be available for other forms of domestic DSR; whether energy efficiency or another means (see SDRC 8.4 and 8.7, Data informed and price signals[38]) this approach could be used to map other interventions.

A screenshot of this mapping exercise is shown across SSEN's southern patch in Figure 22 below, where percentage reduction across domestic households is shown per Lower Super Output Area (LSOA) with darker colouring representing a larger impact.

Figure 22: Mapping of LED impact



It is clear that the impact of LED's in and around urban areas tends to be smaller than in more rural areas, this will largely be as a result of smaller houses and flats in cities and the positive correlation between size of dwelling and LED impact. In the future, DNO's can layer this mapping with other census information such as indications of fuel poverty to understand the added social benefits energy efficiency could bring to different areas. SSEN has built this mapping into its vulnerability mapping as an added layer for stakeholder engagement teams to analyse.

It is important that the DNO selects an intervention beneficial for both customers and the network. This must consider cost-effectiveness as well as social impacts and security of supply. By comparing different measures of network management and their cost the DNO will ultimately be able to determine the most effective means of managing a potential overload (accounting for forecasts in demand). This may be a SAVE intervention, traditional reinforcement or another form of smart intervention, i.e. battery storage. The SAVE project has developed a Network Investment Tool designed to do this; the tool is described in greater detail in SDRC 8.2.

7.2.1.1 Future opportunities

The project has produced a simple case study, based loosely on three sites in the West London area of SSEN's network to understand the value of capacity margins that LEDs might offer in a given network scenario. The results of this can be shown in Table 11 and Table 12 below. It should be noted that these costs do not represent real network costs. There are a range of wider factors to consider in a real network management case, including: season, time and duration of overload, up- and down-stream benefits and long-term load growth (among others). These tables provide a simple illustration of how DNOs may wish to approach energy efficiency business cases in future providing an illustration of both current and forecasted loading on each substation where a forecasted overload triggers a signal for reinforcement.

36 While this may seem contradictory (single person households and homes with a large number of bedrooms both having higher than average impact) it should be noted that larger homes do not always come with more occupants and small homes are not always single person homes.

37 Available at https://www.ssen.co.uk/save/

38 Available at https://www.ssen.co.uk/save/

Table 11: Definition of example feeders

Site	Capacity (KVA)	Current Load	Forecasted (year +6) Load	Feeder overload?	Est. Total reinforcement cost	NPV of 6 year deferral
A	500	495	530	Yes	£47,500	£8100
B	500	490	501	Yes	£45,000	£7,400
C	800	750	810	Yes	£225,000[39]	£37,400

Table 12: LED impact on example feeders

Site	Customers	Of which PSR	LED peak load reduction (Kw)	Forecasted Load - LEDs	Cost of initiative
A	144	26	6.77	523.23	£17,300
B	374	61	17.58	483.42	£44,900
C	473	76	22.23	787.77	£56,800

It is apparent looking at Table 11 and Table 12 that in two of the three case studies (B and C) LED's could provide an effective solution for keeping the networks within capacity. On site A on the other hand, LEDs do not provide enough load-reduction to manage the forecasted overload, so might be dismissed as a solution or require stacking with another smart initiative (see section 7.2.1.2).

Dependent upon how often this overload was forecasted to occur, and for how long, determines the severity of the overload issue. For instance, if the forecasted overload of 530KVA was only expected to be reached once per year for 10 minutes, then any impact on the networks thermal capacity should be limited. If that same substation actually usually runs at around 501KVA, then LEDs could provide an effective mitigation (again this may also be dependent upon continued future load-growth assumptions and highlights where granular monitoring and analysis of substation data is important).

Given the network is able to cope with small overloads for short periods, LEDs could provide an effective option to keep load below capacity where overloads are small and consistent. In this example, if the overload was consistently high at 530KVA, the 6.77kW impact of LED's would not be enough to resolve the challenge in question.

7.2.1.2 A Smarter business case

To build an additional layer into the business case, Table 13 presents a series of theoretical LED rollout scenarios for each of the case study networks. This assumes the value case for not reinforcing (and managing through other means) is derived by the net present value of reinforcement being deferred for six years, shown previously in Table 11. In the scenarios presented below it is clear that LEDs do not appear to be a cost-effective solution for any site. One very important assumption which limits the current business case is that load continues to grow beyond year six, therein rendering the LED engagement not enough to further defer reinforcement. What may happen however, is that load actually begins to flatten or even decrease by year six. In these instances, no further network management would be required and had reinforcement happened in year 0 the DNO's additional capacity would have been a stranded asset. The ability smart interventions give to act with hind-sight is called optionality value, putting a value on this is not included here but is explored in the project's Network Investment Tool (see SDRC 8.2).

39 These high costs are likely to be associated with substations particularly hard to reinforce, one example of this may be costly feeders to replace due to their length, location and the knock-on-effects on the local geography.

However before discounting the business case for LED bulbs in these cases studies, there are additional, non-reinforcement benefits of LED engagement that should be considered. Engagement with customers to promote the installation of LEDs can identify Priority Services Register customers; DNO's are directly incentivised to do this under RIIO[40]. This is a potential additional revenue stream to support the business case for energy efficiency. Secondly, through joint utility working the DNO can work more cost-effectively with organisations who share similar objectives; supporting the vision of a joined-up model of working consistent with the ENA's Open Networks project vision of a DSO. Finally, in the future alternate revenue streams to support energy efficiency uptake could be considered to support social benefits of initiatives (whether to the DNO or a third party). In the case below, carbon[41] and customer bill savings[42] are used as a simple example.

In addition, a smarter rollout programme may substantially reduce costs. For instance, other parties may be better suited to rollout energy efficiency measures and domestic DSR given closer relationships with customers, greater experience in the sector and ability to stack benefits and revenue streams[43]. Such partners may include: local councils, housing associations, other utilities (gas, water and electricity suppliers), registered social charities and many more. The impact on a business case of sharing engagement costs with third parties is illustrated in Table 13 below. In the below table, column 2 and 7 both show different business case Column 2 shows costs before social and stacked benefits, column 7 shows costs discounted by these benefits. The other columns show the potential monetary value of benefit applied.

Table 13: Impact on business case of additional revenue streams

Site	Current Business Case	PSR customer engagement[44]	Joint rollout with 2 partners (engagement costs divided by 3)	Carbon benefits (6 year)[45]	Customer savings (6 year)	Cost-benefit of 6 year scheme assuming all variables accounted for (joint utility rollout with social costs)
A	-£9,280	£85	£5760	£143	£13,670	£16,200
B	-£37,480	£254	£14960	£371	£35,500	£29,100
C	-£19,360	£156	£18920	£469	£44,900	£63,900

40 SSEN is incentivised up to £3.1 million annually (in 2012/13 prices) by Ofgem through RIIO ED1's stakeholder engagement and consumer vulnerability criteria.

41 SAVE analysis suggests that LED's might save an average household 90 kWh per year or 43 kg of carbon. This could arguably be worth xx in carbon credits.

42 Energy Savings Trust estimate one LED bulb could result in a bill saving of £6 per customer per year. "Energy efficient lighting" webpage. http://www.energysavingtrust.org.uk/home-energy-efficiency/lighting. Annual observed energy savings were approximately 90kWh per home, as shown in Section 5.2.6. Using gov.uk estimated prices of £0.176/kWh, this is an annual savings of £15.82 per house. https://www.gov.uk/government/statistical-data-sets/annual-domestic-energy-price-statistics

43 More information is available in the SAVE Regulatory Report, available at https://www.ssen.co.uk/save/.

44 Values derived from WPD consumer vulnerability outcomes report which looks at quantifying value of engaging vulnerable, fuel poor and priority service register (PSR) customers- full details can be seen in Appendix 1.4.

45 Assuming a carbon conversion of: 0.38146 kg CO2/kWh shown in section 6.2.5 and a carbon price of: £4.37/tCO2e. https://www.gov.uk/government/collections/carbon-valuation--2. Over 6 years we assume a customer continues to save 90 kWh of electricity each year through LED's and hence over 6 years saves 540 kWh of electricity.

Table 13 shows that the three case studies examined will not break-even compared to traditional reinforcement costs. It is clear however, that there are a vast array of parties with vested interest in engaging customers around efficient products and that the potential additional social benefits of rolling out energy efficiency are substantial.

It is recommended in future iterations of energy efficiency rollout that the DNO looks to stack engagement benefits by partnering with third parties to devise cost-efficient programmes. Success of such initiatives will be site dependant based upon the cost of reinforcement and cost-efficiency of other smart solutions in an area. On the sites studied, partnership with other utilities suggests a cost-effective business case could be built on 2 of the 3 sites (column 2 + column 4).

To increase benefit stacking and the likelihood of energy efficiency achieving a cost-effective business case, the DNO and government may wish to consider alternate ways of monetising social costs and benefits (such as customer bill savings and carbon reductions). It is clear that commercialising (even part of) these social benefits represent clear additions to any business case, increasing the number of sites where energy efficiency could be used to manage overloaded demand.

Finally, based upon load-forecasts past year six the DNO will be able to design smarter/tailored strategies/business cases. One example of this is given above with regards the value of optionality through avoiding any reinforcement if load actually looked to flatten or decrease by year 6. Another example might be that if load was expected to continue to grow beyond network limits, LED lighting might be able to mitigate this. A DNO could explore the cost-efficiency of packaging this intervention with other interventions, such as deploying LED lighting with other energy efficiency technology such as those considered in Section 1.4.[46]

In practice, the best way to explore these business cases may be to provide the correct market signals for third parties to deliver cost-effective means of managing the network. Here, DNO funding could provide geographical price-signalling for third parties to deliver any of a range of solutions to manage network loading. SSEN is initiating such thinking in their Social Constraint Managed Zones (SCMZ) initiatives.[47]

Energy efficiency measures (like LED lighting, among others) can also support the UK's carbon reduction targets. While ECO and Green Deal are mainly focused on heating measures, further incorporating and promoting other energy efficiency measures would have the dual benefit of network management and carbon reduction.

A full business case can be found in an attached spreadsheet in Appendix 2.7.

7.2.1.3 Learnings from other domestic EE and DSR projects

Other LCNF projects have provided extensive learnings about how to engage with domestic customers as summarised in SDRC 1. Projects reviewed include the Customer-Led Network Revolution (CLNR), Low Carbon London (LCL), My Electric Vehicle and New Thames Valley Vision (NTVV).

LCL and CLNR commenced in 2011 in an environment where DNOs had not previously considered either categorising customers or engaging with them beyond the connection process. Both projects gave initial thought to customer categorisation in an attempt to produce statistically significant results but both projects were challenged to maintain this in the face of poor initial uptake rates. This demonstrates that the projects not only needed to secure initial interest from customers to participate but also needed to find ways to sustain this interest during the full recruitment process. For this reason, SAVE offered small vouchers throughout the trial to encourage engagement and limit drop-out.

Customers in the New Thames Valley Vision project received instruction on the most effective use of installed energy management devices by means of a brochure, followed by a face-to-face meeting with an SSEN (then SSEPD) customer manager and finally from the fitter who installed the system. This has been found to be an effective way of imparting this information to users and ensuring that this equipment is used in the most effective way possible. This is in line with findings from the LED trial, where the most effective engagement approach was the face-to-face LED installations.

46 This may also include other smart interventions such as those trialled in SAVE's other methods or other LCNI projects, i.e. smart charging.

47 A Constraint Managed Zone (CMZ) is a geographical area of the network forecasted for potential overload in future where it could prove advantageous to commercially manage demand through contracts with 3rd party providers as an alternative to traditional reinforcement. A SCMZ is the evolution of this with a procurement process which appropriately advertises the CMZ to local organisations and SME's with a distinct focus on the provision of societal benefits and looks to account for social costs within the procurement process.

For recruitment on My Electric Avenue, EA Technology trained local community members to recruit their neighbours. This was a deliberate strategy to enable trust. NTVV has formed a partnership with the local authority (Bracknell Forest Council) and used their logo to co-brand the materials that were sent to the customers. Again, the main reason for including the local authority was to enable trust. While SAVE has its own logo and branding, messages were deliberately aligned with the University of Southampton and not with any of the for-profit project partners in order to increase customer trust. Future DNO roll out of energy efficiency should continue to seek partnerships. DNO staff have not traditionally needed customer engagement and recruitment skills since customers who wish to connect to the distribution network will contact DNOs without requiring the DNO to solicit for business.

7.2.2 Longevity

The effective useful life (EUL) of LED bulbs can be difficult to quantify. For traditional lighting technologies (halogen, incandescent or fluorescent), the end of life is obvious: they no longer emit light. LEDs, however, can emit light for a very long time. Over time, light from LEDs can change colour or the output will continually decline to the point they are not considered functional (although they will still emit light). This is a departure from traditional EUL estimates. The Next Generation Lighting Industry Alliance recommends defining failure as the time when an LED light is only producing 70% of its initial light level, although they warn that colour shift may also cause removal for some applications.[48] For most white LED bulbs, this is between 35,000 and 50,000 hours of operation; most manufactures estimate lifetime (conservatively) at 30,000 hours.[49]

Hours of use generally varies by room type, with lights in kitchens or living rooms operating more hours per day than lights in bathrooms or bedrooms. The Northeast Residential Lighting HOU Study logged the hours of operation for 4,462 lights at 848 homes to estimate average daily hours of use; the results of this study are presented below in Table 14.[50]

Table 14: Lighting hours of use by room

Lighting hours of use per day	
Bedroom	2.1
Bathroom	1.7
Kitchen	4.1
Living space	3.3
Dining room	2.8
Exterior	5.6
Other	1.7
Household average	**2.7**

Using the household average of 2.7 hours of use per day and the conservative lifetime of 30,000 hours, the LED bulbs installed in this project should last approximately 30 years. Even using the 4.1 hours per day from the living room, this is still a lifetime of over 20 years.

There is a natural uptake of LED lighting, even without incentive programmes like SAVE. At some point, it's possible that UK or EU standards could ban less efficient lighting and cause a rapid uptake in LEDs. Even though the lamps may have a 20+ year lifetime, an LED-based energy efficiency incentive may have a limited lifespan.

However, current penetration of LED lamps in the UK is low, the Energy Savings Trust reported in 2013 that only 1% of lighting stock in domestic properties is LED.[51] There are still significant savings to be had from accelerating the uptake of LEDs.

48 US Department of Energy, Next Generation Lighting Industry Alliance. LED luminaire lifetime: recommendations for testing and reporting. https://www.energy.gov/sites/prod/files/2015/01/f19/led_luminaire_lifetime_guide_sept2014.pdf

49 US Department of Energy. Lifetime of White LEDs. https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/lifetime_white_leds.pdf

50 NMR Group, Inc. Northeast Residential Lighting HOU Study. http://ma-eeac.org/wordpress/wp-content/uploads/Northeast-Residential-Lighting-Hours-of-Use-Study-Final-Report1.pdf

51 Energy Savings Trust. Review of Carbon Savings from Residential Efficiency. https://www.theccc.org.uk/wp-content/uploads/2013/12/Review-of-potential-for-carbon-savings-from-residential-energy-efficiency-Final-report-A-160114.pdf

8

CONCLUSIONS

TP1 had limited uptake, with 5 households participating by purchasing discounted bulbs. While 19% of the trial group visited the project website, less than 1% actually purchased bulbs. While there were no discernible energy impacts from Trial Period 1, the learning on take-up of this approach was extremely valuable when designing Trial Period 2.

While this take up is not entirely unexpected when comparing to direct mail average response rates, it did not prove our hypothesis that take-up may be higher as the offer came from the SAVE project and was not an advertisement. The web conversion rate of 19% was higher than expected. Future sales websites should be simple to understand while remaining aesthetically pleasing and retaining project branding. If possible, partnering with a known retailer may also increase uptake.

TP2 was significantly more successful, with 76% of participants accepting the project's offer to install LED bulbs in their house. The offer of free bulbs and installation coupled with an opt-out trial design was a winning approach that led to statistically significant energy reductions in two weeks of the observation period. This direct installation approach was the most successful of those tested. Repeating this approach with additional customers will likely produce energy savings for both the DNO and the customer. During the maximal week, the median change in consumption in the treatment group over the peak hours (4 to 8 pm) was equivalent to **47 Watts per household**. The energy savings between vulnerable and non-vulnerable are not significantly different; vulnerable customers were even more likely to take up the offer while still receiving similar energy savings. Average **annual savings per household were 90 kWh, resulting in financial savings of approximately £15.82 per year**.

If implementing similar interventions in the future, DNOs should incorporate lessons learned from these two LED interventions, specifically:

- As expected, free bulbs and installation was very popular and will likely be well received by a majority of customers if offered. In addition to popularity, this approach is preferable to others as:
  - Direct installation and removal of old bulbs can help ensure the effects of efficient lighting is seen by the network.
  - Direct installation and removal of old bulbs can limit the number of bulbs stored or sold second-hand. This was an especially common issue in other projects where efficient bulbs were handed out at events or sent through the post. Many people will view the efficient bulb as a replacement for when an old bulb fails.
- A DNO may want to investigate installing more LED bulbs per house and/or other forms of energy efficiency as energy reductions were not statistically significant in all weeks of the observation period. White goods are a major energy user in most domestic properties and would be a reasonable area to tackle next.
- If offering discounted bulbs, marketing should target a very large audience as take up will likely be low.
- Thought should be given to ways to maximise participation if offering bulbs at a discount, such as:
  - Making the sales website as easy to navigate as possible.
  - Clearly stating the price per bulb for easy comparisons to other retailers.
  - Partnering with well-known and trusted retailers.
  - It may also be worth exploring other (non-online) sales options.

- Not all household types respond equally:
  - Treatment effects are larger in single person households (effects decrease as number of occupants increases).
  - Treatment effects are larger in large homes (effects decrease as house size decreases).
  - Treatment effects are larger in households with retired occupants and increases as the age of the occupant increases.
  - If DNOs are looking to maximise impact, it may be worth targeting these types of households. This could be done by partnering with local organisations, for example those that regularly work with older citizens. However, it should be noted that the differences between these groups had very large uncertainties. Future research should be done to more robustly determine where LED installations will have the greatest impact.
- Future SAVE-like schemes may be able to maximise their value by:
  - Partnering with organisations such as local councils, charities or aggregators that can either:
    - Contribute additional funding sources, or
    - Claim benefits that DNOs cannot, such as carbon savings or energy savings.
  - Encouraging measures that are also eligible for funding from other Government schemes. In this case, SAVE funding may be able to act as 'gap-funding' to enable projects to move forward that may not be cost effective with Government funding alone.

Overall, the SAVE LED intervention has proved that, if deployed in adequate quantities, LED bulbs can effectively reduce network load.

Solent Achieving Value from Efficiency

Solent Achieving Value from Efficiency

Technical AnnexSSET206

LCNF Tier 2 SDRC 8.3 LED Trial Report

Scottish and Southern Electricity Networks (SSEN) is the new trading name of Scottish and Southern Energy Power Distribution (SSEPD), the parent company of Southern Electricity Power Distribution (SEPD), Scottish Hydro Electricity Power Distribution (SHEPD) and Scottish Hydro Electricity Transmission. SEPD remains the contracted delivery body for this LCNF Project.

Prepared By

Document Owner(s)	Project/Organisation Role
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Version Control

Version	Date	Authors	Change Description
0.1	17/12/18	E. Steele, M. Dodd, T.W. Rushby, C. Edwards, D. Minissale, M. Fila	Initial draft.
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Scottish & Southern Electricity Networks

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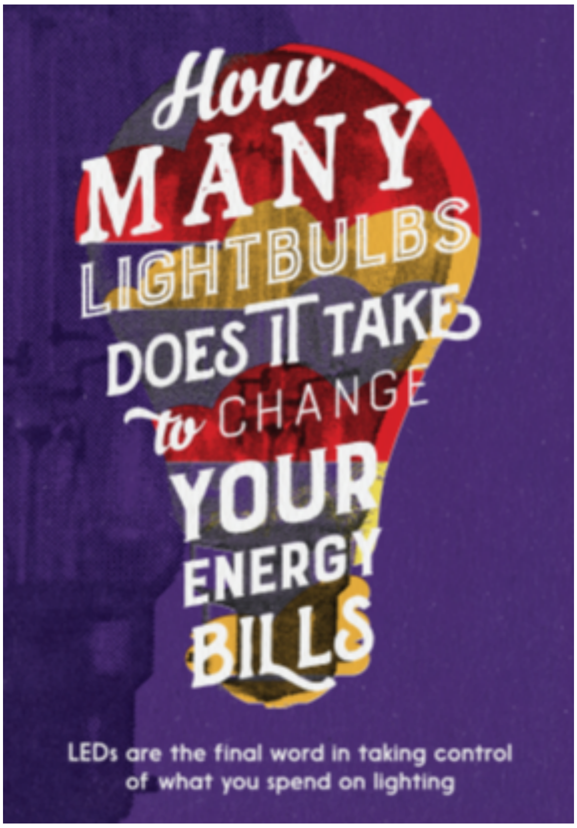
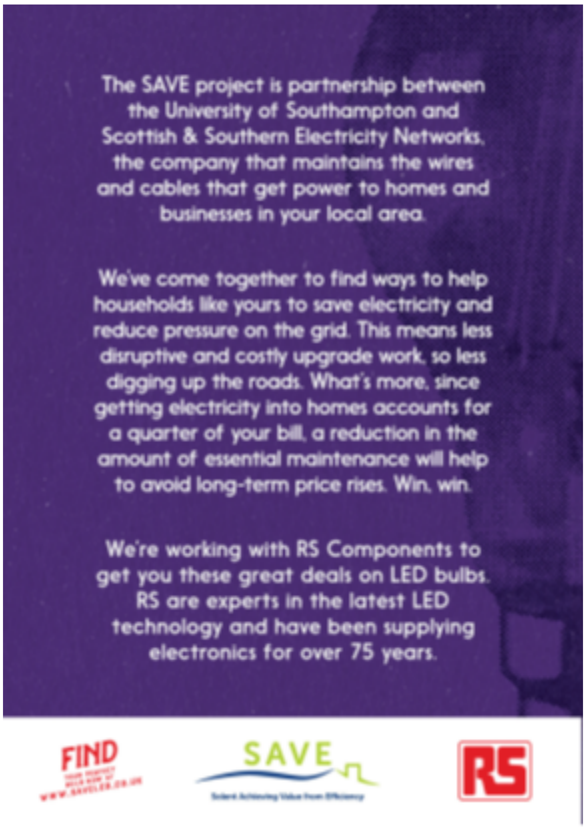
1.1 Trial period 1

1.1.1 Initial booklet




WHAT'S ALL THE FUSS ABOUT LEDS?
Not so long ago all our lights used filament bulbs, the type that hadn't changed since the invention of the lightbulb. Lovely to look at but really inefficient, giving off more heat than they did light and costing us a fortune in energy bills.
Filament bulbs have now all but disappeared in favour of more energy efficient types. LEDs are by far the most efficient option, saving up to 85% in energy use and making them one of the simplest ways to reduce bills.
LEDs have an incredible life span and can last 20 times as long as a filament bulb. This means the higher upfront cost is more than outweighed – in fact, they generally start to pay for themselves in savings after only 5 months.
Modern LED bulbs offer a warm light and come in all shapes and sizes. Not just like-for-like replacements for your existing bulbs but also some beautiful new decorative styles that replicate filament bulbs.
Big Savings ON LEDS EXCLUSIVELY FOR SAVE PARTICIPANTS
20% OFF AND BETTER VALUE THAN THE HIGH STREET
FIND YOUR PERFECT BULB NOW AT WWW.SAVELED.CO.UK
CHANGING 6 HALOGEN BULBS IN YOUR KITCHEN FOR LEDS WOULD SAVE £XXX PER YEAR
Visit www.saveLED.co.uk where a simple guide will help you find the bulb you need to replace your existing one and help with installing it. We've selected top branded bulbs from Osram and RS Pro.
This offer is only available to SAVE participants.
SAVE
Solent Achieving Value from Efficiency


The SAVE project is partnership between the University of Southampton and Scottish & Southern Electricity Networks, the company that maintains the wires and cables that get power to homes and businesses in your local area.
We've come together to find ways to help households like yours to save electricity and reduce pressure on the grid. This means less disruptive and costly upgrade work, so less digging up the roads. What's more, since getting electricity into homes accounts for a quarter of your bill, a reduction in the amount of essential maintenance will help to avoid long-term price rises. Win, win.
We're working with RS Components to get you these great deals on LED bulbs. RS are experts in the latest LED technology and have been supplying electronics for over 75 years.
FIND
SAVE
RS

1.1.2 Follow-up postcard

1.2 Trial period 2

1.2.1 Recruitment script

READ OUT:

Good morning/afternoon/evening. My name is ……. and I am calling from BMG Research on behalf of the SAVE project, partnered by the University of Southampton regarding a research study about energy consumption. You may remember receiving a visit from a member of the BMG field team some time ago regarding the installation of an electricity monitor in your meter box and a device that sends this information to a secure place so that the University of Southampton can analyse patterns of electricity usage across the region.

IF NECESSARY:

The SAVE project is a partnership between the University of Southampton and Scottish & Southern Electricity Networks, the company that maintains the wires and cables that get power to homes and businesses in your local area.

We've come together to find ways to help households like yours to save electricity and reduce pressure on the grid. This means less disruptive and costly upgrade work, so less digging up the roads. What's more, since getting electricity into homes accounts for a quarter of your bill, a reduction in the amount of essential maintenance will help to avoid long-term price rises.

READ OUT:

BMG's involvement in the project was to assist households with the installation of the electricity monitoring kit and now we are contacting households for the next phase of the project. As part of this study, we're giving some homes the opportunity to have energy saving LED light bulbs installed in the home for free; 10 bulbs could be worth £30-£50 from your local DIY store. LEDs are by far the most efficient type of bulb available today, saving up to 85% in energy use and making them one of the simplest ways to reduce bills. They also have an incredible life span - 20 times longer than a traditional filament bulb - so can start paying for themselves in savings in as little as 6 months.

Depending on the type of light bulbs you currently have installed, we would look to replace up to 10 in your home that use most electricity in the evening.

IF NECESSARY:

We are interested in the usage in the evening because this is the period of highest usage and greatest pressure on the electricity network.

IF NECESSARY:

This study is being conducted in accordance with the Data Protection Act. This means your personal details, including information about your energy use, will be kept strictly confidential and you and your household will not be identifiable in any project results.

READ: I am a member of the BMG field team and I will be in your area over the coming weeks to install LEDs as part of the next phase of the SAVE project. I am calling today to arrange appointments for these installations. The site visit should take no longer than 20-30 minutes. I'll need to speak to <<name>> to arrange a convenient appointment, can I confirm if you are <<name>>?

a. Appointment [CONFIRM DATE AND TIME FOR VISIT]

b. Call back (no appointment)

c. Refused

1.3 Detailed Analysis and methods

1.3.1 Trial Period 2 analysis

1.3.2 Software used in data processing

The R packages used for base SAVE data processing are listed below:

- base R - for the basics (R Core Team 2016)
- data.table - for fast (big) data handling (Dowle et al. 2015)
- Hmisc - to capitalize first letter in string (Harrell Jr, Charles Dupont, and others. 2016)
- lubridate - for fast date/time conversions (Grolemund and Wickham 2011)
- dplyr - data manipulation (Wickham and Francois 2016)
- dtplyr - data.table data manipulation (Wickham 2016)
- knitr - to generate reports (Xie 2016)

The analysis report was generated using knitr in RStudio with R version 3.4.2 (2017-09-28) running on x86_64-apple-darwin15.6.0.

The analysis ran and completed in 152.6 seconds (2.54 minutes).

1.4 Vulnerable customer definitions

SAVE participants completed the questionnaire set out below. Responses that would indicate a vulnerability aspect are listed below each question. If a respondent provided one of these responses to three or more questions they were categorised as a ‘vulnerable customer’.

Q2b. What is your age?

7. 65-74

8. 75+

Q2d. What is your working status?

5. Unemployed

7. Retired

9. Permanently sick/disabled

Q2d. What is their [other household members] working status?

5. Unemployed

7. Retired

9. Permanently sick/disabled

Q3.2. Who is your landlord?

3. Private landlord or letting agency

Q3.8. How do you pay your electricity bills?

4. Pre-payment meter

6. Fuel Direct/Third Party Deductions/benefits

Q8.20. Which of the following would you say is the highest level of qualification that you hold?

11. Have no qualifications

Q8.21. Which of the following would you say is the highest level of qualification the household reference person holds?

11. Have no qualifications

Q8.26. Do you or anyone else in your home have any long term illness, health problem or disability which limits your daily activities or the work you can do?

1. Yes

Q8.27. Which of the following matches the total monthly or annual gross income of this household?

1. Monthly: Under £833 OR Yearly: Under £10,000

2. Monthly: £834 to £1,042 OR Yearly: £10,000 to £12,500

3. Monthly: £1,043 to £1,250 OR Yearly: £12,501 to £15,000

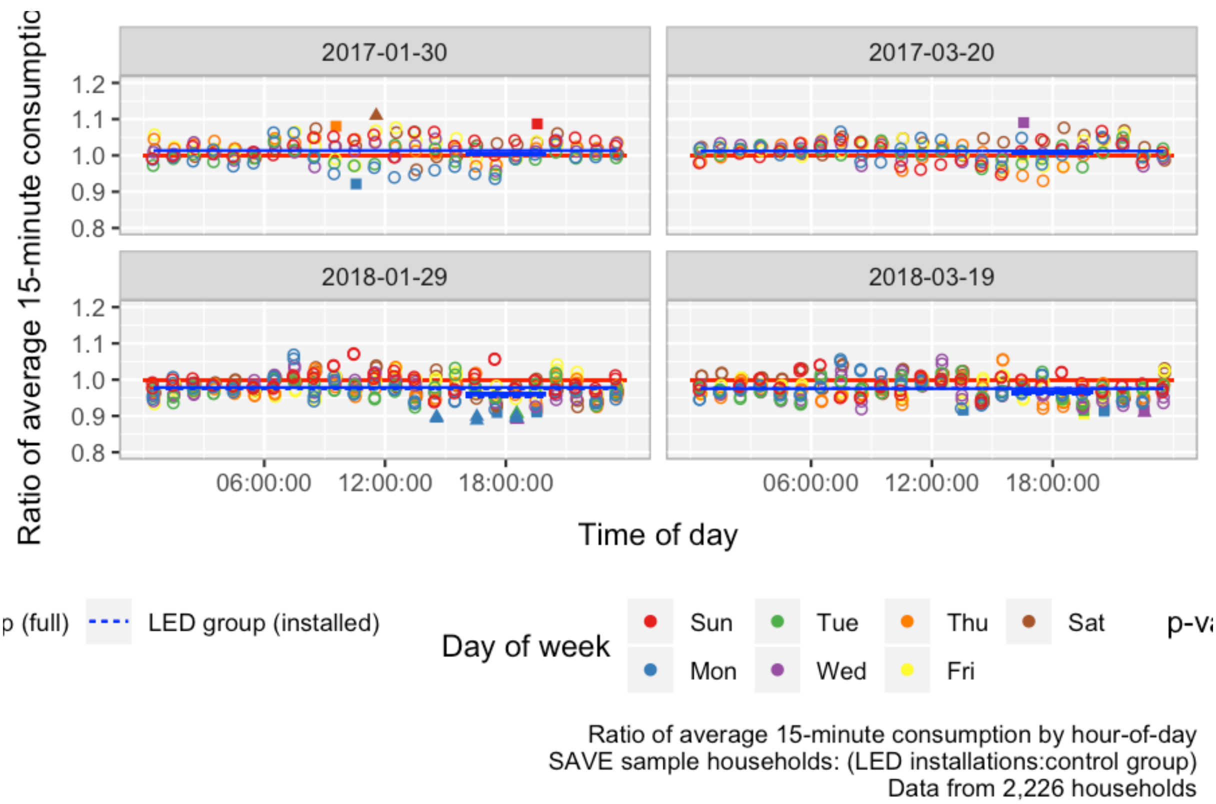
2 Detailed results

2.1 Hourly regression model results

The ‘treatment only’ regression models compare the weekly (log) mean 15-minute consumption in each hour for four selected weeks. Figure 1 shows the combined results of the regression models. The figure shows the ratio of geometric means (log mean Wh) of the treatment groups (i.e. the ratio of LED treatment to control). Points and lines appearing above the red line indicate a coefficient value of above 1 and show that the estimated consumption of the LED treatment group is higher than the control. Points below the red line indicate estimated consumption in the LED treatment group is lower than the control group. Points with fill are statistically significant results (squares indicate 90% confidence level, triangles indicate 95% confidence level). Blue horizontal lines show hourly coefficients averaged across the week (for both all-hours and peak-hours).

The top two panels in Figure 1 show that a large proportion of the estimated coefficients during the weeks commencing 30th January and 20th March 2017 (pre-treatment) lie above the lines, indicating that estimated mean consumption in the LED treatment group is marginally higher than the control group. The bottom two panels show the estimated regression coefficients for the weeks commencing 29th January and 19th March 2018. It can be noted that, in contrast to the pre-treatment measurement, the estimated group mean consumption values for the LED treatment group generally lie below the lines.

Figure 1: Difference in group consumption by hour-of-day and day of week: treatment and control, selected comparison weeks



With a few exceptions, the coefficients remain between 0.9 and 1.1 (values indicating treatment group mean 10 percent above or below the control group). It is also observed that while there is a clustering of several significant results around the peak period, particularly during the week commencing (29th January 2018), the majority of estimates are not statistically significant.

2.2 Sunset and daylight hours

Figure 2 shows that the week commencing 18th December 2017 has the shortest daylight hours. Figure 3 shows that the week commencing 11th December 2017 has the earliest sunset times with the sun visible above the horizon until 15:56.

Figure 2: Number of hours of daylight during the trial weeks

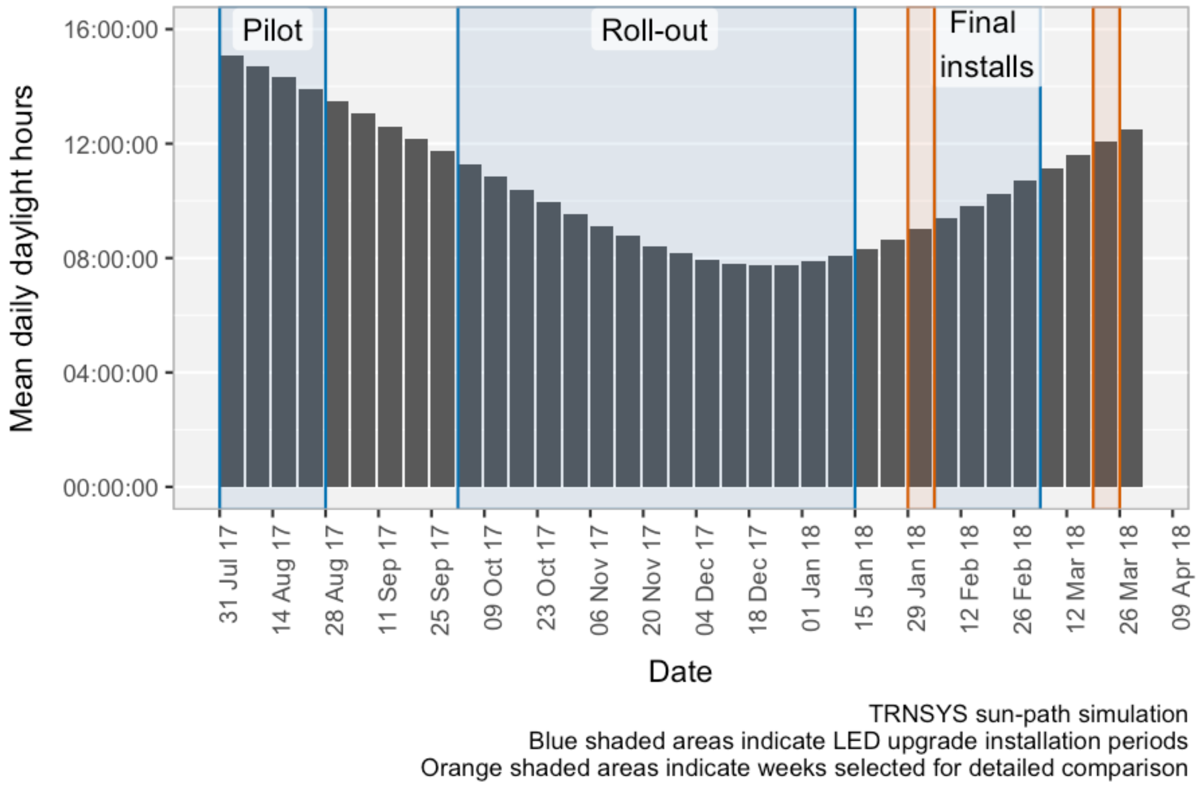
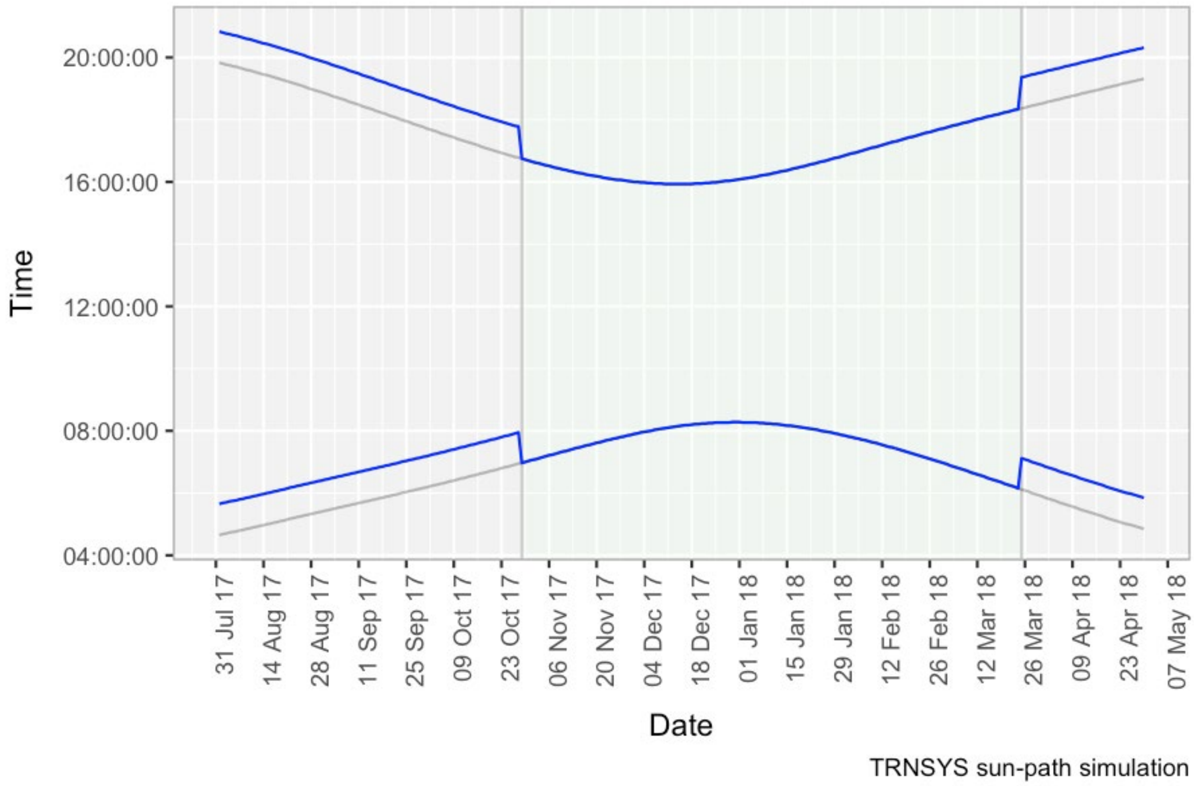


Figure 3: TRNSYS sun-path simulation



2.3 Hourly and day-of-week comparison

Any savings from LED upgrades will occur only when lighting is in use and will therefore occur during only those hours when upgraded lighting is in operation. It has already been shown that observed differences in consumption appear to be seasonal. It then follows that the observable changes will occur where periods of active occupancy coincide with hours of reduced daylight or darkness.

Active occupancy varies by time and weekday, therefore Figure 4 shows the mean 15-minute consumption for the control and LED upgrade groups by hour-of-the-day and day-of-the-week for the week commencing 29th January 2018.

Figure 4: Hourly mean 15-minute Wh consumption by day-of-the-week: LED upgrade and control groups, week commencing 29th January 2018.

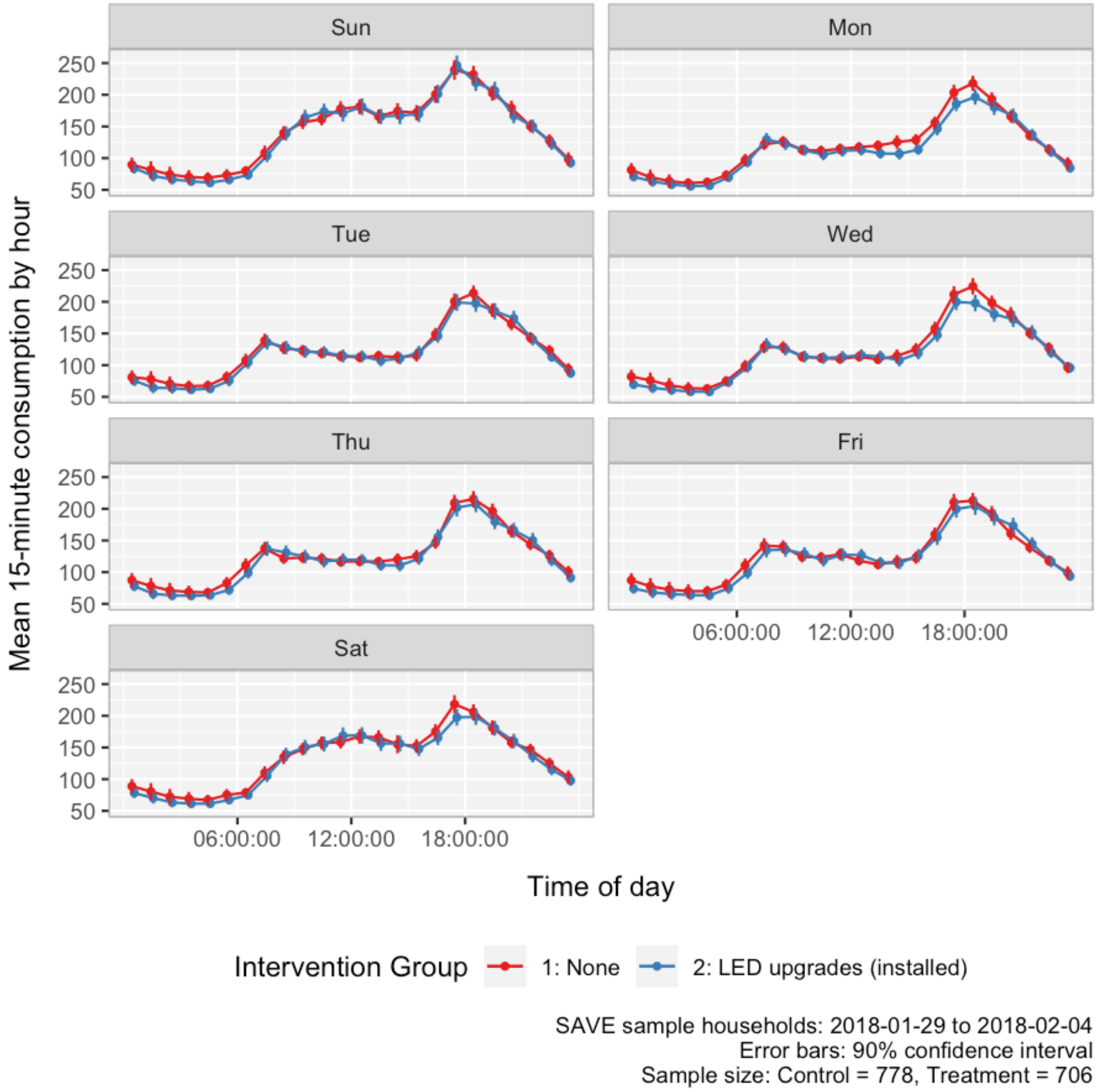
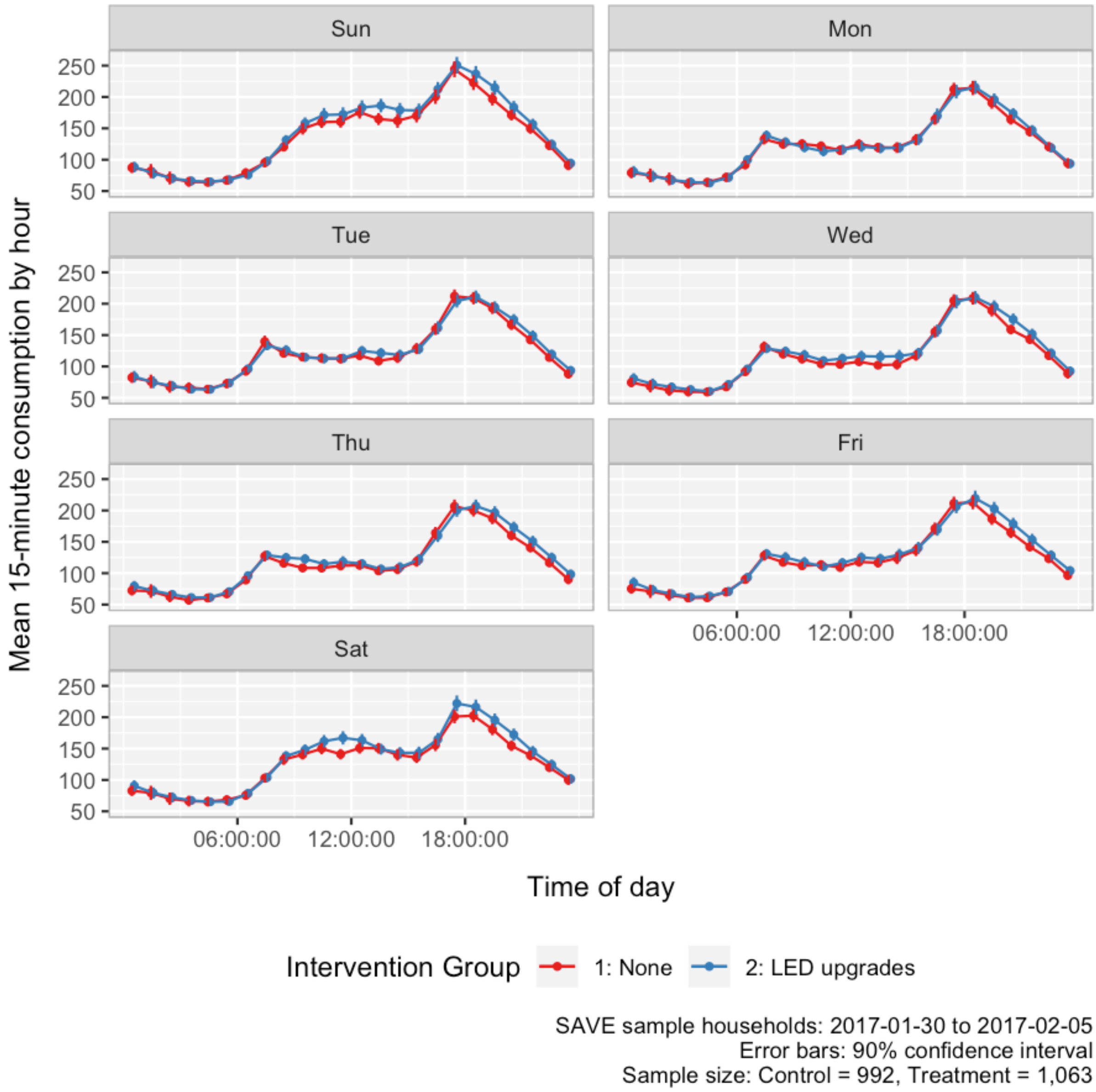


Figure 4 clearly shows differences between the groups are consistent with the hypothesis that the group treated with LED upgrades will have reduced consumption during those hours where active occupancy coincides with darkness or reduced daylight. Consistent differences between the groups appear during weekdays, particularly Monday to Thursday, and in the late afternoon and into the evening (after 4pm).

As a comparison, Figure 5 shows the treatment and control group for the equivalent week in 2017 (week commencing 30th January), prior to the roll-out of LED installations within the group. Figure 5 below shows that mean hourly consumption for the treatment group is generally above that of the control group (with the exception of Tuesday and Thursday between 4-6pm where consumption it is marginally lower). This highlights the variability within weeks, as it illustrates that the small differences between groups change day-to-day for these selected weeks.

Figure 5: Hourly mean 15-minute Wh consumption by day-of-the-week: LED upgrade and control groups, week commencing 30th January 2017



To examine any variation in the differences in consumption between the LED treatment group and the control group by day of the week and hour of the day, a series of 'treatment only' linear regression models were created for each hour of the day in four comparison weeks: the two weeks noted previously (commencing 29th January and 19th March 2018) and the equivalent weeks in 2017 (commencing 30th January and 20th March).

The results are consistent with the hypothesis that the LED treatment group has reduced consumption relative to the control group following the roll-out of the lighting upgrades. The variation in the hourly model results reflect the underlying variability in the consumption data, and individual hourly results were generally not significant and no distinct patterning was observed by day of the week. When averaged across each week, the hourly coefficients show that the differences between the control and treatment group were small (less than 5 percent) but confirm the reduced consumption in the treatment group shown in the weekly 'treatment only' models.

2.4 DiD full model results

The DiD regression model results for the week commencing 15th January 2018 show the difference-in-differences estimate as a reduction of between 6% and 9% relative to the expected treatment group consumption, varying according to which contrast week is selected. The effect is statistically significant at a 90 percent confidence level for the model run using contrast week '2'.

Table 1: Regression results for week commencing 15th Jan 2018, DiD model (peak hours)

Dependent variable:	logMeanWh	
	Contrast Week '1'	Contrast Week '2'
treatedDiD	0.015 (-0.057, 0.086)	0.044 (-0.028, 0.116)
timeDiD	0.495^{***} (0.423, 0.567)	0.487^{***} (0.415, 0.560)
treatedDiD:timeDiD	-0.058 (-0.159, 0.044)	-0.088^{*} (-0.190, 0.014)
Constant	4.587^{***} (4.536, 4.638)	4.587^{***} (4.536, 4.638)
Observations	2,858	2,848
R^2	0.103	0.093
Adjusted R^2	0.102	0.092
Residual Std. Error	0.691 (df = 2854)	0.694 (df = 2844)
F Statistic	108.655^{***} (df = 3; 2854)	97.579^{***} (df = 3; 2844)
Note:		*p<0.1 **p<0.05 ***p<0.01

The regression model results show statistically significant differences for the weeks commencing 1st and 8th January 2018 (at 90 percent confidence level). The full results for the week commencing 1st of January are shown below in Table 2 and show the difference-in-differences model result as a reduction of approximately 6% to 8% relative to the expected treatment group consumption.

Table 2: Regression results for week commencing 1st Jan 2018, DiD model (all hours)

Dependent variable:	logMeanWh	
	Contrast Week '1'	Contrast Week '2'
treatedDiD	0.010 (-0.056, 0.075)	0.030 (-0.036, 0.096)
timeDiD	0.377^{***} (0.311, 0.443)	0.371^{***} (0.305, 0.437)

Dependent variable:	logMeanWh	
treatedDiD:timeDiD	-0.058 (-0.151, 0.035)	-0.082* (-0.176, 0.011)
Constant	4.297*** (4.251, 4.344)	4.300*** (4.253, 4.346)
Observations	2,902	2,898
R^2	0.070	0.063
Adjusted R^2	0.069	0.062
Residual Std. Error	0.639 (df = 2898)	0.642 (df = 2894)
F Statistic	72.359*** (df = 3; 2898)	64.824*** (df = 3; 2894)
Note:		*p<0.1 **p<0.05 ***p<0.01

Inspection of the results shows that consumption in the treatment group was approximately 4% higher than the control group in the baseline week (not statistically significant). However, within the treatment group, 'baseline' consumption in those households that did not receive the LED upgrades (the contrast category in the second model 'treated DiD') was approximately 3% lower (pre-treatment) than those that did receive upgrades ('LED install group').

Table 3: Regression results: LED group difference-in-differences

Dependent variable:	logMeanWh	
	Treatment group only	Treatment and LED installed
timeDiD	0.487*** (0.415, 0.560)	0.487*** (0.415, 0.560)
treatedDiD	0.044 (-0.028, 0.116)	
timeDiD:treatedDiD	-0.088* (-0.190, 0.014)	
ledTreatmentLED: installed		0.048 (-0.027, 0.122)
ledTreatmentLED: not installed		0.016 (-0.138, 0.170)
timeDiD:ledTreatmentLED: installed		-0.088 (-0.193, 0.018)
timeDiD:ledTreatmentLED: not installed		-0.085 (-0.302, 0.133)
Constant	4.587*** (4.536, 4.638)	4.587*** (4.536, 4.639)
Observations	2,848	2,848
R^2	0.093	0.093
Adjusted R^2	0.092	0.092
Residual Std. Error	0.694 (df = 2844)	0.694 (df = 2842)
F Statistic	97.579*** (df = 3; 2844)	58.571*** (df = 5; 2842)
Note:		*p<0.1 **p<0.05 ***p<0.01

Table 4 contains the regression model interaction coefficients (Interaction) and p-values. Each of the interaction coefficients have been added to the contrast category coefficient to provide the effect size for each variable sub-category (Effect column in the table).

Table 4: Regression model treatment effects, p-values and interaction coefficients: all variables

Term	Effect	p-value	Interaction
Diff-in-diff (contrast)	-0.1040	0.6304	**NA**
People2	0.0283	0.3663	**0.1322**
People3-5	-0.0679	0.8442	**0.0360**
People6+	0.1086	0.5497	**0.2125**
Bedrooms3	-0.1891	0.5344	**-0.0852**
Bedrooms4	-0.1975	0.5673	**-0.0935**
Bedrooms5+	-0.2469	0.5124	**-0.1429**
HeatSource_Electric	-0.1565	0.8264	**-0.0525**
HeatSource_Other	-0.1137	0.9686	**-0.0097**
Children_1+ child	-0.0017	0.4936	**0.1023**
Employment_HRP in part-time employment (8-29 hours/week)	0.1532	0.1241	**0.2572**
Employment_HRP retired	-0.1623	0.6620	**-0.0583**
Employment_HRP self-employed (unkown hours)	-0.0949	0.9636	**0.0091**
Employment_Other	-0.2461	0.4817	**-0.1421**
Employment_Unemployed	-0.1659	0.8806	**-0.0619**
Qualification_A/AS level, Scottish Higher, ONC/OND	-0.0662	0.8283	**0.0378**
Qualification_HNC/D, degree and higher	-0.0901	0.9071	**0.0139**
Qualification_Other	-0.1545	0.7622	**-0.0505**
Qualification_Don't know	0.0420	0.6390	**0.1460**
Ethnicity_Asian/Asian British	-0.5713	0.1768	**-0.4674**
Ethnicity_Black/Black British	0.2830	0.5275	**0.3870**
Ethnicity_Mixed	-0.2206	0.8212	**-0.1166**
Ethnicity_Other	0.1209	0.7751	**0.2249**
Ethnicity_Refused	0.1787	0.4715	**0.2826**
Dwelling_Flat/Other	-0.1659	0.8121	**-0.0620**
Dwelling_Semi	-0.0825	0.8628	**0.0215**
Dwelling_Terrace	-0.2074	0.4597	**-0.1034**
Tenure_Private rent	0.0755	0.4122	**0.1795**
Tenure_Social rent	0.0828	0.2887	**0.1867**
Tenure_Refused/Don't know/Other	**-0.3478**	**0.5991**	**-0.2438**

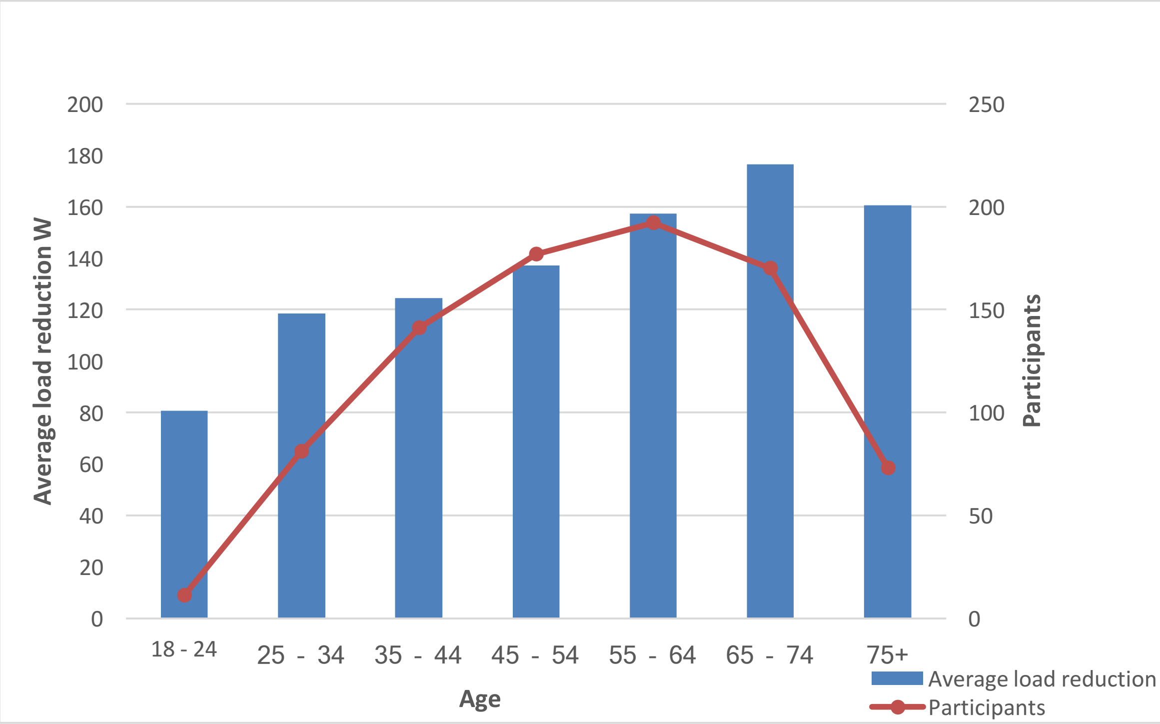
2.5 Maximum reduction by customer categories

Installation data was analysed to determine how the maximum load reduction and bulb types varied depending on household characteristics such as age, income, education level, structure type and others.

Detailed analysis on the theoretical maximum reduction by customer categories is presented below. In all graphs, the columns represent the variable of interest (e.g. load reduction) and the points on each line show the number of participants (i.e. customers) in each group. For groups with a small number of participants, the error (not shown, for simplicity) will be higher. The small number of participants in each sub group means that these results are **not statistically significant**.

Figure 6 shows that the potential load reduction increases as the age of the householder increases.

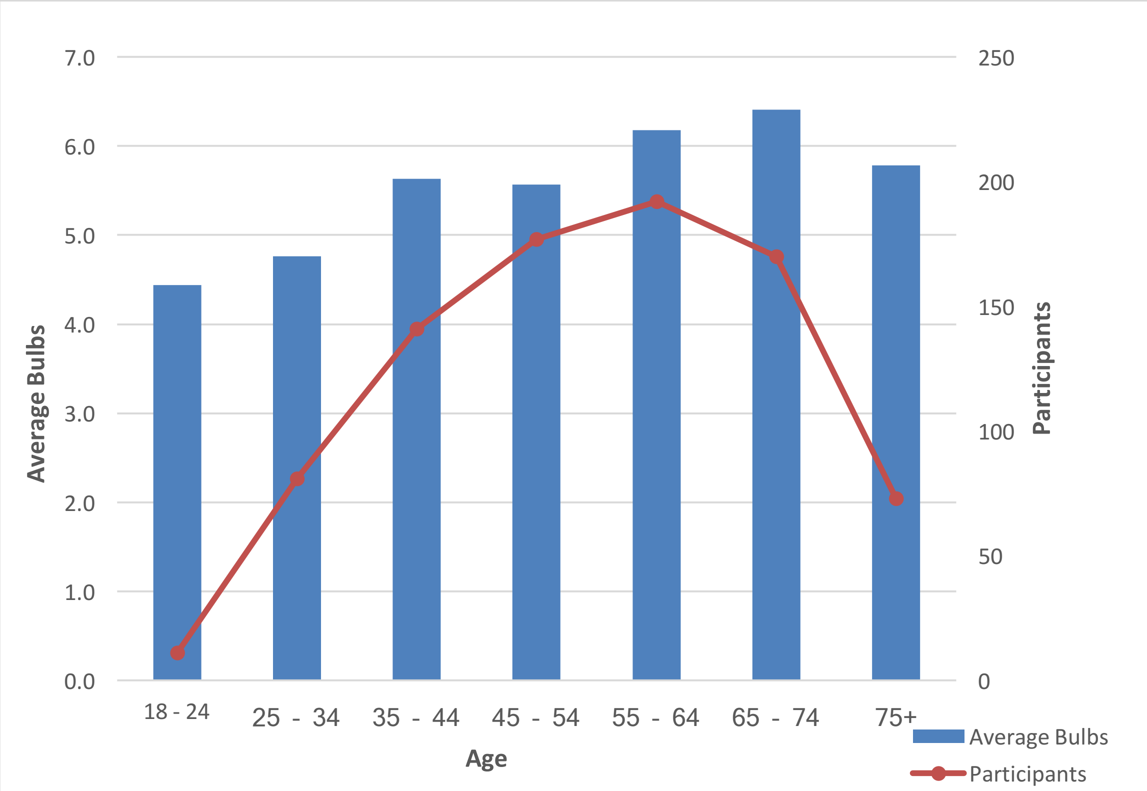
Figure 6: Load reduction by age



As shown below in Figure 7, the number of bulbs installed increases as the occupant age increases until the 75+ category. The 65-74 category has the highest average of bulbs replaced followed by 55-64. This suggests households with younger occupants are more likely to already have efficient bulbs in their homes.

For some variables, differences between groups were not statistically robust as almost all households were in a single group. This was the case when attempting to segment by the presence of connection to the gas grid and primary heat source. In these cases, almost all the households were connected to the gas grid and used a gas boiler for heating. Therefore, statistically valid comparisons between the groups were not possible.

Figure 7: umber of bulbs by occupant age



Potential load reduction was not heavily influenced by work status, although 'Students-19-24 years old', 'Unemployed-seeking work' and 'Self-employed' tended to have the lowest potential reduction, as seen in Figure 8. Interestingly, most of these categories also had fewer bulbs installed but 'Students-19-24 years old' did have a higher install rate, as seen in Figure 9. These younger students tended to have more efficient bulbs already present in their households, and therefore lower potential for load reduction.

Figure 8: Load reduction by work status

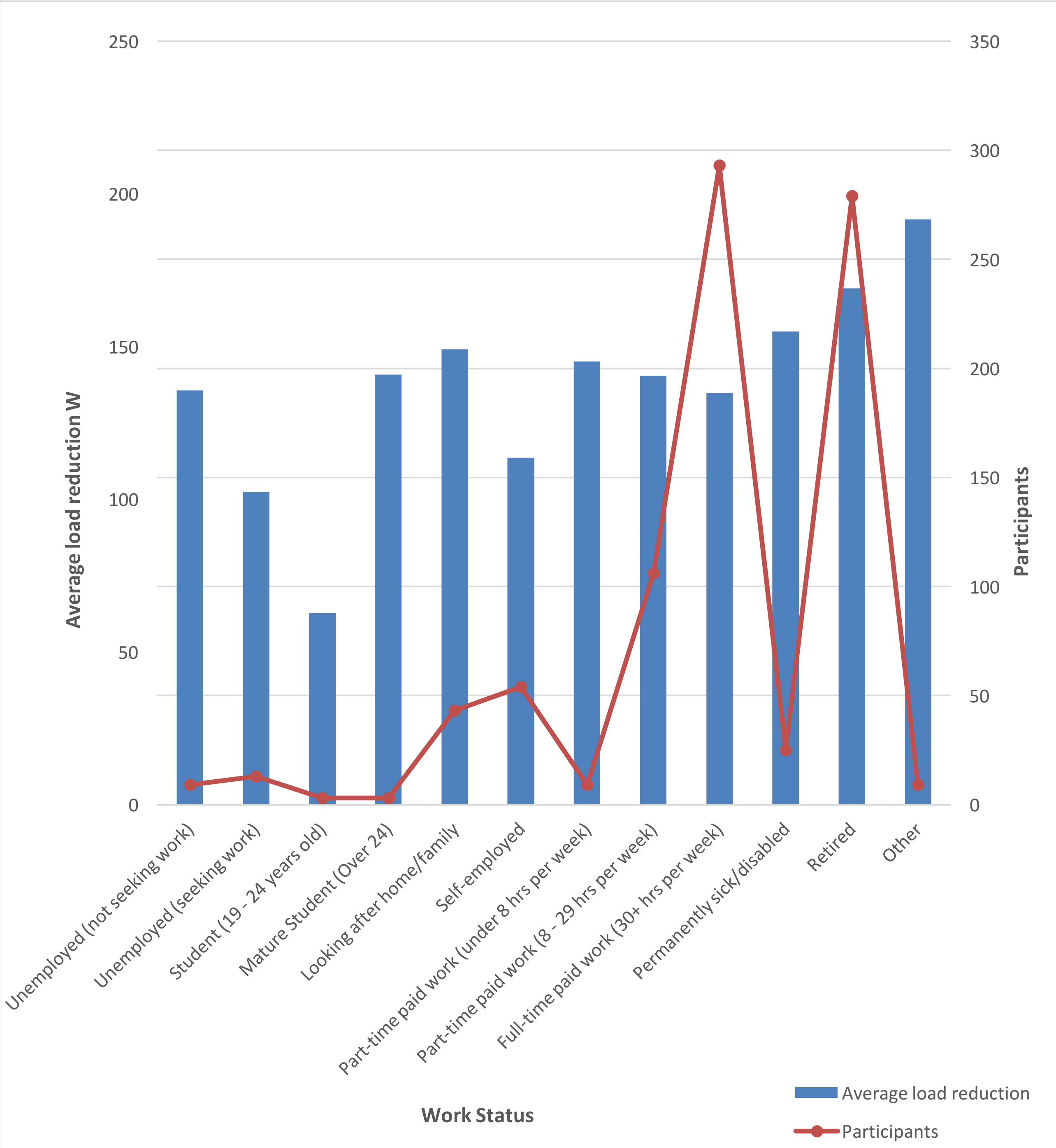
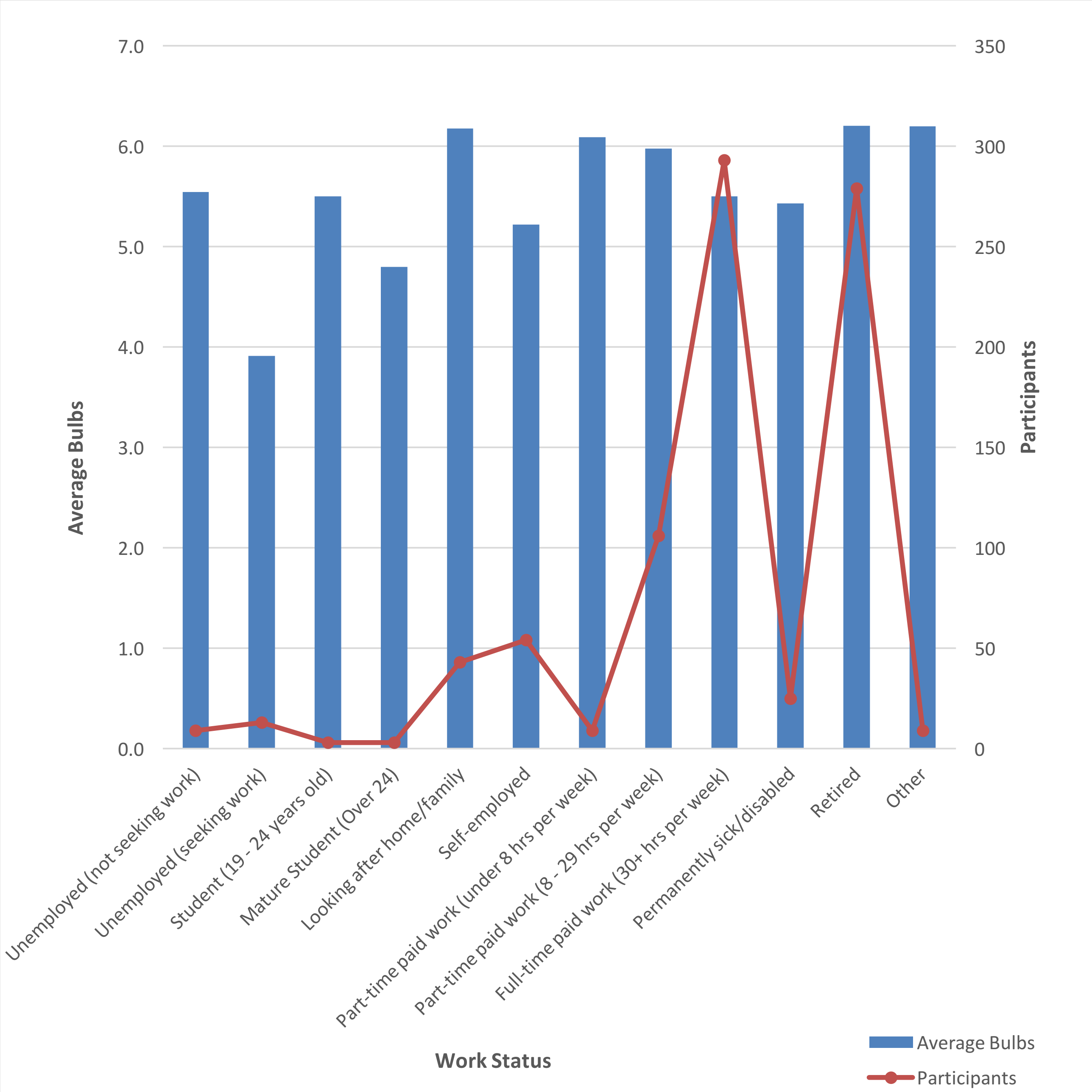


Figure 9: Number of bulbs by work status



When segregated by ownership (rented, owner occupied, owner occupied with a mortgage or mixed), the analysis shows the average load reduction is highest for those that own their homes outright, as shown in Figure 10. As seen in Figure 11, the average number of bulbs in those properties that are owned outright is also higher.

Figure 10: Load reduction by ownership type

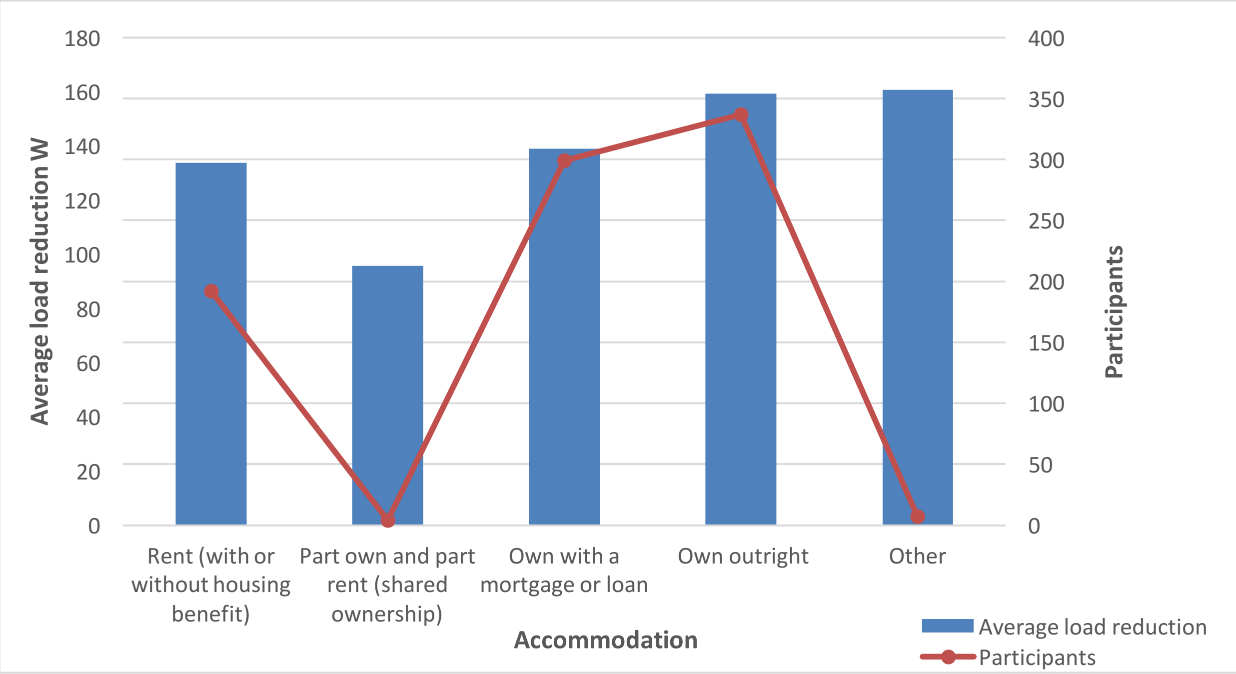


Figure 11: Number of bulbs by ownership type

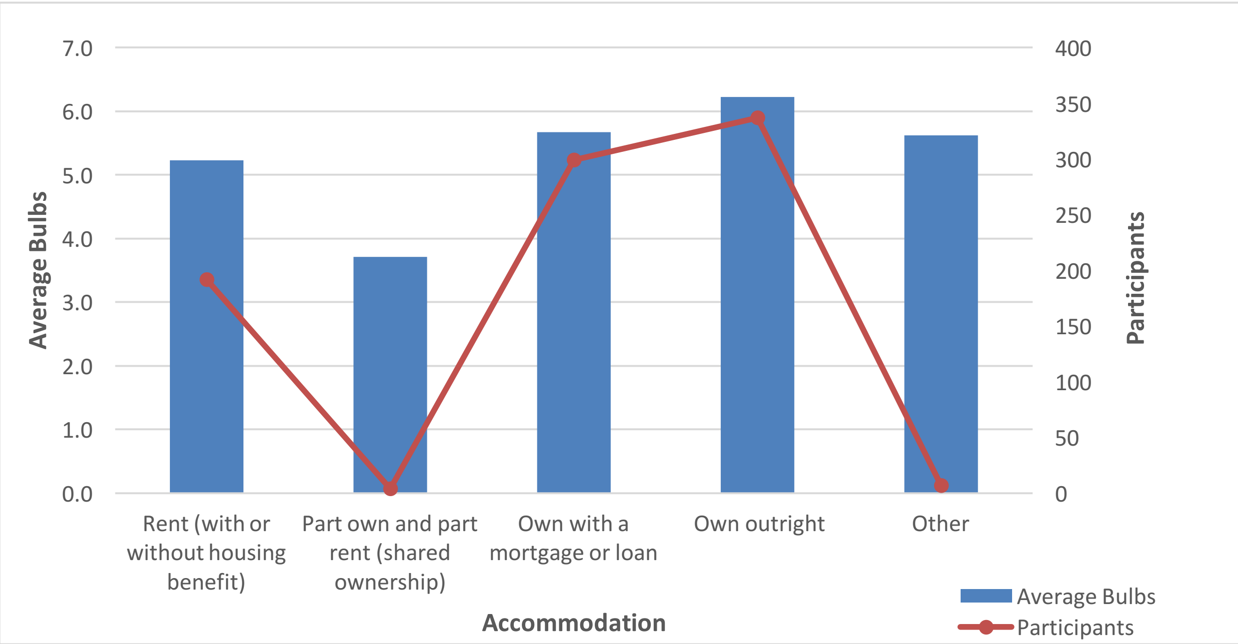


Figure 12 below shows the potential load reduction per household segregated by the presence of gas (either grid connected or from a Liquid Petroleum Gas, LPG, tank) and Figure 13 shows the average number of bulbs replaced using the same categories. Almost all homes in the project were connected to the gas grid, and therefore the applicability of the average reduction and number of bulbs for the other two categories is not able to be assessed.

Figure 12: Load reduction by presence of gas grid

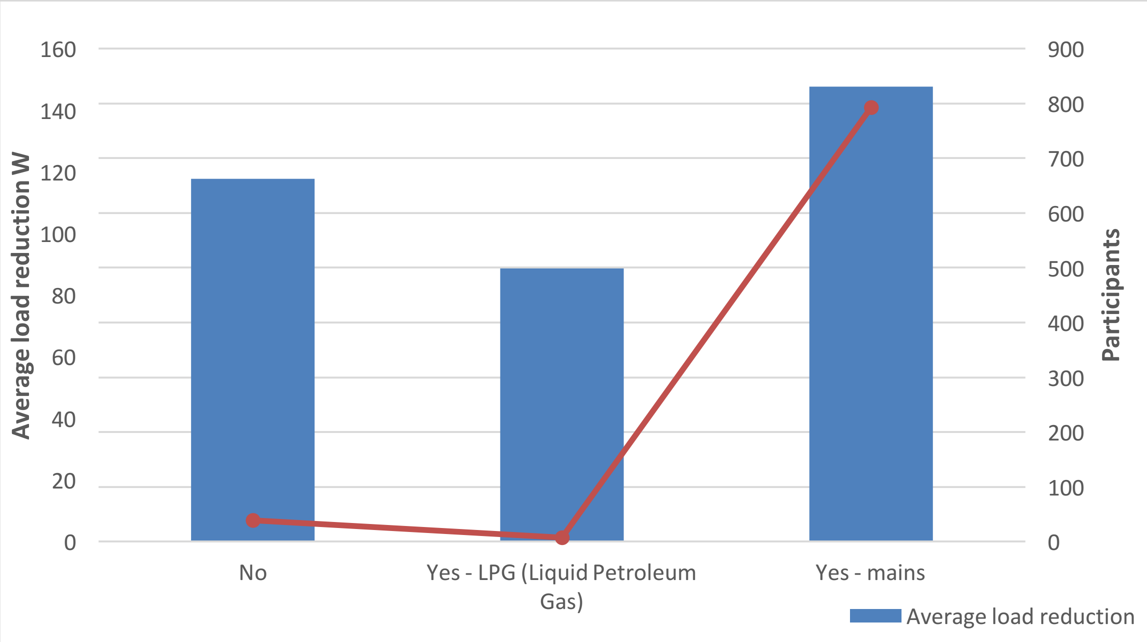


Figure 13: Average number of bulbs by presence of gas grid

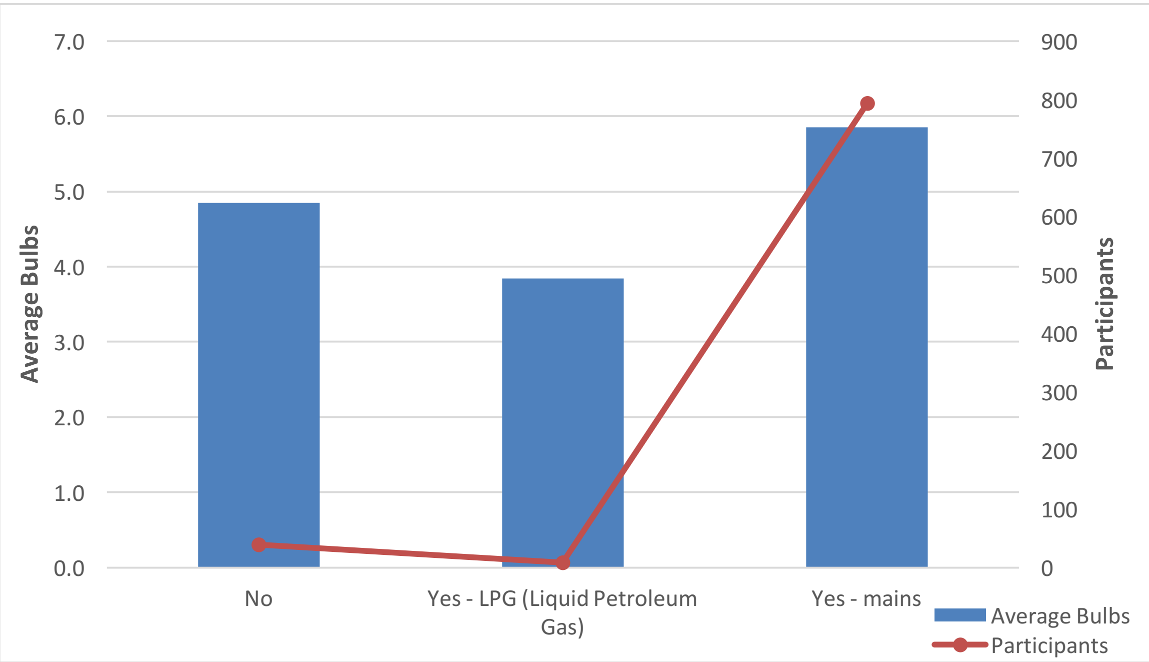


Figure 14 and Figure 15 show the potential load reaction and number of bulbs replaced per household (respectively) by heating source. Like the divisions by gas above, the vast majority of the households use a gas boiler as their primary heat source. Because the other categories have so few households in them, the difference between the groups are not statistically robust.

Figure 14: Load reduction by heating source

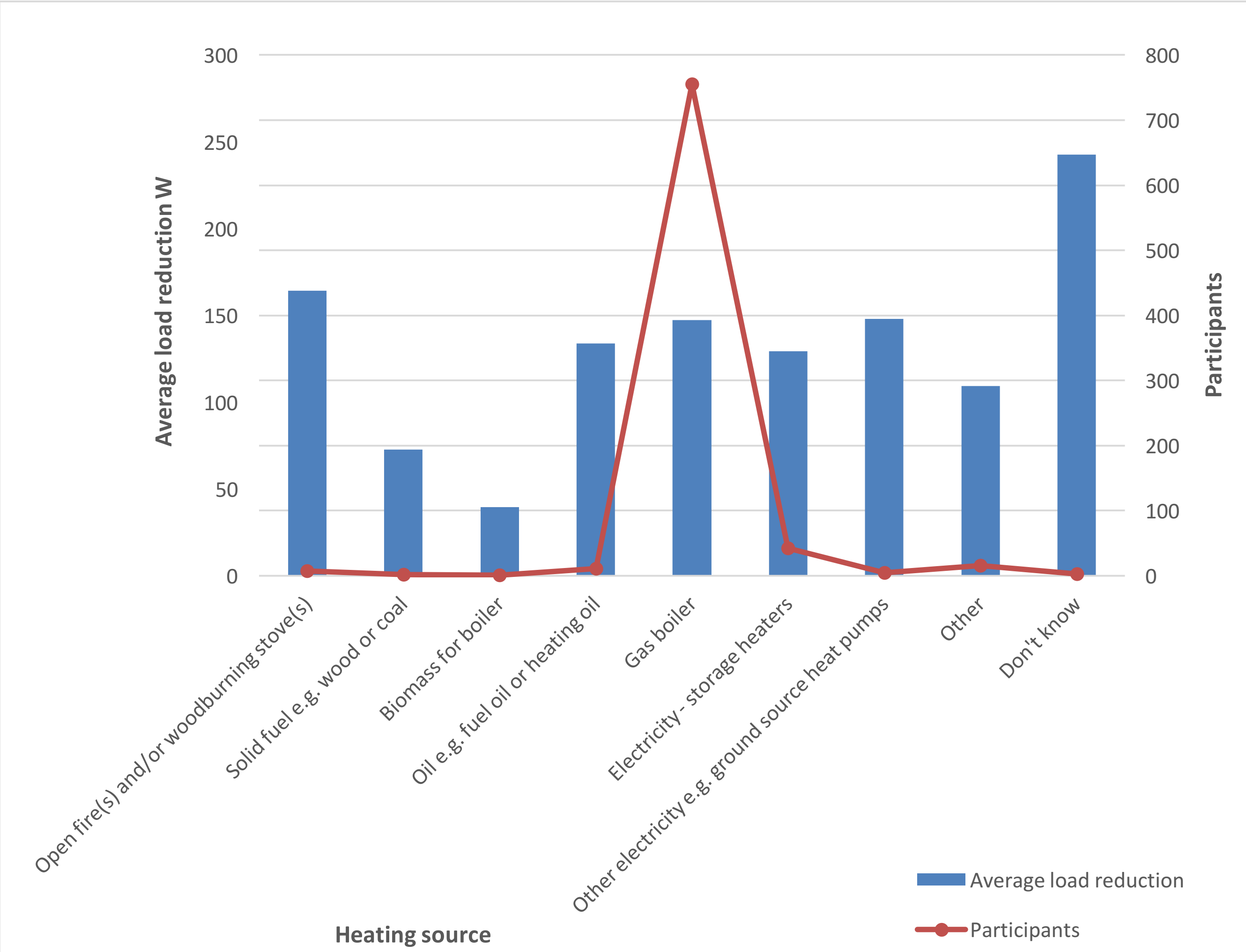
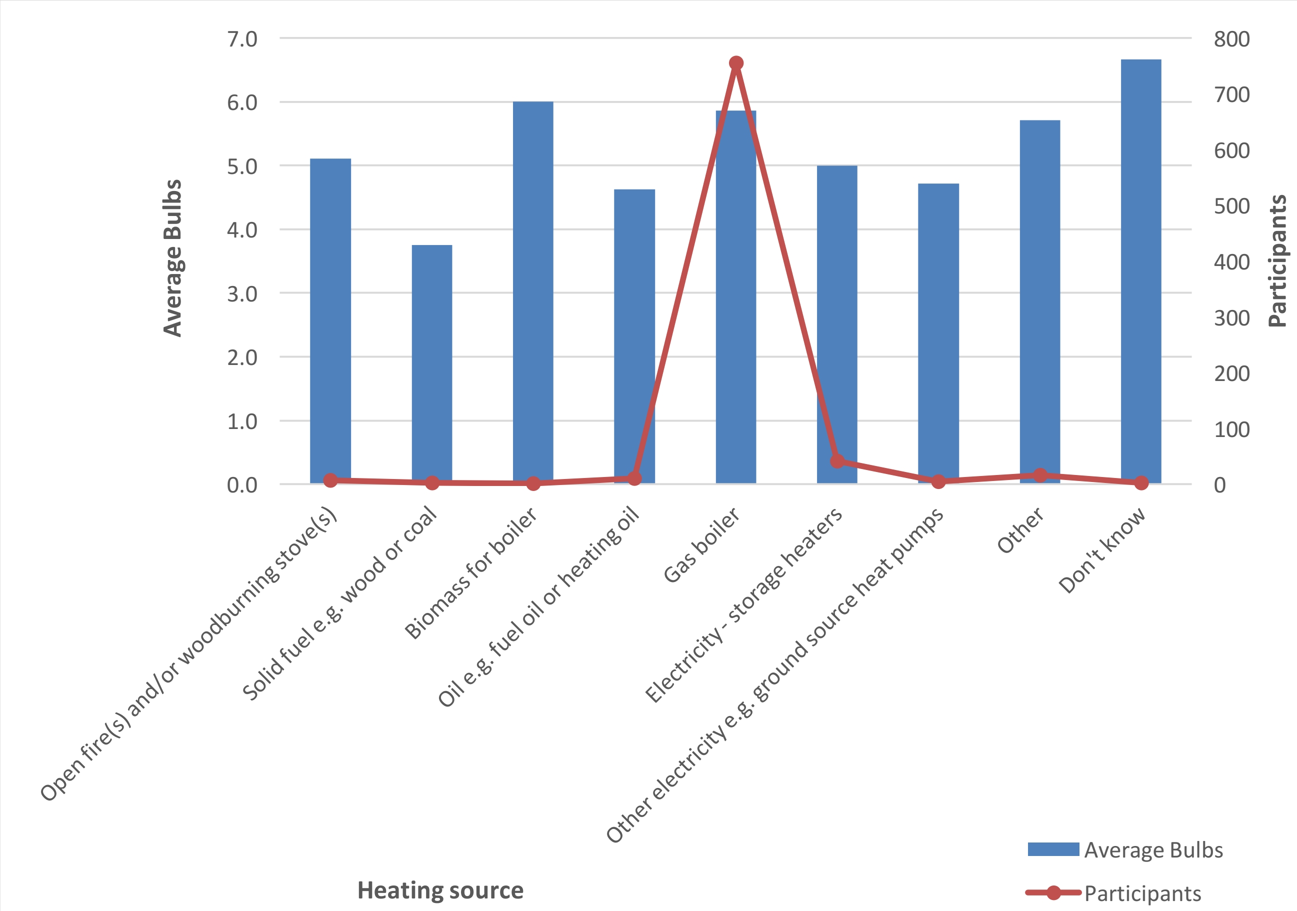


Figure 15: Number of bulbs by heating source



As shown below in Figure 16, the highest potential load reduction is in detached houses. These also have the greatest number of bulbs replaced per house, as seen in Figure 17.

Figure 16: Load reduction by property type

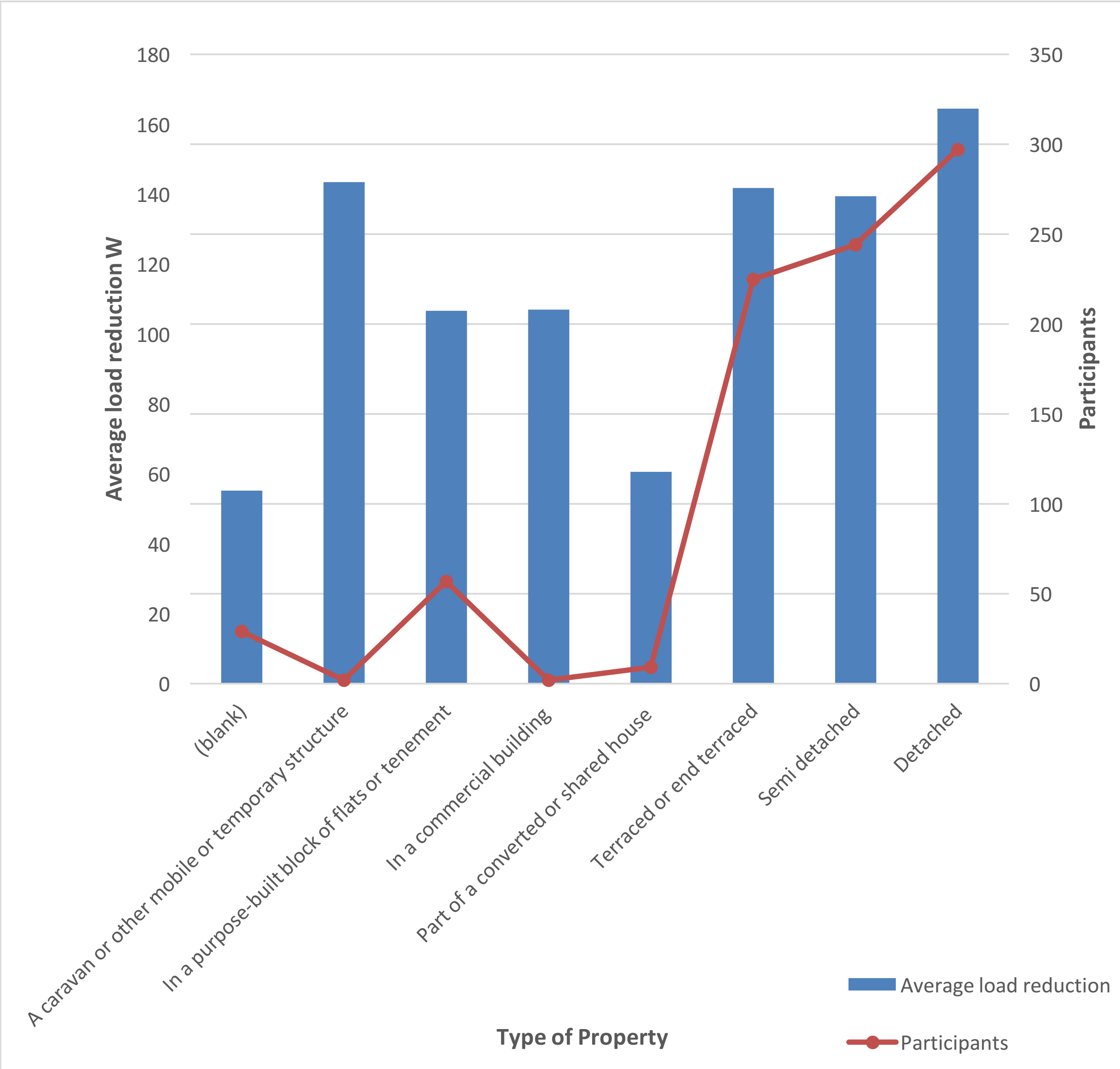


Figure 17: Number of bulbs by property type

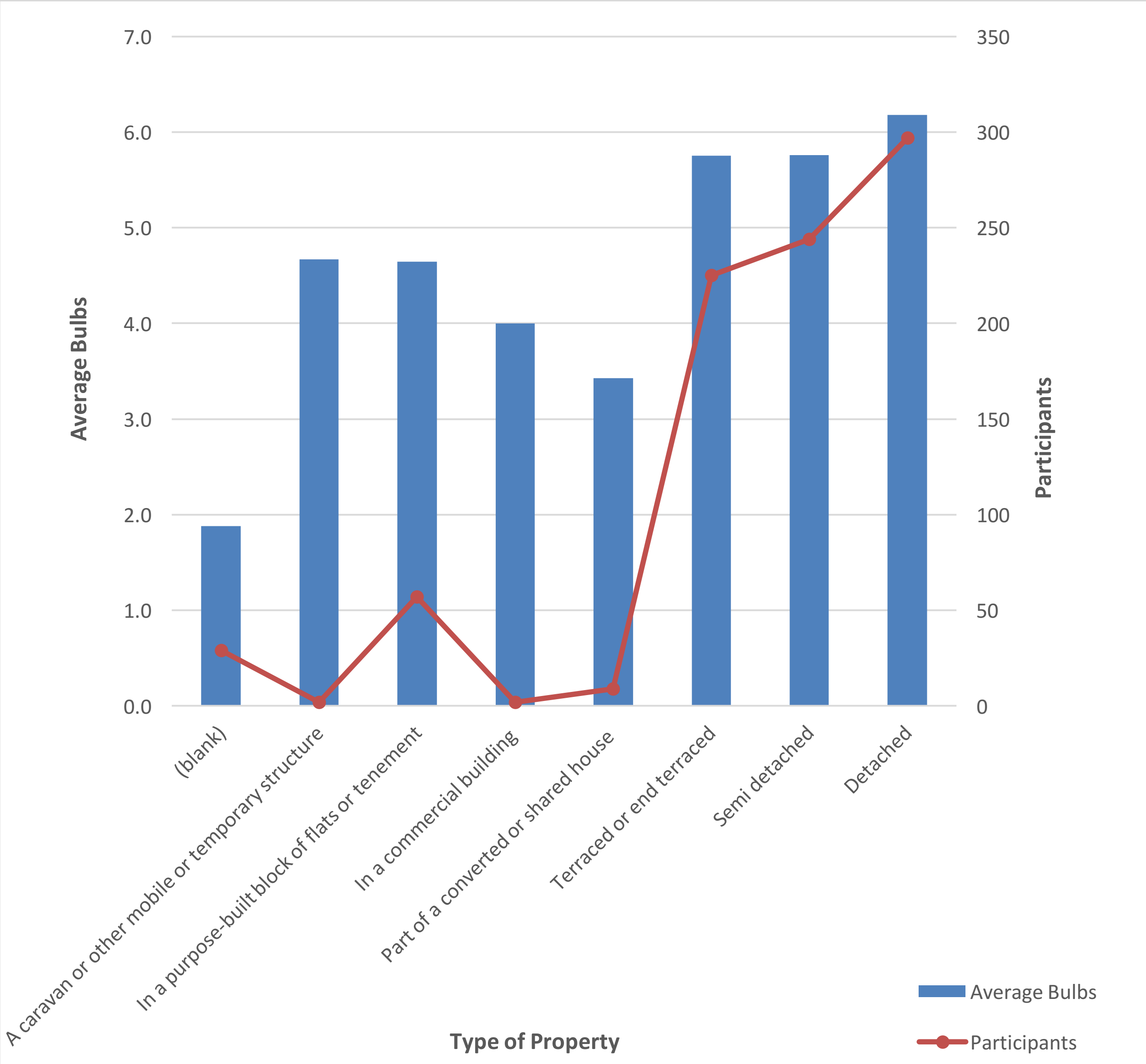


Figure 18 and Figure 19 below show load reduction and bulbs (respectively) per household by education level. In households where the respondent had completed higher education, the reduction is slightly lower despite a similar number of bulbs installed, meaning these households tend to have more efficient bulbs already installed.

Figure 18: Load reduction by education level

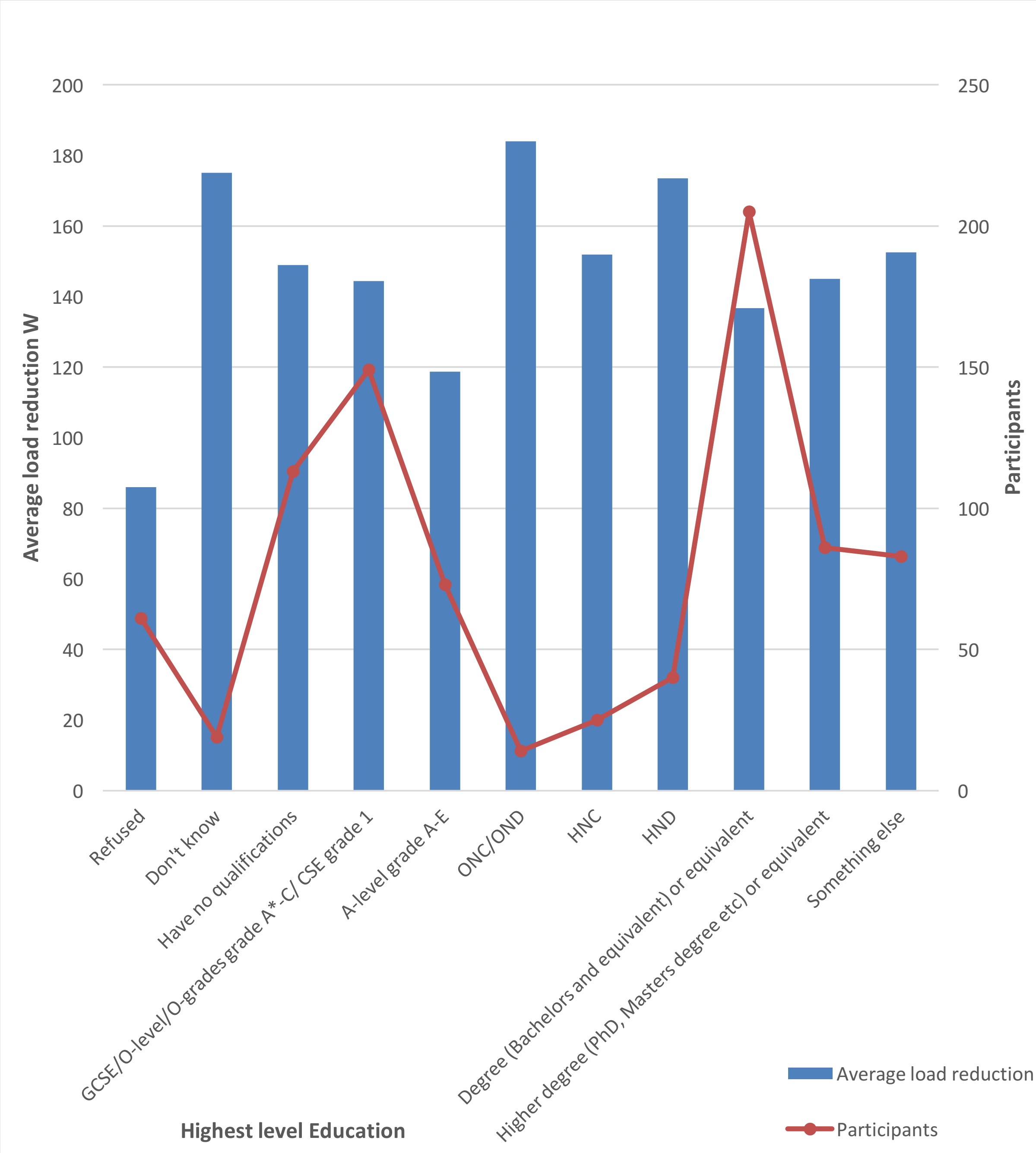
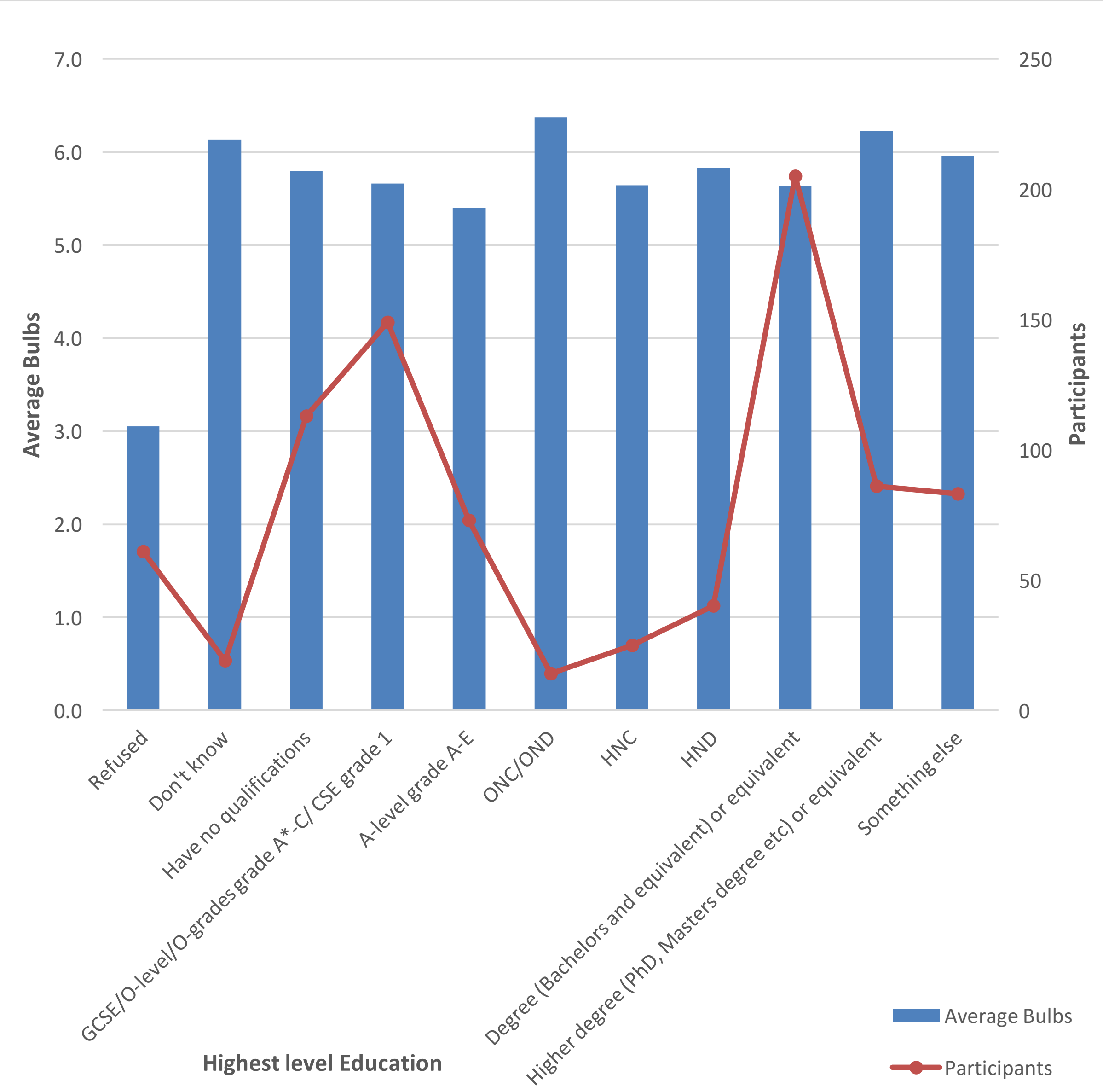


Figure 19: Number of bulbs by education level



As seen below in Figure 20, household income levels do not have significant impacts on load reduction. The exception is the £80k-£100k group, which has higher reductions and numbers of installed bulbs. However, given the small number of households in this category, these findings may not be representative of the population. The number of bulbs installed increases slightly as income increases, as seen in Figure 21, and likely in relation to house size increases.

Figure 20: Load reduction by household income

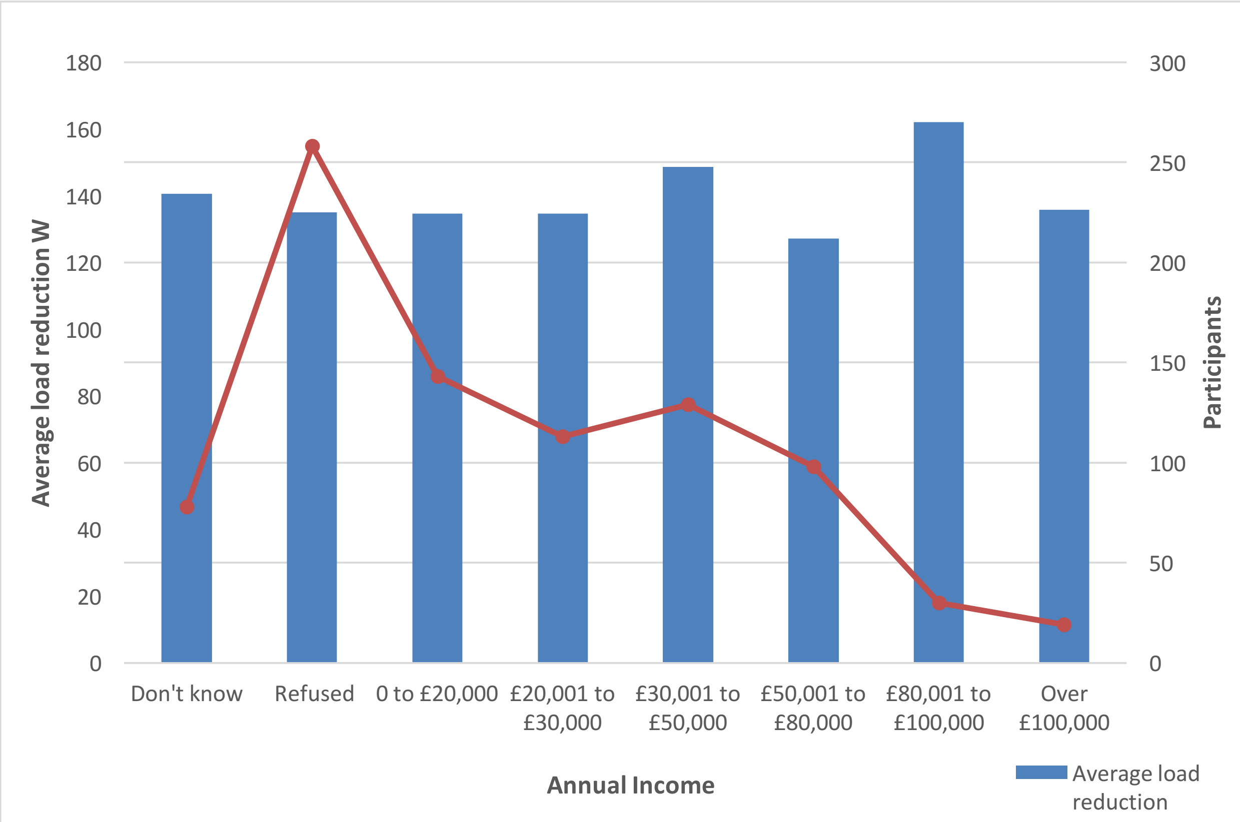
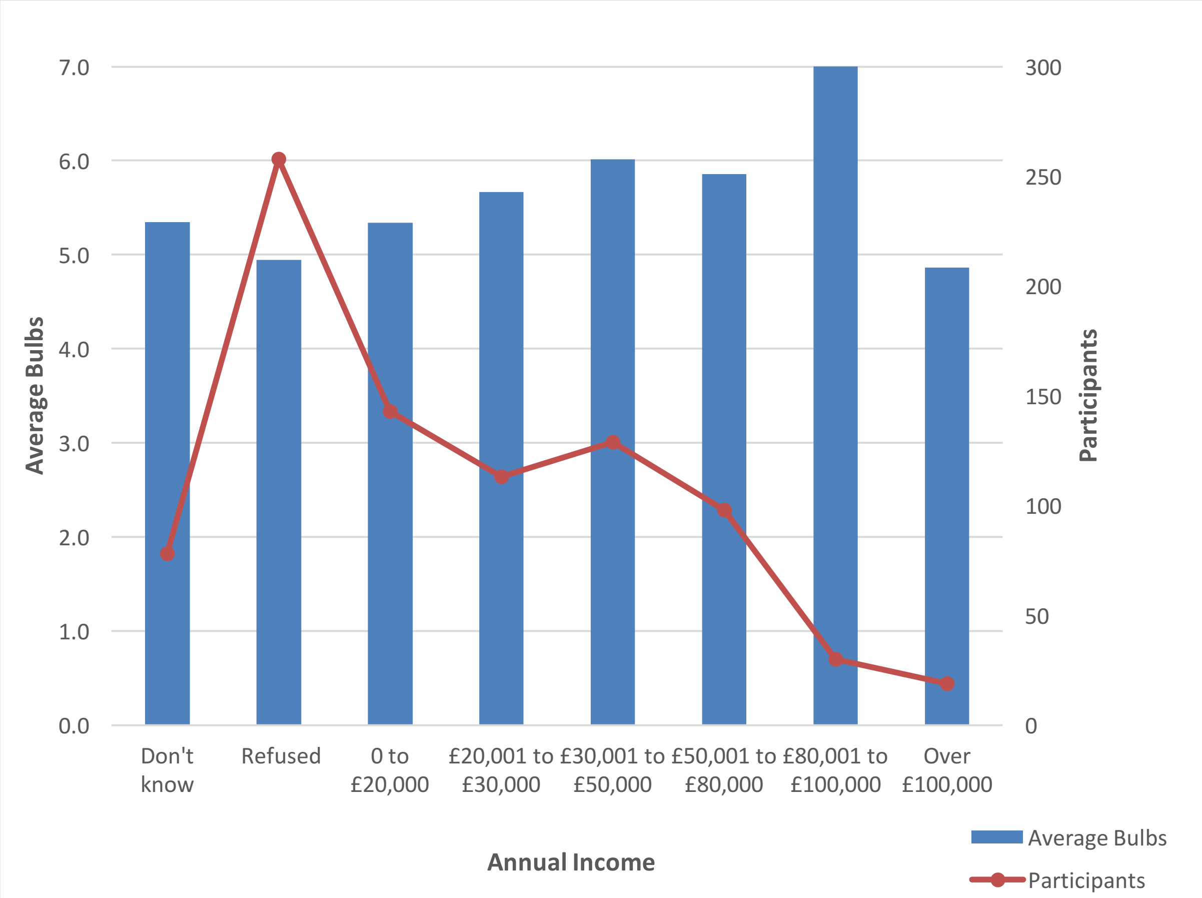


Figure 21: Number of bulbs by household income



2.6 LED laboratory testing results

	W rating	Amps rating	W measured	VA measured	Current measured (Plug Meter)	Current measured meter	PF measured	Volts
LED GLS Frosted Dimmable Warm White (60 W equivalent) B22	8.5	45 mA	8/9	15	0.06	38.7 mA (warm) 41.4 mA (cold)	0.5 cold, 0.58 warm	238 - 239.4
	8.5	45 mA	8/9	14/15	0.06	42 (cold)	0.61 (clod)	240.7
	8.5	45 mA	8/9	14/15	0.06	42.5	0.61	240.3
	8.5	45 mA	8/9	14/15	0.06	42.5	0.61	240.5
LED Candle Frosted Lamp Non dimmable Warm White B22	5.4	47 mA	7 (cold) 6 warm	15	0.06	49 (Cold), 46 (Warm)	0.47 (cold) 0.45 (warm)	240
	5.4	47 mA	7	15	0.06	48.1	0.47	240.5
	5.4	47 mA	7	15	0.06	48.5	0.47	241.1
	5.4	47 mA	7	15	0.06	48.1	0.47	241.3
LED GLS Frosted No-Dimmable	9.5	73 mA	10	21	0.09	78 mA (cold) 76.2 (Warm)	0.48 (cold) 0.47(warm)	242 (cold) 241.1 (worm)

	W rating	Amps rating	W measured	VA measured	Current measured (Plug Meter)	Current measured meter	PF measured	Volts
Warm White E27	9.5	73 mA	10	21	0.09	78.4	0.49	240.7
	9.5	73 mA	10	21	0.09	77.7	0.49	240.6
	9.5	73 mA	10	21	0.09	78	0.49	240.9
LED Candle Frosted Lamp Non dimmable Warm White E14	5.4	47 mA	6	15	0.06	47.9	0.46	240.7
	5.4	47 mA	6	15	0.06	47.9	0.46	240.6
	5.4	47 mA	6	15	0.06	47.9	0.46	240.6

2.7 Business Case

Attached below is a full business case for LED deployment.

Location Name	Cust Number	LED Average reduction	Transformer rating (KVA)	Tranformer Upgrade	Cable Replacement	replacement cost	Cost per KVA	PSR customers	PSR Gap	Fuel Poor
A	144	6.768	500	800	Yes	47500	158.3333333	17	9	16
B	374	17.578	500	800	Yes	45000	150	39	22	63
C	473	22.231	800	1000	Yes	225000	1125	32	44	15

Quantifiable benefits

Location Name	NPV of 6 year deferr	Stakeholder Engagemer	Total Value
A	£8,061.22	£85.05	£8,146.27
B	£7,147.91	£254.45	£7,402.36
C	£37,207.93	£156.60	£37,364.53

Category	**Quant Value**
EE to fuel Poor	£2.20
Update Vuln details	£1.20
PSR info to Vuln	£1.15
New PSR cust.	£1.10

Business Case

Location Name	Engagement Costs	With Water utility (/2)	With Gas Utility (/3)	CBA DNO alone	CBA (NPV-joint utility initative)	CBA joint utility and social benefits
A	£17,280.00	£8,640.00	£5,760.00	-£9,133.73	£2,386.27	£16,214.91
B	£44,880.00	£22,440.00	£14,960.00	-£37,477.64	-£6,813.73	£29,102.34
C	£56,760.00	£28,380.00	£18,920.00	-£19,395.47	£18,444.53	£63,867.79

Social Benefits

Location Name	No. of customers	No of bulbs per home	Carbon benefits	Customer benefits
A	144	7	£143	£13,685.76
B	374	7	£371	£35,544.96
C	473	7	£469	£44,953.92

Social benefits

kWh over 6 years	540
kg of CO2 per kWh	0.38146
kg per ton	907.185
price per ton of CO2	£4.37
Cost per kW of electricity	£0.18

Customer Engagement

Field Resource	£70
LED bulb costs	£15
Total Cost	£85

NPV	4%															
Reinforce																
	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030			
A	47,500	0	0	0	0	0	0	0	0	0	0	0	0	NPV	£45,673.08	
B	45,000	0	0	0	0	0	0	0	0	0	0	0	0	NPV	£43,269.23	
C	225,000	0	0	0	0	0	0	0	0	0	0	0	0	NPV	£216,346.15	
Defer																
	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030			**Value of NPV**
A	0	0	0	0	0	47591	0	0	0	0	0	0	0	NPV	£37,611.86	£8,061.22
B	0	0	0	0	0	45705	0	0	0	0	0	0	0	NPV	£36,121.33	£7,147.91
C	0	0	0	0	0	226667	0	0	0	0	0	0	0	NPV	£179,138.22	£37,207.93

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