Customer-Led Network Revolution

Insight Report: Domestic Time of Use Tariff

A comparison of the time of use tariff trial to the baseline domestic profiles

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Contents

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1 Executive Summary

Peak electricity demand poses a particular challenge both to network operators and to energy suppliers. A reduction in peak demand would allow existing networks to accommodate load growth with lower investment, and also reduce the cost of electricity generation during peak periods. To explore the potential for peak reduction, the Customer Led Network Revolution project has trialled a Time of Use (ToU) tariff scheme. By increasing electricity prices during the weekday peak period (4pm-8pm) for throughout the year and reducing prices in off-peak periods, the tariff incentivises a shift in consumption out of the peak period. A static ToU tariff was used – that is, the tariff remained constant and did not change dynamically depending on expected network loading.

Based on smart meter data and survey responses, Test Cell (TC) 9a investigated the electricity use patterns of 574 domestic users on a ToU tariff between October 2012 and September 2013 and compared them to those of the control group (Test Cell 1a). The impact of demographic profile on customers' responses to the ToU tariff was also considered.

On average, when compared to consumers in the control cell TC1a, customers on the ToU tariff had lower consumption during the peak period on weekdays, and higher consumption at other times – indicating that the tariff achieved the intended behaviour change. There was a small net reduction (0.8%) in annual consumption, although this was not enough to be statistically significant. In particular, the trial showed:

- **Lower electricity consumption during the peak periods** (between 1.5% and 11.3% less than TC1a). This is in line with our qualitative research where customers claim changing time of use of certain appliances.
- **Lower average peak power demands**[1] during the peak period (between 3.2% and 12.5% lower than TC1a when averaged throughout the year and across all customers).
- On average, customers showed a lower maximum half-hourly peak demand (between 2.1% - 10.3% lower than TC1a) during the peak period.
- However at the time of greatest system peak demand – specifically a single half-hour in the year[2] – **there was no (statistically significant) difference in the mean peak demand observed** between TC9a and TC1a.

A potential issue with ToU tariffs is that consumption could be shifted to periods around the peak times, and thus generate new peaks in demand. In this trial, the ToU tariff was not observed to generate new peaks in demand in the times adjacent to the peak period. Rather, a displacement of some load to the weekend was observed. Additionally, the response to the tariff (as measured by the difference in mean peaks between the two test cells) was greater in the winter months and weekdays, which corresponds to periods of greater demand.

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[1] This is calculated by taking the maximum half-hourly demand in the 4-8pm period for each day for each customer, and averaging across the year and across all customers in the group. The peaks therefore do not necessarily occur at the same time, and therefore the overall effect on the aggregate (system) peak is likely to be lower for any given half-hour.

[2] This occurred between 17:30 to 18:00 on Friday 18th January 2013

There was some variation in the uptake of the ToU tariff across TC9a:

- 60% of participants made savings under the ToU tariff. This may include customers who were able to actively adapt electricity use as well as others whose pre-existing electricity use patterns were already less concentrated around the evening peak and so automatically benefited from the tariff.
- Some 40% of participants ended up with electricity bills higher than they would have been under a flat-rate, suggesting that their change in behaviour was insufficient to generate savings under the ToU tariff. For this group, the median extra cost – relative to a flat-rate tariff – was just £18.40 per annum, and these customers had the difference refunded in line with the terms of the trial.
- Testing of the marginal distributional response to the ToU tariff was limited to housing tenure (renter/home owner) and the presence of dependents in the household. It was found that home owners and households without dependents were more likely to respond to the ToU tariff compared to renters and those with dependents.

An on-line survey of (105) participants was undertaken to find out about their experience of the ToU tariff. Based on the *survey responses*, laundry was identified by most respondents as an activity that had been displaced to a different time. This was followed by washing dishes and cooking. There is some evidence from interview responses indicating that laundry was displaced to weekends, in line with the incentive of the ToU tariff.

Through the surveys, most respondents reported their belief that being on the ToU tariff had caused them to reduce their annual energy consumption. However as mentioned above, the comparison made between TC9a and TC1a, did not identify a statistically significant difference in annual electricity consumption between the two trial populations.

The following points may be noted when considering the further deployment of ToU tariffs:

- At the end of the trial a "shadow bill" was calculated based on a flat-rate tariff. If this was lower than their bill under the ToU tariff, customers were reimbursed the difference. From the beginning of the trial, customers were made aware of this "safety net" which meant there was no risk of higher bills. An enhanced level of response might be expected in a trial without such a safety net.
- The peak vs off-peak price differential used in this trial is not as large as has been used in some other trials. Evidence from other trials[3] suggests the correlation between price differential and consumer response is weak, and that price signals alone cannot fully explain the consumer response.
- Other than the shadow billing and a trial report sent in December 2013, customers were not given any formal feedback on their performance under the ToU trial during this period. The trial therefore only tested the effectiveness of the price signal with quite limited feedback. It is expected that providing customers with more detailed and frequent feedback on their consumption may reinforce the engagement and thus success with ToU tariffs.

[3] "Demand Side Response in the Domestic Sector"

- As implemented, this ToU tariff rewarded a reduction in consumption during the peak period throughout the year and was effective in doing so. However, there was no evidence of a reduced demand at the time of greatest system peak demand (as defined by the test cell 1a baseline data). Alternative tariff implementations such as dynamic ToU tariffs can provide a stronger price signal when the load on the network is greatest. These (and other ways of engaging effectively with customers) could complement the static ToU tariff during these critical times.
- Further research would be usefully targeted at understanding: why some customers engaged more with the tariff than others; which customer types “gained” or “lost” because the ToU tariff rewarded their underlying consumption, the response to greater tariff differentials, and the impact of providing feedback to customers on their consumption.

2 Introduction

2.1 Test Cell overview

During this study we aim to compare Time of Use (ToU) tariff customers in test cell (TC) 9a against baseline customers in TC1a. Interest lies in whether there has been a change in the peak power demand in the 4-8pm period (peak period) as well as investigating the peak power demand in the periods 2-4pm and 8-10pm (shoulder periods). By investigating the shoulder periods we hope to establish whether the tariff has shifted the peak, and as a consequence created a new peak (which could be of a higher value than the original peak) either side of the perceived peak. We look to see if there are any differences in the annual absolute electricity consumption of a TC9a and TC1a customer, as well as investigating the electricity consumed during the peak (R1) and off-peak (R3) time periods (see Table 1).

We are interested in the extent to which a TC9a customer would modify their behaviour, and therefore their demand profile, to exploit lower electrical energy costs at off-peak times. We aim to compare the behaviour of a TC9a customer against a TC1a customer on a flat rate tariff. As such a TC1a customer has no incentive to alter their behaviour to exploit lower costs (or indeed avoid the higher costs); the assumption is that a TC1a customer forms a baseline against which the effect of interventions can be tested.

TC9a customers were placed on a 3-rate ToU tariff as detailed in Table 1 and as designed within [1]. The tariff consisted of 3 registers R1, R2 and R3 referring to peak, day and off-peak respectively, each priced in relation to the British Gas standard tariff in the market at that time. The peak period was priced at 99% above the standard rate (1.99) whilst day was priced at 4% below the standard rate (0.96) and off-peak at 31% below the standard rate (0.69).

A TC9a customer is therefore encouraged to use less electricity in the R1 period and more in the R3 period to make the most savings financially; that is to shift electricity use from the peak period into the evenings or weekends. Shifting into the R2 period would not show as much of a saving. Our assumptions about how a customer understands and perceives this tariff are discussed in more detail in Section 3.

Note that there was a "safety net" in place whereby customers were protected from an increase in electricity bills due to switching to the ToU tariff: households whose bills were higher than they would have been under the flat-rate tariff had the difference reimbursed. Section 4.9 looks into this in more detail, and the customer correspondence and trial terms are appended to this report.

<table>
<tr><th colspan="2">Tariff Band</th><th>Times</th><th>Price in Relation to the Standard Rate (1.00)</th></tr>
<tr><td rowspan="3">Weekday</td><td>Day (R2)</td><td>07:00 – 16:00 (Mon – Fri)</td><td>0.96</td></tr>
<tr><td>Peak (R1)</td><td>16:00 – 20:00 (Mon – Fri)</td><td>1.99</td></tr>
<tr><td>Off Peak (R3)</td><td>Mon: 00:00 – 07:00
Mon – Thurs : 20:00 – 07:00
Fri: 20:00 – 00:00</td><td>0.69</td></tr>
<tr><td colspan="2">Weekend (R3)</td><td>All-day</td><td>0.69</td></tr>
</table>

Table 1: Tariff structure for a TC9a customer

The Customer-Led Network Revolution (CLNR) project included a significant data collection component on customer profiles and electrical energy consumption. The data collected consists of two parts: a demographic survey of the customers (e.g. household size, income, geographic region, etc.) and half hourly smart meter readings. Both forms of data are available for TC1a and TC9a. This analysis therefore aims to combine both the survey data and meter readings to obtain a complete and unique representation of TC1a and TC9a in relation to each other. A set of surveys and interviews with customers were also used to provide additional qualitative insight, although low participation rates mean the results of these cannot be proven to be representative of the whole test cell.

Smart meters within TC1a and TC9a customers' properties recorded electrical energy consumption to a 30 minute resolution. The trial recorded meter readings from 574 customers in TC9a and 8415 customers in TC1a over the period 1st October 2012 – 30th September 2013. Measured data consists of total power in kWh taken at 30-minute intervals plus daily cumulative kWh totals. Average interval power can be calculated (normally presented in kW) from these data. Occasionally, daily cumulative meter readings were missing, in these cases a linear interpolation approach was used across the missing days.

The populations of TC1a and TC9a can be regarded as a whole, see Section 3 for assumptions made regarding this approach, or alternatively can be broken down by demographics; these are as defined in [2], and by mosaic categories as defined by [3]. However the demographics as defined in [2] are not coherent between TC1a and TC9a and therefore direct comparisons cannot be made across all demographics. The only comparable Durham Energy Institute (DEI) demographics are housing tenure and those with/without dependencies. This issue is discussed in more detail in Section 4.1.

The rest of this document is arranged as follows. In Section 3 we outline our assumptions regarding TC1a and TC9a, both at a data and customer level, plus limitations to this study. We also acknowledge previous work regarding the TOU tariff, whilst also providing a list of common definitions. Section 4 contains the main analysis of TC9a in relation to TC1a, beginning with a sample comparison before considering peak power demand and total electrical energy use; we finish by considering the behaviour of individual demographics. Conclusions are drawn in Section 5 before further work and research areas are suggested. References and an appendix containing p-values and additional figures conclude this document.

2.2 Test Cell recruitment

The recruitment of customers for TC9a was especially successful and did not experience any particular difficulties. Customers were recruited from a population of British Gas' existing Foundation stage smart meter customers as well as customers who met the criteria for a smart meter installation at the time. Recruitment actually exceeded the original recruitment target. This was despite this being a test cell where customers were required to "opt in".[4]

As with other test cells, in order to incentivise participation, customers were offered a subsidy of £50-worth of vouchers on joining the trial and a further £50-worth of vouchers at the end of the trial.[5] Customers were also subsequently offered an additional £50 to extend their trial beyond the original end date. The recruitment was carried out by British Gas and consisted of a direct mail letter campaign, followed by; an outbound telephone campaign to explain the trial and key facts (of the terms & conditions). Thereafter a welcome pack and terms and conditions were issued, followed by a seven day 'cool off period' and finally a smart meter installation (where required) and tariff activation. The tariff was activated either, 28 days after the smart meter installation or in less than 24 hours for those customers already with an existing smart meter.

The recruitment campaign was particularly successful with a high 8% response to the direct mail campaign as well as over 800 customers consenting to the trial vs. the target of 600, see table 2.

Opt in Reasons	Customers	%
Cost Reduction	99	12
Cost Reduction – Lifestyle	342	41
Cost Reduction – Behaviour Change	204	25
Eco Friendly	54	7
Technology Driven	38	5
Vouchers Incentive	8	1
Wants more information	0	0
None Given	83	10
Total	**828**	

Table 2: TC9a ToU Recruitment reasons given by BG customers

Source: British Gas

During recruitment, it became clear that there were customers who had an interest in the ToU tariff but who had not yet had a smart meter installed. The prospect of a smart meter proved to be an additional and strong incentive for recruitment [4]. For those that didn't previously have a smart

[4] When asked by British Gas' call centre agents their reason for their interest in the tariff, the overwhelming reason for sign up was related to cost reduction **rather than the voucher incentive.**

[5] Staff involved in the recruitment reported that customers showed interest in joining the ToU tariff as they thought they could reduce their bills, even before the voucher incentive was explained.

meter but who received one as part of the tariff, recruitment rates were 11% higher, strongly suggesting that smart meters installation was seen as an additional incentive by customers to sign up to the trial tariff.

British Gas ended up offering the tariff, branded as the ’Off-Peak Saver 3-Rate tariff’ to approximately half of their addressable population who already had a smart meter and the other half was to those who were eligible for smart meters at the time.

Overall, the recruitment campaign was not too dissimilar from British Gas’ ‘Business as Usual’ sales and marketing approach, with the key differences being the dual branded communications material with both British Gas, CLNR branding and Project partners featuring, as well as the trial joining / completion vouchers being used as an incentive.

As part of the Terms & Conditions of the trial, British Gas made a commitment to customers that if they paid more on the trial tariff than they would have paid on British Gas’ Standard tariff over the period, then British Gas would refund the difference via a credit to their account. This was calculated on a customer by customer basis at the end of the trial by British Gas via a ‘shadow billing’ exercise.

3 Assumptions, Limitations, Previous Work and Definitions

We begin by outlining assumptions made regarding the meter data for TC1a and TC9a. Within TC9a a small number of customers were discarded from the study as their daily (computed) meter readings reported abnormally high variances, suggesting that there might have been problems with the meter reading technology. Although these customers are not included in the 574 customers mentioned above. For both TC1a and TC9a, if a customer had recorded data of all zeros for a particular day (or particular time period of that day) they were assumed to have no peak for that day (or period of that day) and a "NaN" was recorded. Theses NaN's are disregarded when calculating respective mean/max peaks.

TC1a is assumed to be representative of the population as a whole, see 'Baseline domestic profiles report TC1a' for a discussion of TC1a in relation to the population. TC9a was designed to match TC1a and the initial assumption is that both test cells are representative of each other. A more detailed discussion of this assumption is given in Section 4.1, although it should be noted that it is difficult to quantify this assumption either way due to the structure of the data. Further to this we have the mosaic structure of the test cells, using MOSAIC 2009 categories as defined by [3], allowing us to compare the geo-demographic composition of both test cells with one another and with UK national averages. The launch of MOSAIC 2014 [5] which claims to make marked improvements to classification accuracy reminds us that we must anticipate some degree of misclassification in the data used here which was classified prior to the release of MOSAIC 2014. We also assume that the level of misclassification is the same across both test cells.

Additional assumptions are made for TC9a customers regarding the ToU tariff. Firstly this report will test the assumption that a customer would want to move electricity use into the evenings and weekends to make use of the cheapest price bracket. It was also of interest as to whether any reduction in the 4-8pm peak resulted in the creation of a new peak at another time.

Following this logic, if a new peak had been created for TC9a it is more likely to be in the evening 8-10pm shoulder period. This hypothesis will be examined in more detail in Section 4.3.

From figures released by British Gas ([6], Appendix 8.7) refunds were made to 40% of customers on the ToU tariff as they incurred higher annual electricity costs by switching to the tariff rather than staying on the flat rate. This indicates that a number of customers made insufficient changes to their electricity use to save financially from the tariff.

We have evidence from the surveys and face to face interviews to suggest that this is unlikely to be the result of customers not understanding the tariff structure. For example, in the survey, participants were asked how easy it was to understand the new tariff. The responses indicate that the tariff was, for most respondents, quite easy (58%) or very easy (29%) to understand. Only one respondent found it very difficult (See '*Domestic Survey report 2014'*. Quotes such as these illustrate that the tariff was widely understood (also see 'Social Science report April 2014):

> *The tumble dryer will be used at night-time … Even if I have to stop up later or something. I would rather use it at night-time than on the peak [tariff] … (GP0025)*
> *Things like the dryer and the washing we'll put on during the day, then if at 4 o'clock if we haven't finished drying then we stop then and pile it up on usually just put it on the back of the chair and wait 'til 8'oclock and then we'll finish it then because the dryer's expensive to run… (MJRTL14)*

> *We try and do washing on a weekend or after 8. … The dishwasher doesn't go on 'til after 8 now either … before we got the [IHD/tariff] we would just put it on when it needed to go on … Couple (GP1902)*

In order to financially protect customers for the duration of the trial, customers were made aware that they could not financially lose out on the tariff, when compared to the flat rate tariff. This trial protection could have biased the trial results, so that customers need not fully engage with the tariff as there was no penalty for failure; however there is little evidence for or against this.

This work does not investigate the electricity usage of customers before they joined the trial, comparing those customers' electricity usage to that of the control group in TC1a.

At several points during the analysis, when comparing the means of distributions broken down by months and then further by weekday or weekend, multiple t-tests occur in order to check whether a result is statistically significant. This means that in any of these situations we will have 12 individual comparisons to perform. The repeated nature of multiple comparisons increases the chance of a type 1 error (when the null hypothesis is correct but is rejected, giving a false positive result). Let the 12 comparisons of any scenario be one experiment, to preserve an overall experiment-wide significance level of α^* we correct our significance level. If $\alpha^* = 0.05$ we have,

$$1 - (1 - \alpha)^n = 0.05.$$

This gives a significant value of $\alpha = 0.0043$ for each individual t-test where multiple comparisons are carried out. For small α, the correction is approximately $\frac{\alpha}{n}$, where n is the number of individual comparisons, this is known as the Bonferroni correction.

During the analysis in Section 4, values are given to 3 decimal places, this means that at certain points a p-value of 0.000 may be observed. In these instances the p-value may not be truly zero, but only appears so as a consequence of only taking figures to 3 decimal places.

3.1 Previous Analysis Regarding TC9a

During the course of the CLNR project a number of prior interim studies have been undertaken regarding a TC9a customer's behaviour, see [7], [8] and [9]. The work undertaken in these prior analyses contains statistical limitations and report single point estimates.

This report takes a different approach which focuses on proving the statistical significance of the findings; however we consider that the overall themes of the prior studies are broadly in concordance with our findings. A summary of previous reports can be found in table 3. Reports [7] and [8] acknowledge that further analysis (or significance testing) is needed to quantify their findings.

All 3 reports base their findings primarily on observations rather than statistical tests; [8] compares mean profiles, [9] compares profiles but does not indicate how these were constructed and [7] uses average half-hourly consumption. Report [8] found that the tariff reduced the early evening peak when comparing TC9a to TC1a, whilst also witnessing a reduction in the peak for customers pre and post tariff. Report [9] discusses how customers have reduced their weekday and weekend peak consumption (along with overall consumption) compared to TC1a, however the report does not detail how the peaks were calculated, or in which period the peaks occurred. The analysis in [7] suggests that the average half-hourly consumption reduced in the peak period.

Report	Date Range	Number of Customers	Tests Performed	General Findings
Initial Load Profiles from CLNR Intervention Trials [8]	September 2012	625	Observational (Comparing TC9a to TC1a)	Tariffs reduce the early evening peak, at least in the summer, although there is then significant payback as demand increases sharply at the end of the peak rate period.
	01/05/2011 – 31/10/2011 & 01/05/2012 – 31/10/2012	87 (with 34 recording null readings)	Observational (Comparing TC9a pre and post tariff)	Demand was similar during the day but a reduction of around 0.1 kW was witnessed in the evening peak. In terms of actual load reduction during the peak period a reduction of 0.2 kW was seen in the post intervention trials.
CLNR Customer Trials A guide to the load and generation profile datasets[9]	01/01/2013 – 31/12/2013	559	Assumed to be observational (Comparing TC9a to TC1a)	Estimate that customers have reduced their weekday peak consumption on average by 10.4% and overall consumption by 3.3%. Customers have also reduced their weekend peak consumption on average by 5.8% and overall consumption by 1.4%
Initial Time of Use Tariff Trial Analysis [7]	April 2011 – November 2011 & April 2012 – November 2012	112	Assumed to be observational (Comparing TC9a pre and post tariff)	Preliminary analysis indicated that the average half-hourly consumption reduced by 14% during the peak period, suggesting behavioural change in consumption.

Table 3: Summary of previous reports regarding TC9a

3.2 Definitions

Table 4 below contains a list of common definitions which feature throughout this analysis.

Term	Description	Mathematical formulation
1. Peak day	The day on which the maximum of the mean demand occurred during a specific time period	$\bar{D}_{max,t} = max\left(\frac{1}{N}\sum_{i=1}^{N} D_{i,t}\right)$
2. Energy consumption	Total electrical energy consumed for a given customer over a specific time period ranging from t_0 to T	$E_i = E_{i,T} - E_{i,t_0}$ or $E_i = \sum_{t \in S} E_{i,t}$ where S is the time period considered
3. Peak power demand	Peak power for customer i in the time period given by S	$\hat{P}_i = \max_{j \in S}(P_{i,j})$ where $P_{i,j}$ are the individual power measurements for customer i
4. Mean peak	The average peak power demand for customer i in the time period S over the number of days M	$\bar{P}_i = \frac{1}{M}\sum_{k=1}^{M}\sum_{j \in S} \max(P_{i,j,k})$
5. Max peak	The maximum peak power demand for customer i in the time period S over the number of days M	$\tilde{P}_i = \max_{j \in S, k \in M}(P_{i,j,k})$
6. Mean mean peak	The mean of the average peak power demand for customer i in the time period S over the number of days M	$\bar{\bar{P}}_i = \frac{1}{N}\bar{P}_i$
7. Mean maximum peak	The mean of the maximum peak power demand for customer i in the time period S over the number of days M	$\bar{\tilde{P}}_i = \frac{1}{N}\tilde{P}_i$
8. Peak power	Peak power is the average power in the half hour of maximum consumption.	

Table 4: Common definitions featuring within the analysis

4 Analysis of Test Cell 9a in Relation to TC1a

4.1 Sample Comparison

We begin this analysis by comparing the compositions of TC1a and TC9a. Due to the way in which the design of each test cell was defined we find that TC1a is subset into 144 categories as detailed in the Test cell protocol document produced by Durham University at the start of the project[6] whilst TC9a is subset into 16 categories. Unfortunately we are unable to reduce the 144 categories of TC1a to match the 16 of TC9a. This is due to a variable in the make-up of TC1a (rurality) which does not feature at all in TC9a, plus the fact that two variables (household thermal efficiency and income) are rated as high, medium or low in TC1a but only as either high or low in TC9a. This means that we can only directly compare the proportions of renters/non-renters and those with/without household members under 5 or over 65 in both test cells.

Performing a Chi-Square Test for Independence (which tests if the categories are independent of each other) we find that the proportion of renters is the same in both test cells (p-value = 0.109) as is the proportion of those with household members under 5 or over 65 (p-value =0.368). Subsequently the proportions of non-renters and those without household members under 5 or over 65 are also the same in both test cells. We note that the proportion of those with household members under 5 or over 65 who are also renters or non-renters are similar in both test cells; as are the proportions of those without household members under 5 or over 65 who are also renters or non-renters, although these cross proportions have not been statistically tested for independence.

Additionally to this we have the 15 mosaic category compositions of the two test cells, which are consistent across both test cells. The MOSAIC system is a proprietary consumer segmentation system initially developed by Prof Richard Webber (visiting Professor of Geography at Kings College University, London) in association with Experian. MOSAIC2009 is considered to be a 'sophisticated' but largely opaque segmentation system [10]that employs over 400 variables taken from public and private data sources such as the electoral register, land registry, credit scores, and Census data as well as bespoke surveys to perform clustering analyses to produce 15 consumer groups which have been associated with research participants by British Gas. These mosaic categories are as defined by [3].Table 5 compares the percentage of participants allocated to each MOSAIC2009 category in test cells 1a and 9a, and provides the UK national average for reference.

In order to test for equal proportional composition of the test cells we perform a Chi-Square Test for Independence in which observe a p-value of 0.000 meaning that the two test cells do not have equal proportions of all the mosaic categories. We find that Active Retirement, New Homemakers and Upper Floor Living are over represented in TC1a and that Suburban Mindsets and Claimant Cultures are possibly over represented in TC9a. There are further doubts cast over the proportions of Small Town Diversity, Ex-Council Community, Industrial Heritage and Terraced Melting Pot, although the differences in these proportions are less obvious and further study would be required to conclusively

[6] CLNR-L107 (2014) Test Cell Protocol

determine whether there are any differences in the proportions. In the datasets current state this means we have comparable proportions for 10 of the 15 mosaic categories.

Therefore taking into account the variables mentioned above where there are no differences in the proportions, plus the fact that there may be an issue with misclassification when calculating the mosaic categories, we proceed by comparing the two test cells as a whole. We note that there could be an over representation of Active Retirement, New Homemakers and Upper Floor Living in TC1a and an over representation of Suburban Mindsets and Claimant Cultures in TC9a. Further to this we have no comparable information on the proportions relating to income, Proxy efficiency measure and rurality. These facts must be considered when drawing conclusions throughout this analysis.

In order to construct a truly comparable sample, rurality would need to be disregarded and a method devised to convert the ratings of income and Proxy efficiency measure. This has not been included in this study.

Mosaic Category	TC1a Composition	TC9a Composition	UK National Average [10]
A Alpha Territory	2.08%	2.34%	3.00%
B Professional Rewards	9.08%	7.18%	8.00%
C Rural Solitude	2.43%	1.50%	4.00%
D Small Town Diversity	12.11%	8.85%	9.00%
E Active Retirement	4.45%	1.67%	4.00%
F Suburban Mindsets	11.87%	16.86%	11.00%
G Careers and Kids	4.32%	3.01%	6.00%
H New Homemakers	2.20%	1.17%	5.00%
I Ex-Council Community	14.27%	17.86%	9.00%
J Claimant Cultures	6.34%	10.35%	5.00%
K Upper Floor Living	1.14%	0.17%	6.00%
L Elderly Needs	8.13%	8.51%	6.00%
M Industrial Heritage	10.09%	13.02%	8.00%
N Terraced Melting Pot	6.63%	4.17%	8.00%
O Liberal Opinions	2.87%	2.17%	9.00%
No value supplied	0.01%	0.17%	0.00%

Table 5: MOSAIC composition of TC1a, TC9a and UK National Average

4.2 Peak Power Demand in the 4-8pm Period

We begin by assessing whether there has been a change in the peak power demand in the peak period between TC1a and TC9a; specifically we are interested if there has been a reduction in TC9a. For each customer in a specific test cell we collect the daily peak power demand in the peak period, meaning we have 365 4-8pm peaks for each customer. We can then break these peaks down by months, by weekday/weekend or by a combination of the two. Using a partition of these peaks we can calculate the mean peak in the peak period for each customer for a specific timescale (or indeed the max peak); from these we form a distribution of mean peaks (or max peaks) for each test cell.

The annual mean peak is therefore, the average across the year for each customer of the highest half-hour demand each day, within the 4-8pm time period; the annual max peak is the highest half-hour recorded on any day of the year for each customer. Note that for each customer, these peaks could happen in any half-hour slot for the 4-8pm period and therefore not necessarily be coincident in time.

Let us first consider the distributions of the annual mean 4-8pm peaks and annual max 4-8pm peaks for TC1a and TC9a, illustrated in Figure 1 and Figure 2 respectively.

Figure 1 shows some differences in the distribution of the mean 4-8pm peaks for TC1a and TC9a, we see that TC9a has a greater density at lower values whilst TC1a has a larger tail to its distribution, these facts give a hint that we may expect to see a reduction in the mean of the distribution for TC9a. Figure 2 shows more subtle differences between TC1a and TC9a compared to Figure 1, however we do see some change around the peak of the distribution with TC9a being multimodal. Figure 2 gives no clear visual indication of a change in the mean max 4-8pm peak between TC1a and TC9a. TC1a has a mean annual mean 4-8pm peak of 1.219 kW with a standard deviation of 0.674 kW and a mean annual max 4-8pm peak of 4.188 kW with a standard deviation of 2.015 kW, with the

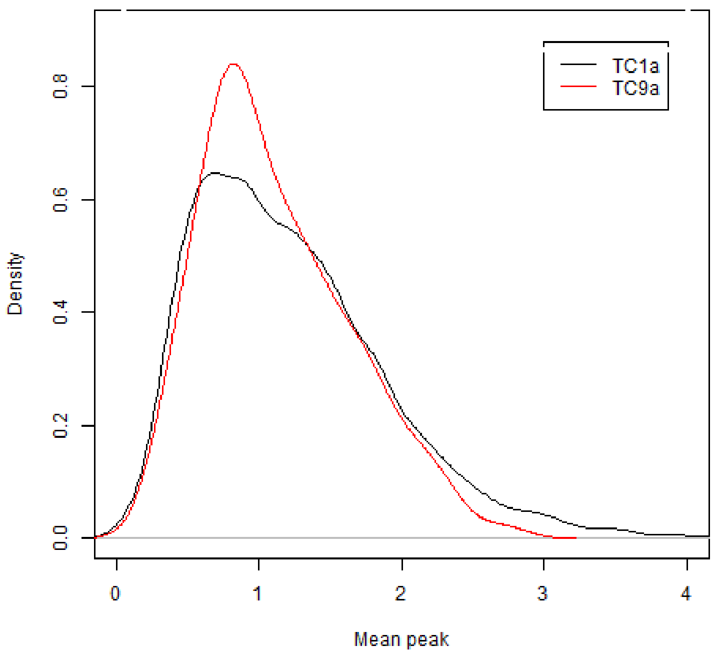

Figure 1: Distribution of the annual mean 4-8pm peak in kW for TC1a and TC9a

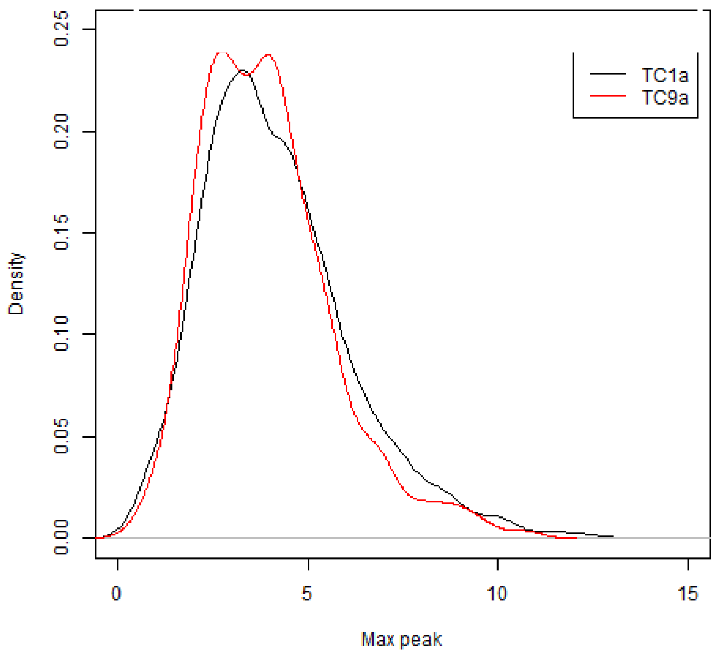

Figure 2: Distribution of the annual max 4-8pm peak in kW for TC1a and TC9a

respective figures for TC9a being 1.123 kW with a standard deviation of 0.525kW and 3.927 kW with a standard deviation of 1.729 kW. To quantify if there has been any change in the means (μ) of these distributions we perform a two-tailed t-test, with null hypothesis

$$H_0\colon \mu_{TC1a} = \mu_{TC9a}$$

and alternative hypothesis

$$H_1\colon \mu_{TC1a} \neq \mu_{TC9a}.$$

First we consider the distributions of the annual mean 4-8pm peak for TC1a and TC9a which gives a p-value of 0.001 (see Table A1 in the appendices for a full list of p-values relating to the 4-8pm period). This is significant and as such we can say there has been a change in the mean of these distributions, the 95% confidence interval produced with the test is (0.039,0.152) which suggests that TC9a has a mean mean 4-8pm peak which is lower by 0.039 kW to 0.152 kW. There has therefore been a reduction in the mean of the distribution of mean peaks for TC9a, although only a small reduction (3.2% - 12.5%).

Considering the distributions of the annual max 4-8pm peak for TC1a and TC9a we observe a p-value of 0.003, this is again significant and shows a change in the mean max 4-8pm peak between TC1a and TC9a. A 95% confidence interval of (0.090, 0.431) suggests a reduction in the mean max 4-8pm peak of TC9a by 0.090 kW to 0.431 kW (2.1% - 10.3%).

4.2.1 Social Science Cross Reference

In seeking to identify whether this apparent reduction in peak values accords with social science data we consult the analyses of survey and qualitative research conducted as part of CLNR.

In terms of increased likelihood of reduced electricity use peaks in the 4-8pm period for TC9, it is clear in the analysis of survey data that participants on the trial reported changing the time at which they use some appliances. Respondents were asked whether the new tariff caused them to change the time they use some electric appliances and answers indicate that the majority of respondents to the survey did change the time they used some appliances with 33 people agreeing and 60 people strongly agreeing (See *Domestic Survey report*).

Furthermore, the appliances most often reported to be used at different times were those associated with laundry (tumble dryers and washing machines), washing dishes and cooking (in that order). As each of these activities is associated with devices with relatively high power ratings we suggest that taken together the two studies support a conclusion that participants are likely to sometimes move these practices out of the 4-8pm period and that this contributes to lower averaged peak readings (as seen in Figure 1).

This is in line with our qualitative data in which laundry in particular was reported as being most likely to have been moved out of the peak period, as can be seen in this quotation taken from Social science report 3*;*

> *She'll do washing after 8 o'clock at night when it goes onto the night time tariff, the lower tariff. (GP2702)*

The tumble dryer will be used at night time … Even if I have to stop up later or something. I would rather use it at night time than on the peak [tariff] … (GP0025)

4.2.2 Monthly and Weekday / Weekend Analysis

To assess whether the results above are affected by weekly or seasonal variation, rather than taking the annual mean and annual max 4-8pm peak we can take a subset and calculate these mean and max 4-8pm peaks by month and by weekday or weekend. This method produces 24 mean 4-8pm peaks for each customer (and indeed 24 max 4-8pm peaks). Using the same tests as above we can then test any differences between test cells for a specific month, given the condition of either being weekdays or weekends (see Table A1 for p-values). Performing these tests gives the variation between TC1a and TC9a for each month by weekday or weekend but gives no indication of the variation within each test cell, that is we can say something about a specific month between TC1a and TC9a but we can say nothing about two months within the same test cell.

Looking first at the variation between the two test cells for all months, Figure 3 shows the distributions of the monthly weekday mean 4-8pm peaks for TC1a and TC9a with Figure 4 showing the same for monthly weekday max 4-8pm peaks. Looking at Figure 3 we see similar observations to those above for the annual mean 4-8pm peaks, that is, TC9a (red line) has a greater density at lower values when compared to TC1a (black line) but there does not appear to be as much of a prominent change in the tails of distributions. The change in the density at lower values may be less prevalent in the months May 2013 to August 2013, but this is just by eyeballing the data and has no statistical basis. Figure 4 gives the impression that for some months (e.g. December 2012) the distributions of the weekday max 4-8pm peaks differ between the two test cells, however the distributions are near identical for other months (e.g. June 2013).

Performing t-tests and looking at Table A1 we observe significant p-values for 7 months when considering the mean weekday mean 4-8pm peak and 10 months when considering the mean weekday max 4-8pm peak, suggesting there is a difference in the means of the distributions of TC1a and TC9a. To quantify the difference we must consider the confidence intervals from the relevant t-tests. The 95% confidence intervals for the difference in the means of the monthly weekday mean 4-8pm peaks are plotted in Figure 5, with the corresponding values for the monthly weekend max 4-8pm peaks in Figure A1 in the appendix.

To look at the impact of the day of the week, differences in monthly mean peaks are compared between weekdays (Figure 5) and weekends (Figure 6). Figure 5 shows confidence intervals ranging over solely positive values for all months which are significant, indicating that the mean monthly weekday mean 4-8pm peak is greater in TC1a than in TC9a. Thus we have seen a reduction in the mean weekday mean 4-8pm peak for TC9a for 7 months (November 2012 – May 2013). Thus, from the above we know there has been a significant annual reduction, and a percentage of this reduction is witnessed in the months November 2012 to May 2013 (for weekdays).

Conversely Figure 6 shows confidence intervals which include 0, meaning we observe no difference in the mean monthly weekend mean 4-8pm peak between the two test cells. Table A1 provides further evidence to this where we witness non-significant p-values in the t-tests. We observe similar patterns when considering the monthly weekday and weekend max 4-8pm peaks, (see Figure A1 and

A2 in the appendix for the relevant 95% confidence intervals and Table A1 for the relevant p-values). We see that for 10 months the mean of the weekday max 4-8pm peaks is greater in TC1a than in TC9a and that the mean of the weekend max 4-8pm peaks is greater in TC1a for November 2012 to January 2013.

Therefore changes in both mean and max peaks from TC1a to TC9a seem to be more visible in weekdays rather than weekends, and are possibly greater in the winter months.

4.2.3 Social Science Cross Reference

The qualitative data suggests that some activities that were taken out of the evening period – most often laundry – were performed in the weekend as in this example:

> *My washing I definitely do over the weekend when it's cheaper, unless it's absolute necessity. (MJRTL06)*

In most cases, however, survey participants claimed that these and other house-work related activities were moved to weekend mornings rather than evenings, leaving the weekend 4-8 period unaffected. For many, weekend evenings were a particularly important social time at which the tariff was never described by any of our participants as being able to affect energy use.

In addition, the impact of weather on tumble drying may contribute to an explanation of the greater difference between the test cells in winter months. As laundry becomes more electricity intensive in poor weather, it adds a significant load to many homes and one which is not tightly tied to a particular time of day. As a result, the greater difference observed in winter between the groups may be partly explained by the seasonal electrification of a time-flexible practice.

The impact of weather, and by extension winter, on laundry is illustrated in this quotation from Social science report 3;

> *If it's like this or sunny we'd put that on the line. If it's raining, there is a tumble dryer in shed or on the radiator.*

The survey responses do not contain data which differentiates between weekdays and weekends.

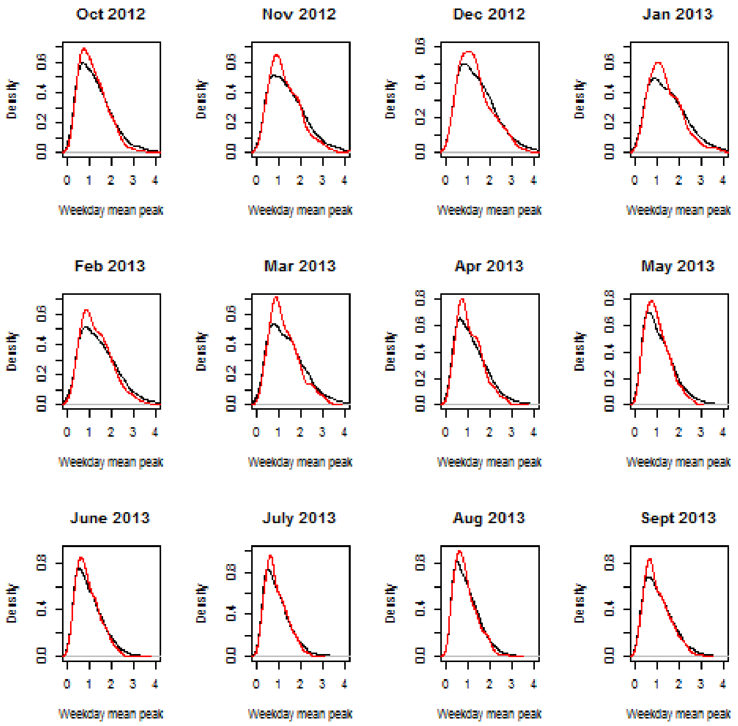

Figure 3: Distributions of the monthly weekday <u>mean</u> 4-8pm peak in kW for TC1a (black) and TC9a (red)

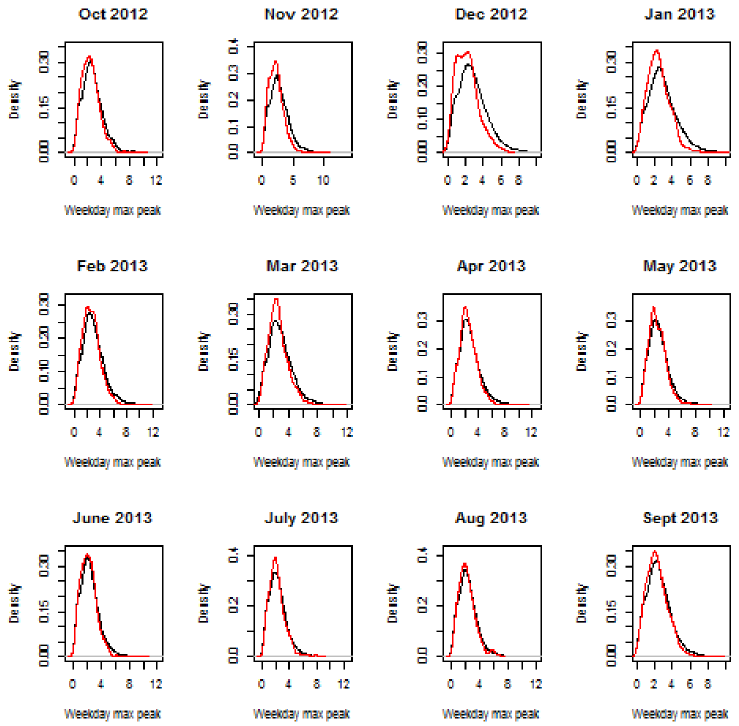

Figure 4: Distribution of the monthly weekday <u>max</u> 4-8pm peak in kW for TC1a (black) and TC9a (red)

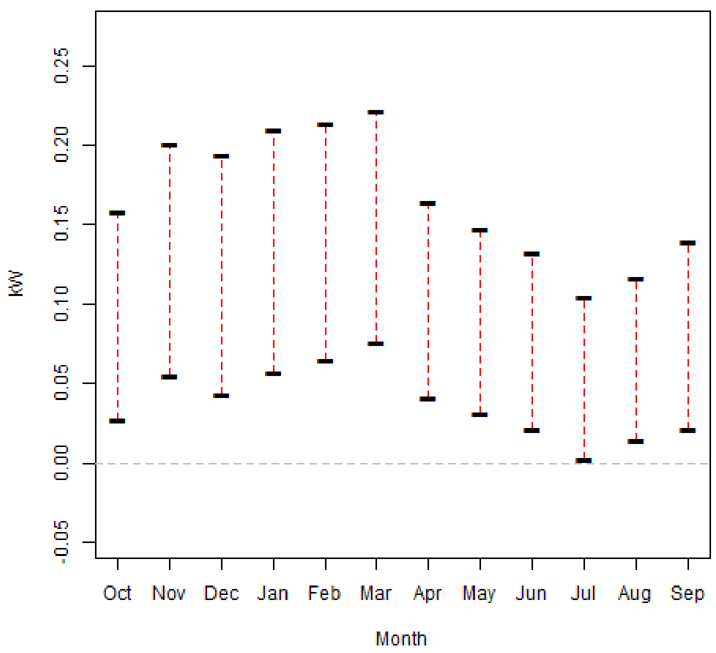

Figure 5: 95% confidence intervals for the difference in the means of the monthly <u>weekday mean</u> 4-8pm peak in kW for TC1a and TC9a. Positive values indicate that the mean of TC1a is greater than the mean of TC9a.

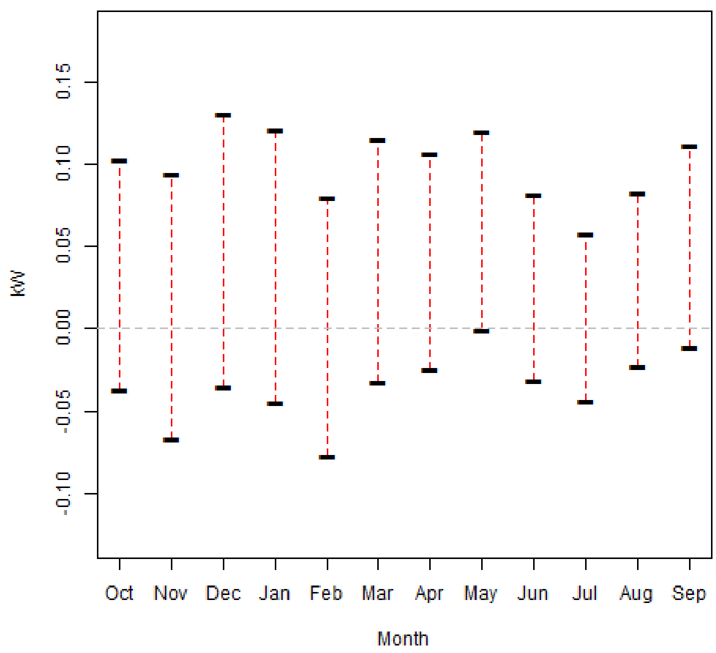

Figure 6: 95% confidence intervals for the difference in the means of the monthly <u>weekend mean</u> 4-8pm peak in kW for TC1a and TC9a. Positive values indicate that the mean of TC1a is greater than the mean of TC9a.

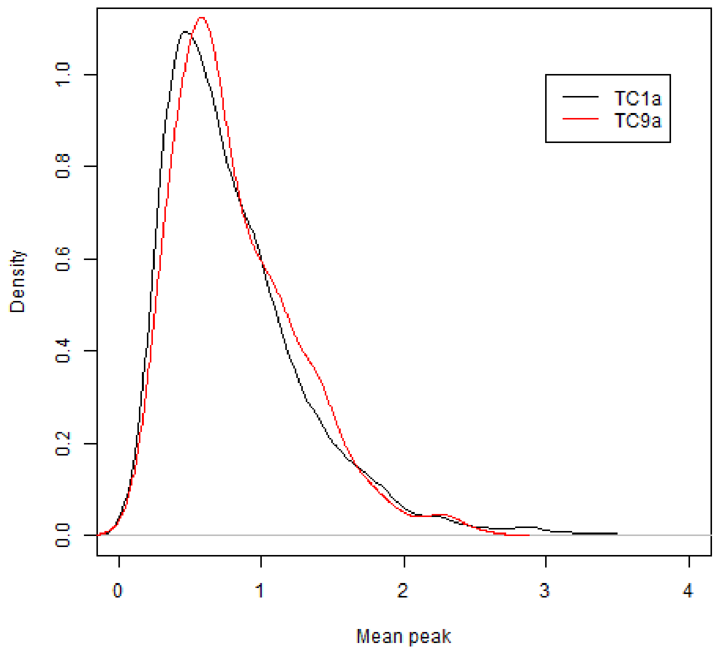

Figure 7: Distribution of the annual mean 8-10pm peak in kW for TC1a and TC9a

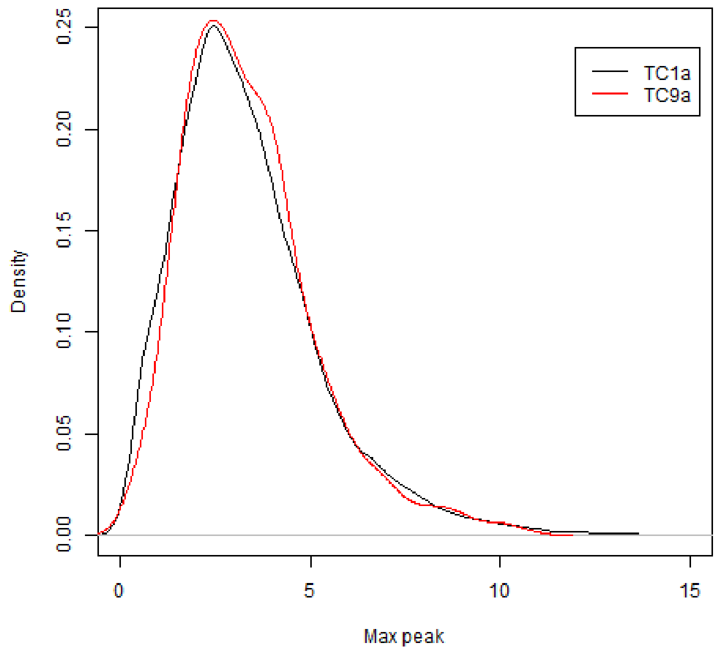

Figure 8: Distribution of the annual max 8-10pm peak in kW for TC1a and TC9a

4.3 Peak Power Demand in the 8-10pm Late Shoulder

Next we investigate whether there has been a change in the peak power demand in the shoulder periods between TC1a and TC9a; specifically we are interested in whether there has been the creation of a new peak, that is to say, is TC9a now greater than TC1a during these periods. Treating the data in the same way as outlined above we can create distributions for the mean and max peaks in the 2-4pm and 8-10pm periods. We first consider the 8-10pm period as our initial suspicion is that if a new peak has been created it will be later in the evening when people are more likely to be home, whilst also making use of the cheapest electricity price available. We first consider the distributions of the annual mean 8-10pm peaks and annual max 8-10pm peaks for TC1a and TC9a, illustrated in Figure 7 and Figure 8 respectively. We instantly note the difference to the above when considering the respective 4-8pm peaks, that being, in both figures there appears to be no difference between TC1a and TC9a. That being said there may be a faint indication of an increase in the annual mean 8-10pm peak of TC9a, although this suspicion is less convincing than the differences for 4-8pm. We find that TC1a has a mean annual mean 8-10pm peak of 0.813 kW and a mean annual max 8-10pm peak of 3.365 kW, with 0.826 kW and 3.402 kW for TC9a respectively. Performing two-tailed t-tests with the same null and alternative hypotheses as outlined above we observe a p-value of 0.561 when considering the distributions of the annual mean 8-10pm peaks for TC1a and TC9a, this is not significant and means there is no difference in the means of these distributions. For a full list of p-values relating to the 8-10pm period consult table A2 in the appendices. Considering the distributions of the annual max 8-10pm peak for TC1a and TC9a we observe a p-value of 0.664, again showing that there is no difference in the means of the annual max 8-10pm peaks.

Thus we must conclude that there is no difference between either of the mean annual mean and max 8-10pm peaks for TC1a and TC9a. This means that, at least on an annual level, a new peak has not been created in the 8-10pm shoulder period.

4.3.1 Monthly and Weekday / Weekend Analysis

Following on from this and partitioning the 8-10pm peaks by month and weekday or weekend we can perform a similar analysis to the above. The 95% confidence intervals for the difference in the means of the monthly weekday mean 8-10pm peaks are plotted in Figure 9, with Figure 10 showing the same for the monthly weekday max 8-10pm peaks. Table A2 illustrates that we have no significant p-values considering the monthly weekday or weekend mean 8-10pm peaks (with 1 and 2 significant p-values for the max 8-10pm peaks for weekdays and weekends respectively). Looking at the 95% confidence intervals in Figure 9 we see confidence intervals for November 2012 to January 2013 consisting of solely negative values, meaning that the mean of the monthly weekday mean peaks for TC9a is greater than the mean of the respective distribution for TC1a. However all of those months have confidence intervals too close to zero to give significant results. When looking at Figure 10 we see that the confidence intervals suggest that the mean of the weekday max 8-10pm peaks is greater in TC1a for December 2012, which would suggest ToU has also reduced demand after the peak period for this month, which is unexpected. Similar patterns are observed if we consider weekends; see Figure A3, Figure A4 and table A3 in the appendices.

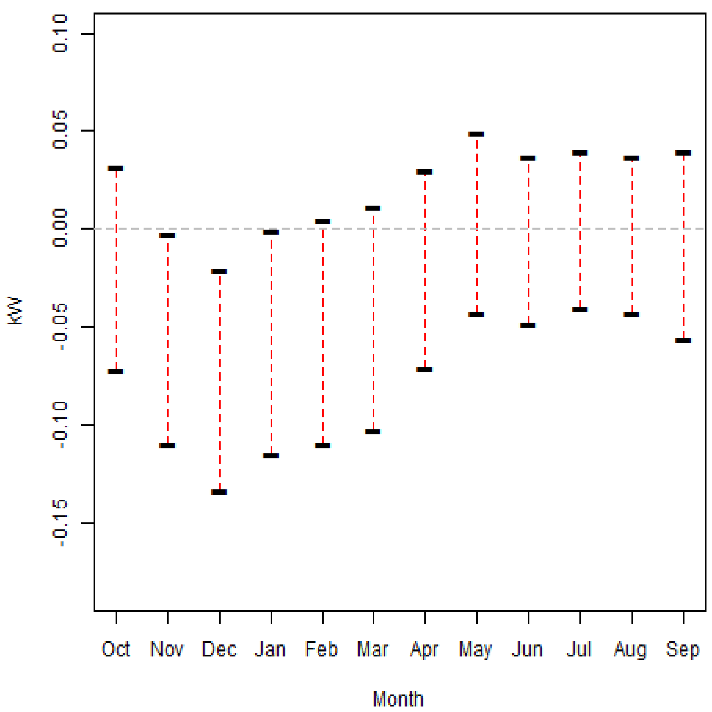

Figure 9: 95% confidence intervals for the difference in the means of the monthly weekday mean 8-10pm peak in kW for TC1a and TC9a. Positive values indicate that the mean of TC1a is greater than the mean of TC9a.

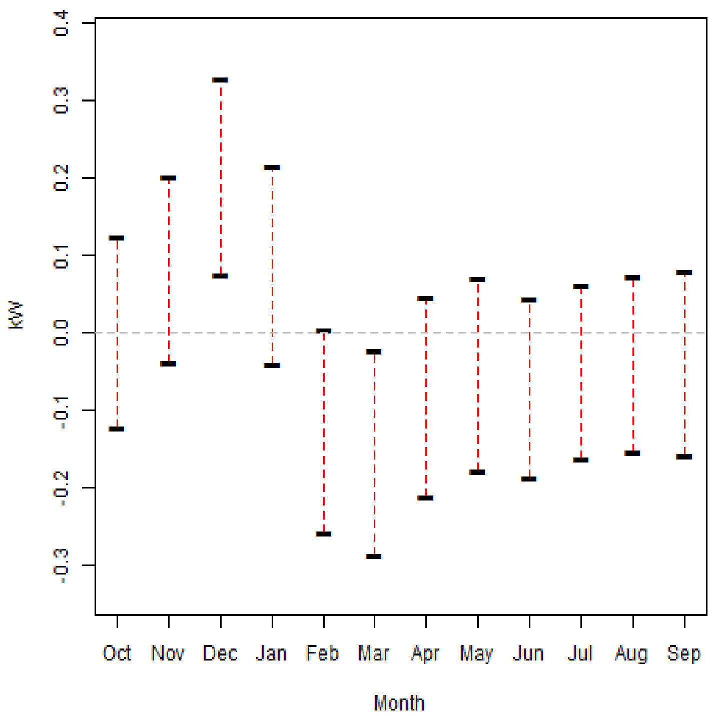

Figure 10: 95% confidence intervals for the difference in the means of the monthly weekday max 8-10pm peak in kW for TC1a and TC9a. Positive values indicate that the mean of TC1a is greater than the mean of TC9a.

4.3.2 Social Science Cross Reference

Looking at the annual analysis, there is no significant association to cross check with the social science data. The month of December raises interesting questions but is not readily explained by the social science data.

4.4 Peak Power Demand in the 2-4pm Early Shoulder

Turning our attention to the 2-4pm period we first consider the distributions of the annual mean and max peaks. Looking at Figure 11 we see some differences in the distributions of the annual mean 2-4pm peaks for TC1a and TC9a. We see that TC9a has a greater density at lower values whilst TC1a has a larger tail to its distribution, the differences are not as clear as for the case when considering the 4-8pm mean peaks but are more evident than when we considered the 8-10pm peaks. It is worth noting at this point that TC1a contains an over representation of Active Retirement which could cause an increase in the mean 2-4pm peak, this could be a factor as to why TC1a has a longer tail (indicating larger mean values) and a smaller density at the lower peak values. However we will ignore this fact at present and continue with our statistical analysis as is, to determine whether there are any differences between TC1a and TC9a. Figure 12 suggests that there is little difference in the distributions of the annual max 2-4pm peaks between TC1a and TC9a, although there is a hint of a reduction in TC9a, this again may relate to the issue regarding Active Retirement. TC1a has a mean annual mean 2-4pm peak of 0.665 kW and a mean annual max 2-4pm peak of 3.579 kW, with the respective figures for TC9a being 0.637 kW and 3.386 kW.

As above we perform two-tailed t-tests and record p-values of 0.103 and 0.012 for the difference in the mean annual mean 2-4pm peaks and mean annual max 2-4pm max peaks respectively, (a full list of p-values relating to the 2-4pm period can be found in table A3). This means we have no significant difference between the means of the annual mean 2-4pm peaks but we do have a significant difference between the means of the annual max 2-4pm peaks. The 95% confidence interval relating to the test regarding the max peaks is given by (0.043,0.342), meaning that the TC9a mean annual max 2-4pm peak is between 0.043 kW and 0.342 kW lower than the mean TC1a annual max. This increase is small and could be related to the issue discussed above. A stratified sample study would need to be conducted to assess whether there is a true increase from TC9a to TC1a or if indeed this is a false result from the over representation of Active Retirement.

4.4.1 Monthly and Weekday / Weekend Analysis

We again subset the data by month and weekday or weekend and carry out a between-variation analysis using two-sided t-tests. The 95% confidence intervals for the difference in the means of the monthly weekday mean 2-4pm peaks are plotted in Figure 13, with Figure 14 showing the same for the monthly weekday max 2-4pm peaks.

Table A3 shows that we have 0 significant p-values when considering the monthly weekday mean 2-4pm peaks and 0 significant p-values when considering the weekend mean 2-4pm peaks (with 4 and 3 significant p-values for the max 2-4pm peaks for weekdays and weekends respectively). Looking at the 95% confidence intervals in Figure 13 we see that the confidence intervals are very close to 0 or include 0, from this we can conclude that there are no differences in the mean monthly weekday mean 2-4pm peaks. Interestingly when we consider the means of the monthly max 2-4pm peaks we see that we have significant p-values for October 2012 to December 2012 for both weekdays and weekends, (see Figures A5 and A6 in the appendices for the relevant weekend plots). The 95% confidence intervals for these months are purely positive, as illustrated in Figure 14, which indicates that the mean of the monthly max peaks is greater in TC1a than in TC9a. As no other months (bar January 2013 for weekdays) are significant it is the weight at which these months are different which causes us to observe a difference annually in the max 2-4pm peaks.

There is no great change in weather between months to suggest this change, and weather as a cause is most likely irrelevant as it will affect both test cells. This study has not investigated whether the initial reduction in the max of TC9a compared to TC1a is as a result of the customer starting on the tariff, but followed by a reduction in engagement with the tariff over time. Further to this we see no change in the means of the monthly mean 2-4pm peaks which you would expect if the tariff is having a larger effect in certain months. These 3 months therefore pose something of a quandary and are close to being anomalous with the rest of the sample. It is beyond the current knowledge of this analysis to offer reasons as to these vast differences in the months October 2012 to December 2012.

With the above evidence we must conclude that there are no differences in the shoulder period annual mean peaks or in the annual 8-10pm max peaks of TC1a and TC9a but there is some difference in the annual 2-4pm max peaks, although be it down to the heavy influence of 3 months. There is therefore little evidence to suggest that a new peak has been created in one of the shoulder periods on an annual level, however at a monthly level there may be differences between test cells on a month by month basis with no common theme to the differences.

4.4.2 Social Science Input

There is no clear preponderance in the social science data about 2-4pm period.

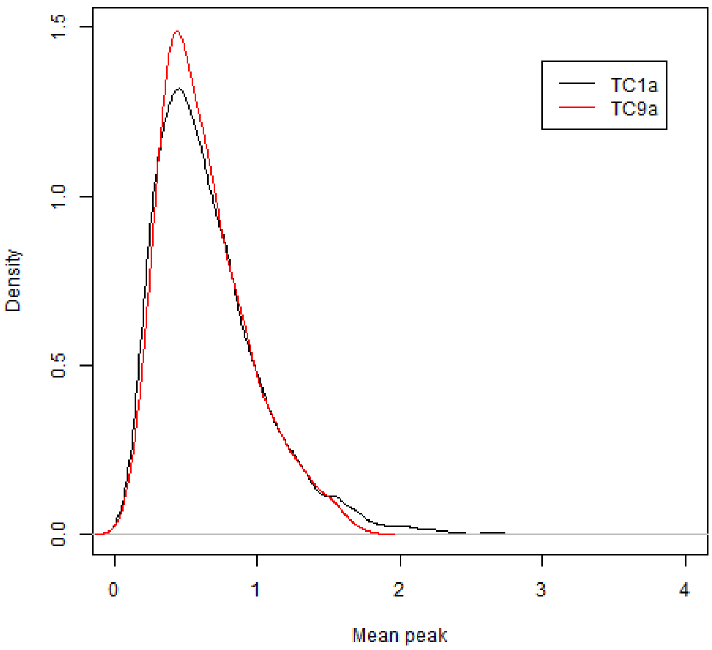

Figure 11: Distribution of the annual <u>mean</u> 2-4pm peak in kW for TC1a and TC9a

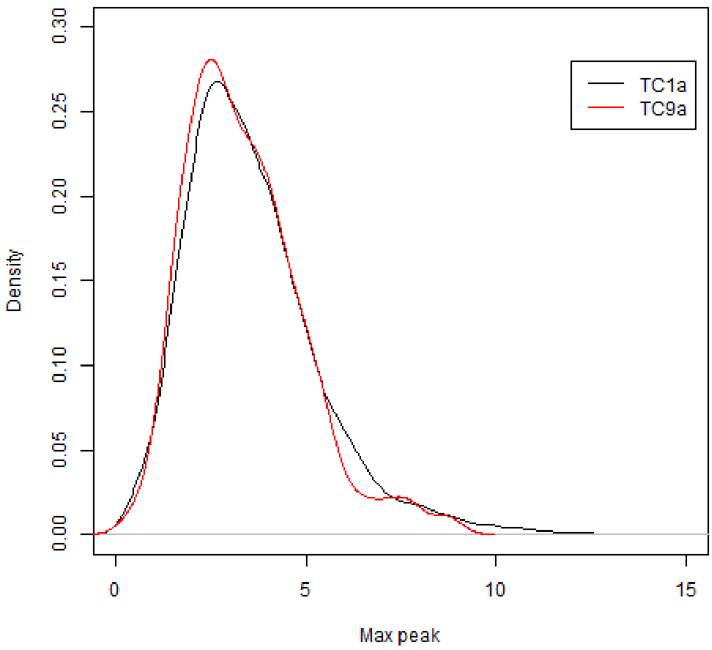

Figure 12: Distribution of the annual <u>max</u> 2-4pm peak in kW for TC1a and TC9a

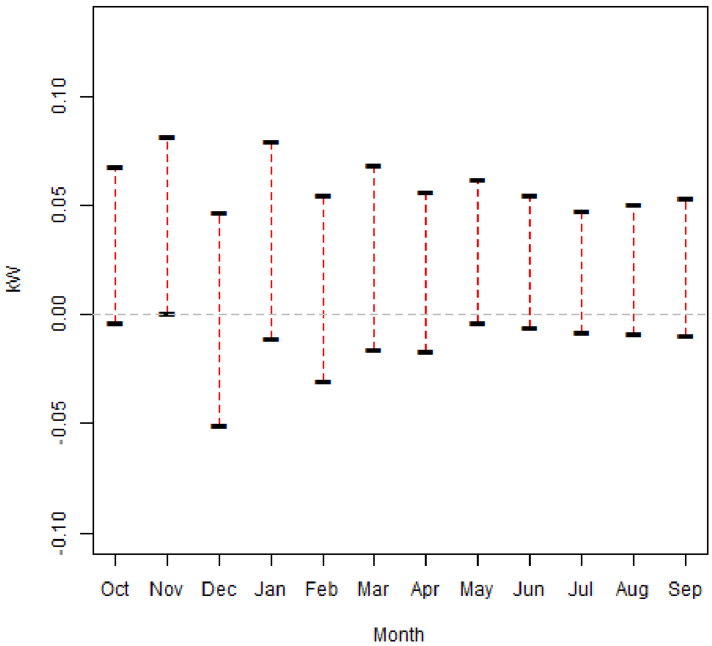

Figure 13: 95% confidence intervals for the difference in the means of the monthly <u>weekday mean</u> 2-4pm peak in kW for TC1a and TC9a. Positive values indicate that the mean of TC1a is greater than the mean of TC9a.

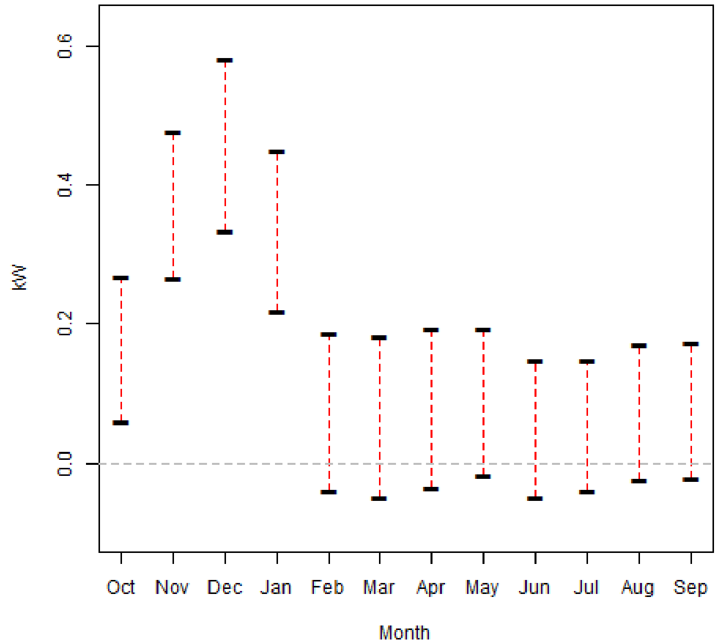

Figure 14: 95% confidence intervals for the difference in the means of the monthly <u>weekday max</u> 2-4pm peak in kW for TC1a and TC9a. Positive values indicate that the mean of TC1a is greater than the mean of TC9a.

4.5 Total Electricity Use

Next we consider the annual absolute electrical energy consumption of a TC9a and TC1a customer. We begin by comparing the annual absolute electricity consumption for all periods. Figure 15 shows the distributions of the annual absolute electricity consumption for all periods in kWh for both TC1a and TC9a. We see no real differences between these distributions with means of 3507.122 kWh and 3481.522 kWh for TC1a and TC9a respectively. Carrying out a two-tailed t-test on the means of these distributions with the same null and alternative hypotheses as outlined above when considering the peak power demand we observe a p-value of 0.765. This p-value is non-significant and as such we must conclude that there is no difference in the means of the annual absolute electricity consumption for a TC1a and TC9a customer. That is to say, across the whole year a TC1a and TC9a customer will use the same amount of electrical energy.

4.5.1 Social Science Input

Despite there being no significant difference between the recorded total electrical energy use of TC1 and TC9 customers the survey reveals that most TC9 participants felt that they had reduced total energy use to some extent with 50 of 101 respondents reporting a slight reduction and 26 of 101 respondents reporting a significant decrease in total energy use (Domestic Survey Report). Most striking here is the disconnect between the perceived and real effects of the tariff on total energy use. We also found that participants in the qualitative study reported being more aware, more careful and more vigilant as a result of being on the tariff, which accords with the survey responses.

This perhaps reveals power of socio-technical conventions, structures and capacities of domestic energy use to re-configure and re-establish themselves around, rather than be fundamentally altered by, an intervention such as a time of use tariff

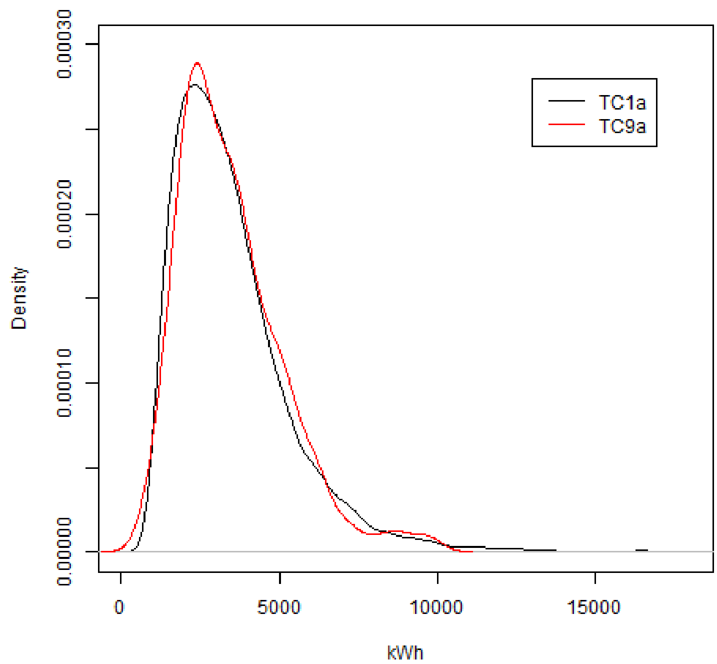

Figure 15: Distribution of the annual absolute energy consumption for all periods in kWh for TC1a and TC9a

4.6 Total Electricity Use in the Peak and Off-Peak Periods

We now aim to quantify the absolute electrical energy consumption for TC1a and TC9a in the peak period (4-8pm) and in the off-peak period (all other times). We consider the electricity used annually as well as breaking down the data by month and weekday or weekend.

4.6.1 Annual Usage

We first consider the annual absolute electrical energy used in the peak and off peak periods beginning with the peak period. Figure 16 illustrates the distributions of the annual absolute electricity consumption in the 4-8pm peak period in kWh for both TC1a and TC9a; we see that TC9a has a greater density at lower values whilst TC1a has a slightly larger tail to its distribution, with a slightly higher density for values of 1500 kWh to 2500kWh. We find that TC1a has a mean of 861.673 kWh and that TC9a has a mean of 806.621 kWh. We perform a two-tailed t-test on the means of these distributions with the same null and alternative hypotheses as outlined above and observe a p-value of 0.011. This p-value is significant, all be it only with moderate evidence, meaning that we see a difference in the mean annual absolute electrical energy usage in the 4-8pm peak period between TC1a and TC9a. The appropriate 95% confidence interval associated with the test is given by (12.875, 97.228), showing that the mean of TC1a is between 12.875 kWh and 97.228 kWh greater than the mean of TC9a.

Thus we conclude that the mean TC1a customer uses between 1.5% and 11.3% more electricity than the mean TC9a customer annually in the 4-8pm peak period.

Figure 17 shows the distributions of the annual absolute electricity consumption in the off-peak period for TC1a and TC9a. Any differences in the distributions are marginal but there is a suggestion that TC9a has a slightly higher density at lower values whereas TC1a has a slightly longer tail to its distribution. The means of the distributions are 2637.88 kWh and 2674.901 kWh for TC1a and TC9a respectively. We again carry out a two-tailed t-test gaining a p-value of 0.589, this value is not significant and we must conclude that there is no difference in the means of the annual consumption in the off-peak period for a TC1a and TC9a customer. Therefore at an annual level a TC9a customer will use less electricity in the peak 4-8pm period but will use the same amount of electricity as a TC1a customer outside of this period.

This may appear odd that a TC9a customer has reduced electricity use in the peak period, with no pick up of this in the off-peak period, given that we observed no difference in the annual consumption of a TC1a and TC9a customer when considering all time periods; this is due to t-tests occurring on values of differing magnitudes. To elucidate a TC1a customer has an annual mean across all periods of 3507.122 kWh and a TC9a customer has an annual mean across all periods of 3481.522 kWh, this is a reduction of 25.6 kWh for a TC9a customer, but it is not significant reduction when considering values in the thousands. Looking at the annual peak usage a TC1a customer has a mean of 861.673 kWh and a TC9a customer has a mean of 806.621 kWh, a reduction of 55.052 kWh.

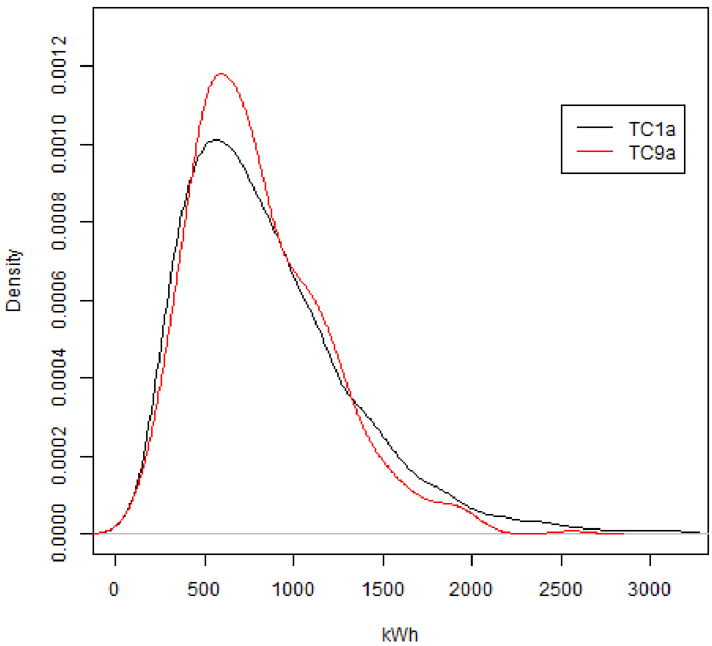

Figure 16: Distribution of the annual absolute energy consumption in the <u>4-8pm peak period</u> in kWh for TC1a and TC9a

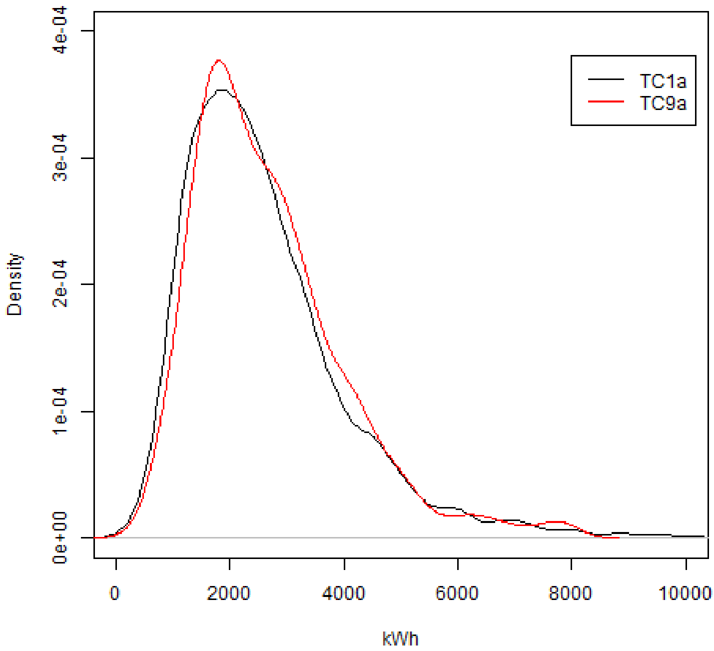

Figure 17: Distribution of the annual absolute energy consumption in the <u>off-peak period</u> in kWh for TC1a and TC9a

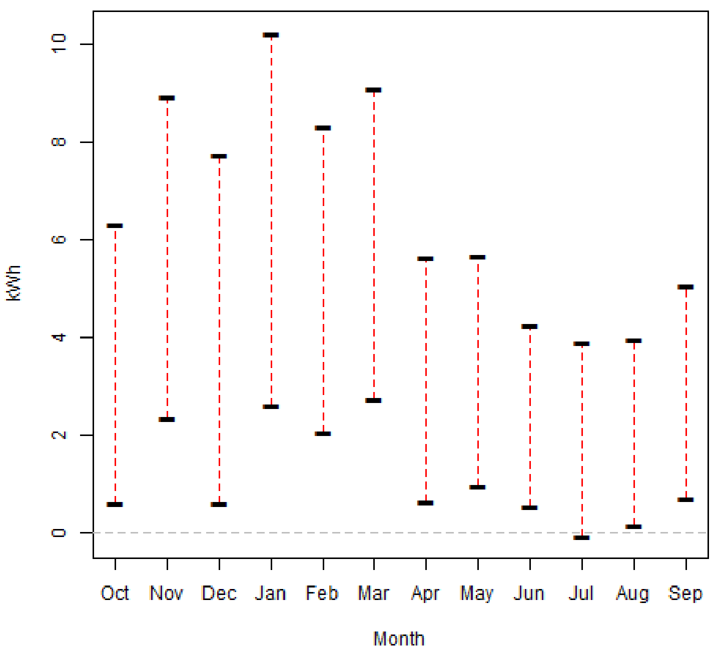

Figure 18: 95% confidence intervals for the difference in the means of the monthly <u>weekday 4-8pm peak usage</u> in kWh for TC1a and TC9a. Positive values indicate that the mean of TC1a is greater than the mean of TC9a.

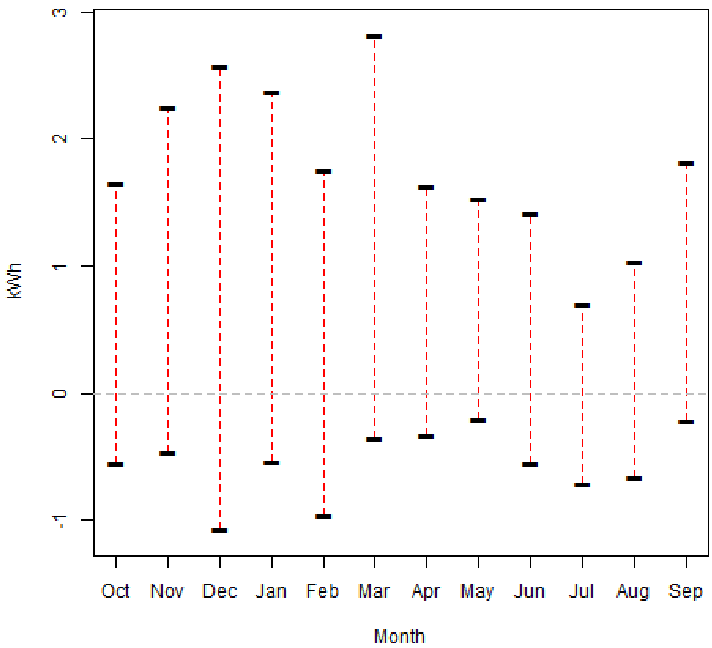

Figure 19: 95% confidence intervals for the difference in the means of the monthly <u>weekend 4-8pm peak usage</u> in kWh for TC1a and TC9a. Positive values indicate that the mean of TC1a is greater than the mean of TC9a.

At this scale a reduction of around 55 kWh proves to be significant showing a valid reduction in the peak period for a TC9a customer. In the off-peak period the annual means of a TC1a and TC9a customer are 2637.88 kWh and 2674.901 kWh respectively. This amounts to an increase of 37.021 kWh for a TC9a customer, again though this increase is not significant on this scale. By thinking of the means of TC9a in terms of the means of TC1a, we view TC9a's reduction as (55.052 - 37.021) =18.031 kWh, which is close to the annual reduction of 25.6 kWh; the difference in the values (18.031 and 25.6) is representative of the missingness structure within the dataset.

4.6.2 Monthly and Weekday / Weekend Usage

By partitioning the data as outlined previously we next consider the absolute electricity used in the peak and off-peak periods by month and either by weekday or weekend. Table A4 in the appendices gives the relevant p-values for the two-tailed t-tests carried out using the same null and alternative hypotheses as outlined above. We observe that for the peak period 4 p-values relating to the peak period on weekdays are significant. Figure 18 shows 95% confidence intervals associated with the t-tests for weekday electricity usage in the peak period. We see that for all significant months the confidence intervals are purely positive, indicating that the mean of TC1a is greater than the mean of TC9a. Figure 19 shows the corresponding confidence intervals for weekends. Here we see that all confidence intervals include 0, indicating that there is no difference in the mean usage between TC1a and TC9a for weekends in any given month. This is supported by the fact that we observe no significant p-values when considering the electricity used in the 4-8pm peak period on weekends. Figures A7 and A8 in the appendices show the 95% confidence intervals relating to the electricity usage in the off-peak period. We observe no significant p-values for either weekday or weekend when considering the electricity usage of TC1a and TC9a customers in the off-peak period.

Thus we can conclude that there is no difference in the monthly mean absolute electricity usage of a TC1a and TC9a customer in the off-peak period for both weekdays and weekends and no difference in the peak period when considering weekends. We do however see some difference when looking at the absolute electricity used in the weekday peak period, with TC1a having a greater mean than TC9a for 4 of the 12 months considered (with no difference in the other months). Therefore there has been a shift of electricity consumption away from weekday peak periods, dominated by the months of November, January, February and March.

4.7 A Demographic View

As mentioned above we can break down TC1a and TC9a by demographics as defined by [2] and [3]. The demographics, by which we can subset each test cell, are: Dependencies (those with/without household members under 5 or over 65), Housing Tenure (renter/non-renter), Housing Income and Proxy Efficiency Measure, with the addition that TC1a also features rurality. Unfortunately the scales on which Housing Income and Proxy Efficiency Measure are rated differ between test cells and as such no direct comparison can occur here; meaning the only demographics we can compare TC1a and TC9a on are Dependencies and Housing Tenure. We can also subset the test cells based on the 15 mosaic categories of [3], the definitions of which are the same across both test cells.

4.7.1 A descriptive look at TC9a

We begin by investigating the makeup of each demographic in TC9a. This is a purely descriptive analysis, as no within-variation is considered in this analysis, and as such no statistical tests will be performed here, meaning we can offer no statistical rigor to any conclusions drawn in this section. As above we consider how each demographic in TC9a behaves in relation to their peak power demand in the 4-8pm peak period and their annual absolute electricity consumption for all time periods.

Peak Power Demand in the 4-8pm Period

Firstly let us consider a TC9a customer's peak power demand in the peak period relative to their demographic as defined in [2]. Table 6 shows means and standard deviations for the annual mean 4-8pm peaks and annual max 4-8pm peaks in kW for TC9a customers by DEI demographic. Figures 20 – 27 show the relevant distribution for the annual mean 4-8pm peaks for each demographic, (Figures A9 – A16 in the appendices show the same plots for the annual max 4-8pm peaks). Looking at the graphs for the annual mean peak we see no obvious differences between any of the demographics in regards to the shape of their distributions, with the same also being true for the annual max peaks. There is a slight indication that Low Income and Renters have a slightly shorter tail to their distributions with a higher density at lower values, although these differences are subtle. From table 4 we can see that Low Income, Renter and With Dependencies have a slightly lower mean annual mean 4-8pm peak, although there is little difference between all demographics. We see little variation in the standard deviations of the annual mean peaks, with all approximately 0.5; this is evidenced in Figures 20 – 27 where we see little difference between the distributions. Looking at the annual max 4-8pm peaks it is possible that High Income and Without Dependencies have higher mean annual max 4-8pm peaks with Low Income and With Dependencies having lower means. The variation within the standard deviations of the annual max 4-8pm peaks is greater than the variation within the standard deviations of the annual mean 4-8pm peaks, but it is still relatively small.

	Annual mean 4-8pm peak in kW		Annual max 4-8pm peak in kW	
Demographic	**Mean (μ)**	**Standard Deviation (σ)**	**μ**	**σ**
High Efficiency	1.132	0.514	3.851	1.670
Low Efficiency	1.113	0.528	3.932	1.732
High Income	1.206	0.540	4.113	1.674
Low Income	1.016	0.483	3.657	1.723
With Dependencies	1.036	0.490	3.623	1.679
Without Dependencies	1.202	0.541	4.181	1.697
Renter	1.016	0.518	3.778	1.932
Non-renter	1.167	0.519	3.963	1.597

Table 6: Means and standard deviations for TC9a annual mean 4-8pm peaks and annual max 4-8pm peaks by DEI demographic. All values reported in kW.

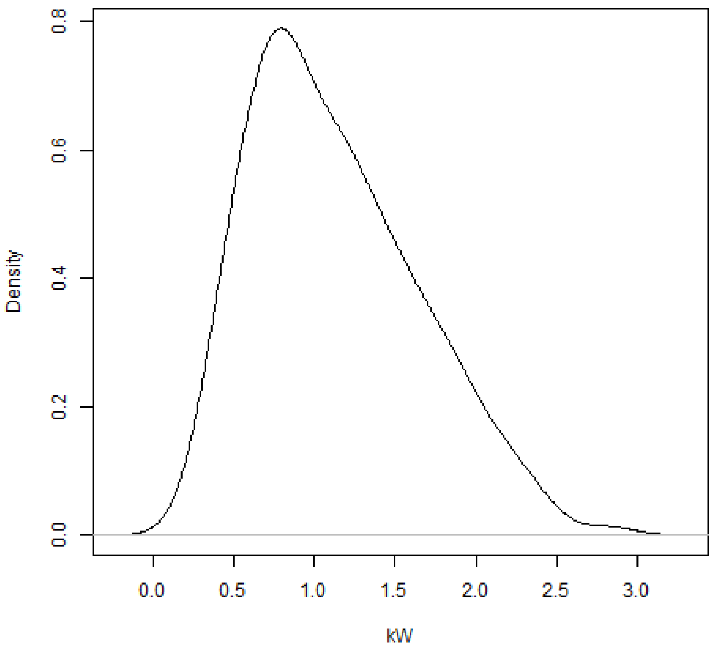

Figure 20: Distribution of the annual mean 4-8pm peak in kW for TC9a (High Efficiency)

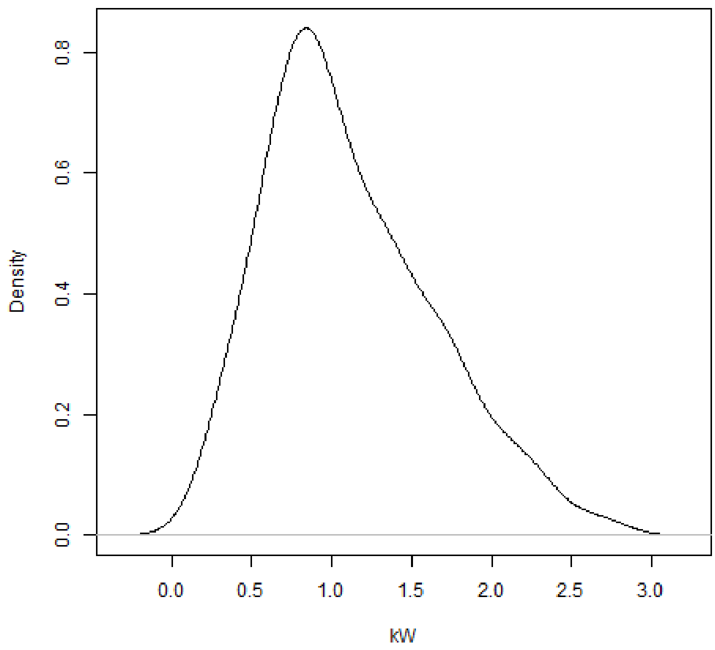

Figure 21: Distribution of the annual mean 4-8pm peak in kW for TC9a (Low Efficiency)

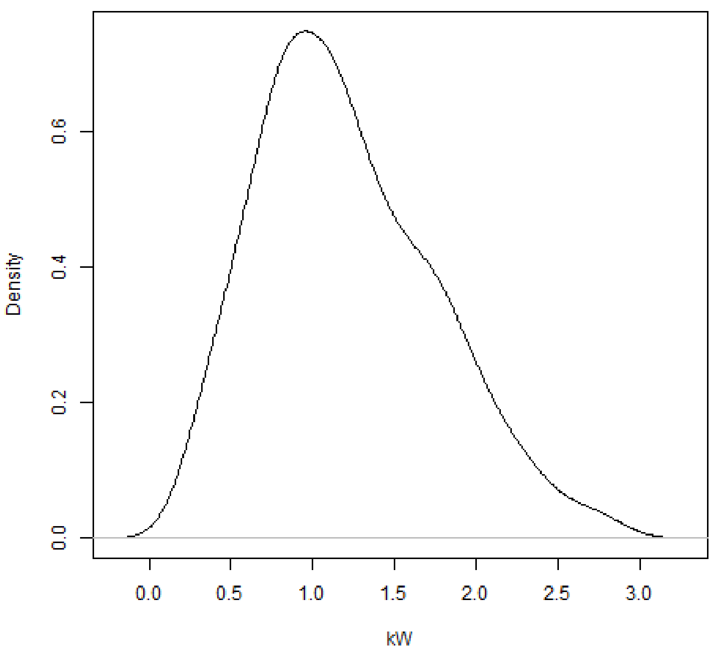

Figure 22: Distribution of the annual mean 4-8pm peak in kW for TC9a (High Income)

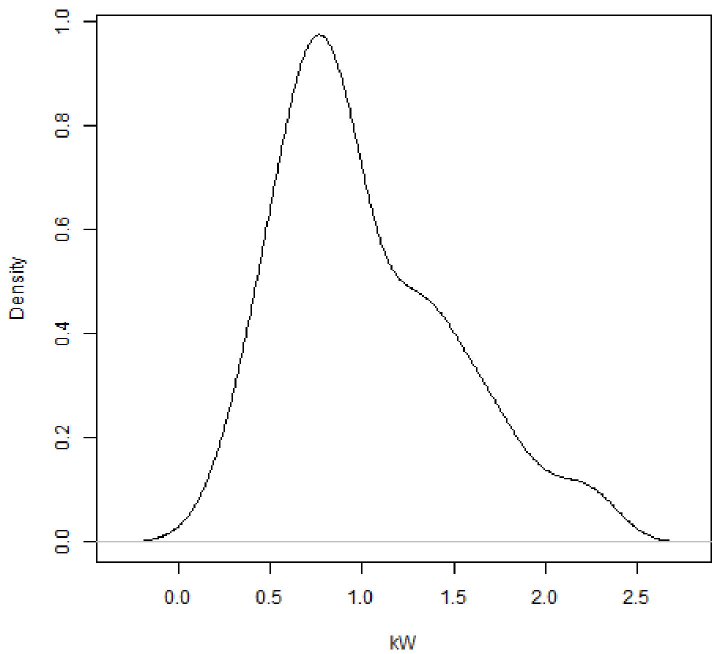

Figure 23: Distribution of the annual mean 4-8pm peak in kW for TC9a (Low Income)

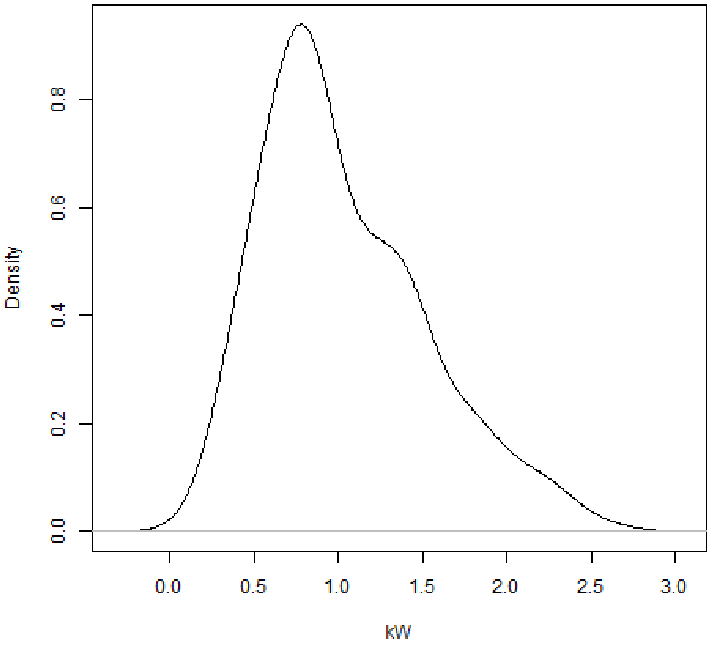

Figure 24: Distribution of the annual mean 4-8pm peak in kW for TC9a (With Dependencies)

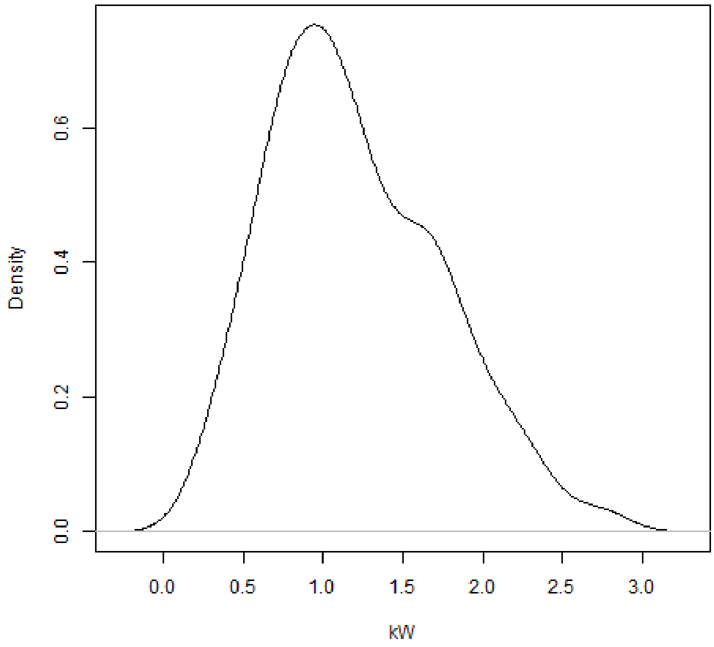

Figure 25: Distribution of the annual mean 4-8pm peak in kW for TC9a (Without Dependencies)

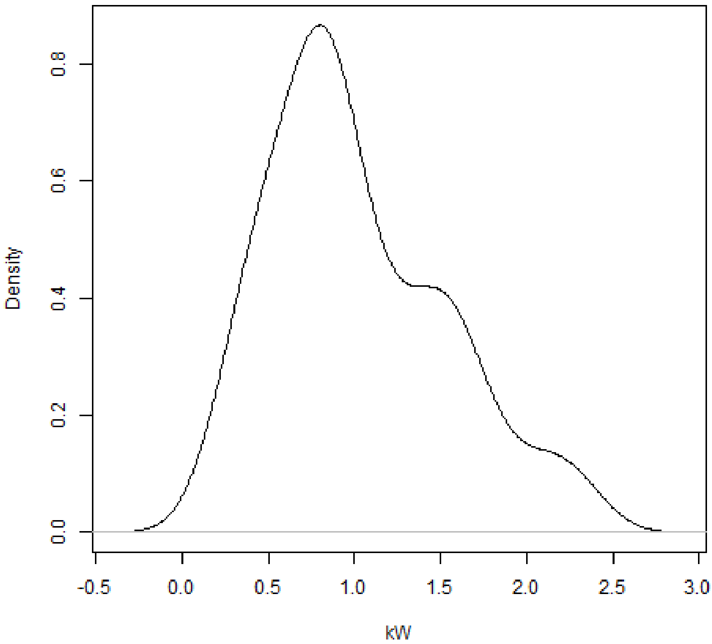

Figure 26: Distribution of the annual mean 4-8pm peak in kW for TC9a (Renter)

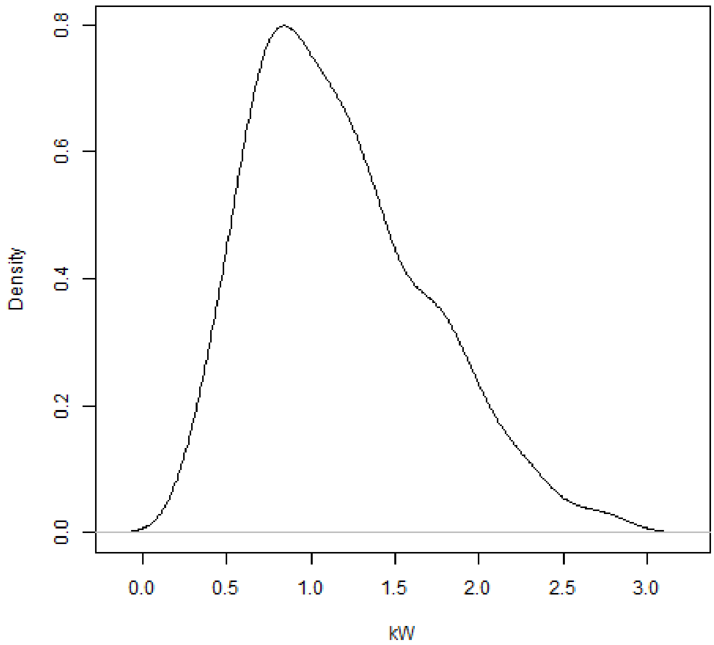

Figure 27: Distribution of the annual mean 4-8pm peak in kW for TC9a (Non-renter)

We now consider a TC9a customer's peak power demand in the 4-8pm period relative to their mosaic category as defined in [3]. Table 5 gives a full list of the 15 mosaic categories. We note at this point that only two Mosaic categories contain more than 100 customers in TC9a, and that only 1 customer was defined to be in mosaic category K, as such no analysis will be carried out regarding mosaic category K. If interest lies in the behaviour of Upper Floor Living then new data for this customer subset would need to be collected. Table 6 shows means and standard deviations for the annual mean 4-8pm peaks and annual max 4-8pm peaks in kW for TC9a customers by mosaic category. The relevant distributions for the annual mean 4-8pm peaks and the annual max 4-8pm peaks for each mosaic category can be found in the appendices, Figures A17 – A30 and Figures A31 – A44 respectively.

Most of the mosaic categories appear to be fairly similar in their distributions with any obvious differences difficult to detect given the small sample sizes for some of the mosaic categories (see table 7). Mosaic L appears to have a larger tail to its distribution, with a higher density for smaller values. There is some suggestion that Mosaic N has a higher density at smaller values, and whilst its distribution is similar in shape to other mosaic categories it does not cover the same range. Looking at table 6 we see that Mosaic E appears to have a lower mean annual mean 4-8pm peak and a lower mean annual max 4-8pm peak with a slightly smaller standard deviation for the annual mean peak and a greatly smaller standard deviation for the annual max peak. It is also possible that Mosaic L and Mosaic N have a smaller mean annual mean 4-8pm peak and a lower mean annual max 4-8pm peak although their standard deviations are not greatly different from the rest. There is some suggestion that Mosaic A and Mosaic G have larger mean annual mean peaks with Mosaic G also possibly having a larger mean annual max peak as well. Mosaic H may have a larger standard deviation for the annual max peak but these values are distorted by the sample size. Table 7 shows that we have small sample sizes for Mosaic A, Mosaic C, Mosaic E, Mosaic G, Mosaic H, Mosaic O and possibly Mosaic N.

Mosaic Code	Mosaic Category	Number of Customers in TC9a	Mosaic Code	Mosaic Category	Number of Customers in TC9a
Mosaic A	Alpha Territory	14	Mosaic I	Ex-Council Community	107
Mosaic B	Professional Rewards	43	Mosaic J	Claimant Cultures	62
Mosaic C	Rural Solitude	9	Mosaic K	Upper Floor Living	1
Mosaic D	Small Town Diversity	53	Mosaic L	Elderly Needs	51
Mosaic E	Active Retirement	10	Mosaic M	Industrial Heritage	78
Mosaic F	Suburban Mindsets	101	Mosaic N	Terraced Melting Pot	25
Mosaic G	Careers and Kids	18	Mosaic O	Liberal Opinions	13
Mosaic H	New Homemakers	7			

Table 7: Mosaic categories and their definitions as defined by [3].

	Annual mean 4-8pm peak in kW		Annual max 4-8pm peak in kW	
Demographic	**Mean (μ)**	**Standard Deviation (σ)**	**μ**	**σ**
Mosaic A	1.556	0.579	4.311	1.509
Mosaic B	1.353	0.494	4.291	1.300
Mosaic C	1.192	0.585	4.052	1.273
Mosaic D	1.075	0.423	3.735	1.377
Mosaic E	0.626	0.368	2.293	0.622
Mosaic F	1.188	0.537	4.191	1.659
Mosaic G	1.504	0.469	4.878	1.330
Mosaic H	0.972	0.450	3.866	2.333
Mosaic I	1.216	0.487	4.288	1.727
Mosaic J	0.947	0.490	3.759	1.872
Mosaic L	0.811	0.471	3.096	2.019
Mosaic M	1.068	0.502	3.618	1.707
Mosaic N	0.920	0.453	3.100	1.289
Mosaic O	1.125	0.697	4.714	2.461

Table 8: Means and standard deviations for TC9a annual mean 4-8pm peaks and annual max 4-8pm peaks by mosaic category. All values reported in kW.

These small sample sizes mean that it is unlikely we will have an accurate reflection of the demographics behaviour; this means we may see wildly different observations within the demographic, possibly leading to a larger than expected variance or a non-representative mean. This is evidenced in the distributions; see Mosaic E (Figure A21) or Mosaic H (Figure A24) for multimodal examples.

Total Electrical Energy Use

We now move on to investigate a TC9a customer's absolute electricity consumption (for all time periods) relative to their demographic as defined in [2]. Table 9 shows means and standard deviations for the annual consumption in kWh for TC9a customers by DEI demographic with Figures 28 - 35 showing the relevant distributions. Looking at the figures it is possible that Low Income, With Dependencies and Renter have larger tails to their distributions. Although these are marginal distributions and as such there is potential crossover between the distributions, another reason that anything within this section should be regarded with no statistical power or conclusive evidence. From table 9 we see that Low Income, With Dependencies and Renter possibly have lower mean annual consumption with High Income and Without Dependencies having greater means. There appears to be little difference in the standard deviations if we subset by DEI demographic.

Table 10 shows the means and standard deviations for the annual consumption in kWh for TC9a customers subset by mosaic category, (the corresponding distributions can be found in Figures A45 - A58 in the appendices).Again, due to small sample sizes it is difficult to detect any real differences between the distributions.

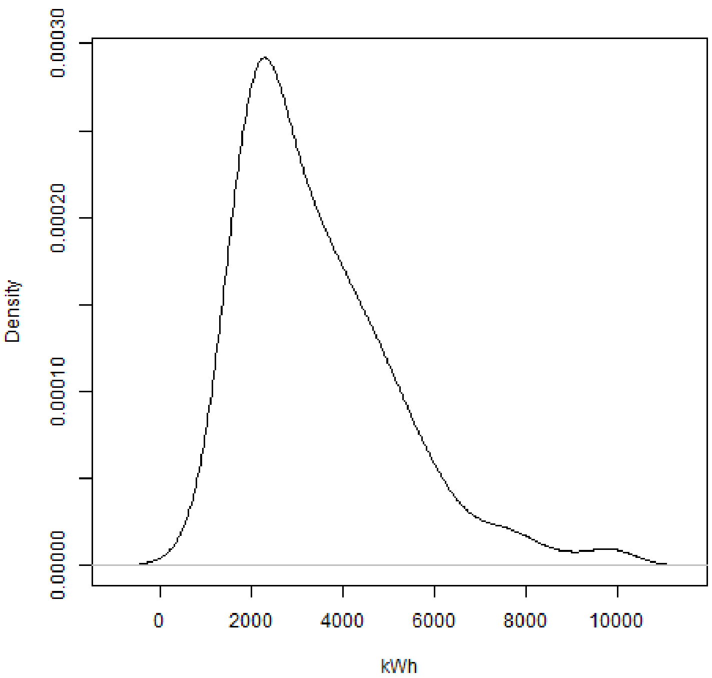

Figure 28: Distribution of the annual energy consumption in kWh for TC9a (High Efficiency)

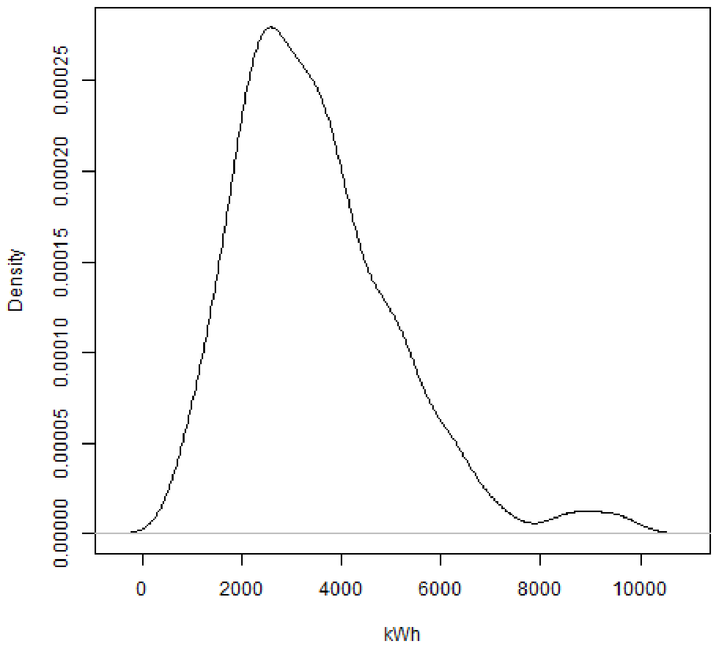

Figure 29: Distribution of the annual energy consumption in kWh for TC9a (Low Efficiency)

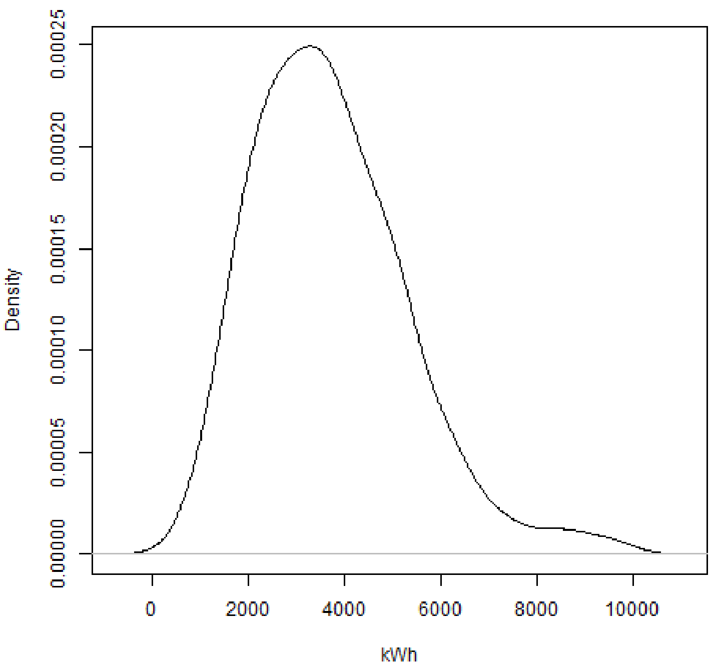

Figure 30: Distribution of the annual energy consumption in kWh for TC9a (High Income)

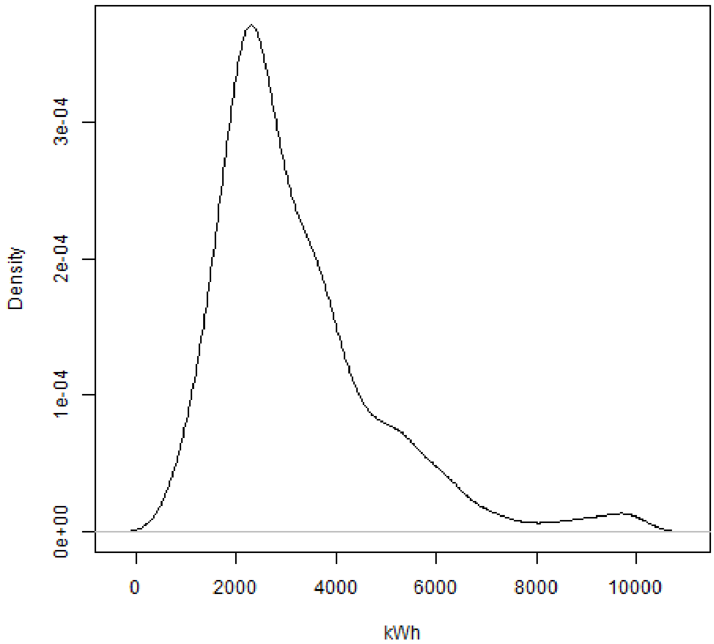

Figure 31: Distribution of the annual energy consumption in kWh for TC9a (Low Income)

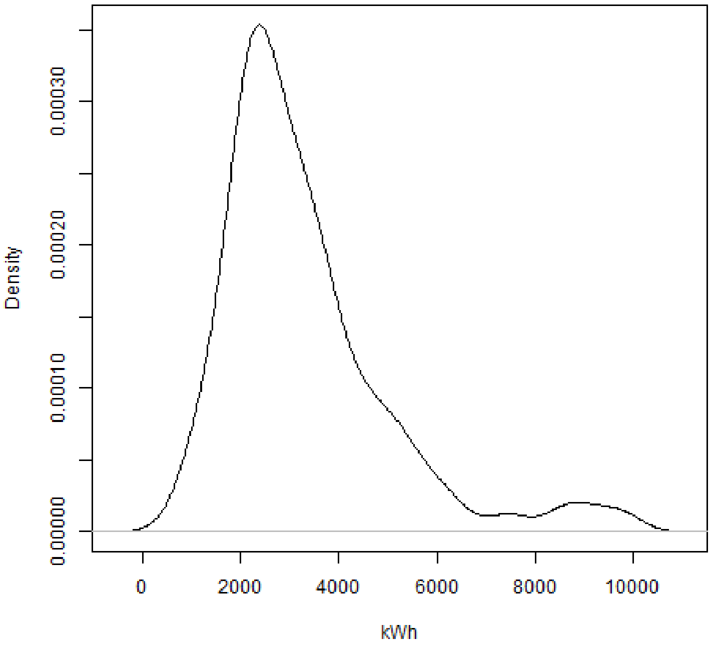

Figure 32: Distribution of the annual energy consumption in kWh for TC9a (With Dependencies)

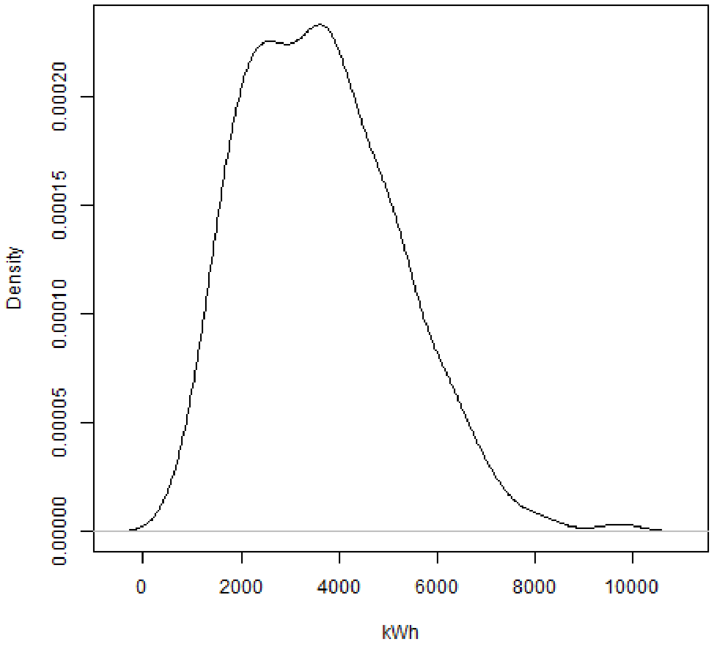

Figure 33: Distribution of the annual energy consumption in kWh for TC9a (Without Dependencies)

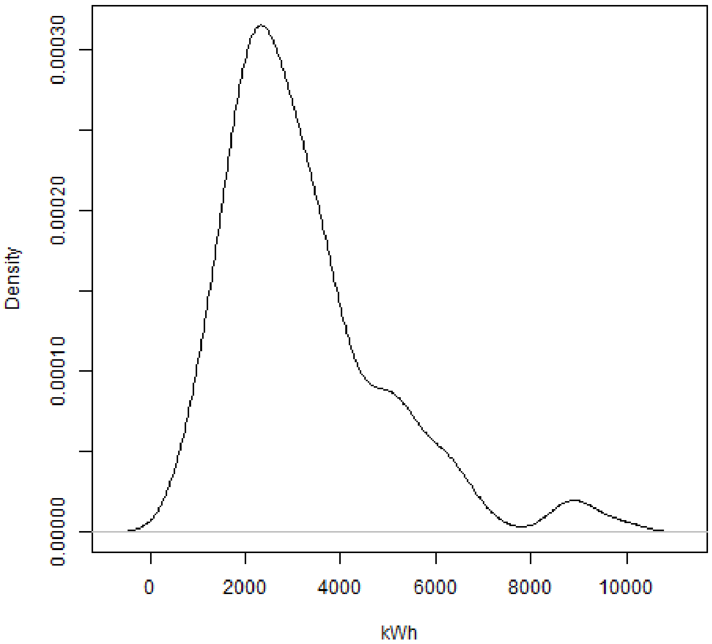

Figure 34: Distribution of the annual energy consumption in kWh for TC9a (Renter)

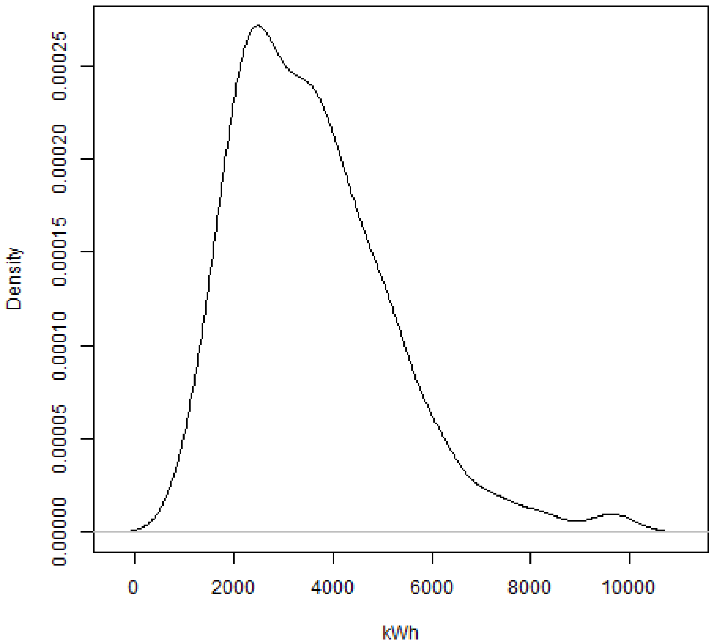

Figure 35: Distribution of the annual energy consumption in kWh for TC9a (Non-renter)

	Annual consumption in kWh	
Demographic	**Mean (μ)**	**Standard Deviation (σ)**
High Efficiency	3448.673	1707.720
Low Efficiency	3479.927	1609.032
High Income	3699.647	1608.416
Low Income	3196.890	1641.979
With Dependencies	3299.980	1715.383
Without Dependencies	3636.807	1550.301
Renter	3216.212	1716.831
Non-renter	3586.584	1594.392

Table 9: Means and standard deviations for TC9a annual electricity consumption (all time periods) by DEI demographic. All values reported in kWh.

	Annual consumption in kWh	
Demographic	**Mean (μ)**	**Standard Deviation (σ)**
Mosaic A	5690.897	2406.464
Mosaic B	3935.227	1446.348
Mosaic C	4447.274	1702.549
Mosaic D	3307.956	1451.685
Mosaic E	2166.996	1083.822
Mosaic F	3638.948	1388.711
Mosaic G	5019.540	2577.690
Mosaic H	2500.181	830.947
Mosaic I	3577.407	1456.747
Mosaic J	3075.440	1612.864
Mosaic L	2394.025	1311.873
Mosaic M	3268.780	1460.990
Mosaic N	3400.237	1603.435
Mosaic O	4020.378	2379.833

Table 10: Means and standard deviations for TC9a annual electricity consumption (all time periods) by mosaic category. All values reported in kWh.

It appears that Mosaic I, Mosaic J, Mosaic L and Mosaic M have larger tails to their distributions, with Mosaic L being the most different to the others, although it is difficult to quantify this in any way. As above when discussing peak power demand we see many multimodal distributions, caused by the small sample size for certain mosaic categories. Table 10 suggests that Mosaic E, Mosaic H and Mosaic L possibly have smaller mean annual consumptions, whilst Mosaic A possibly has a larger mean. We observe that Mosaic H has a smaller standard deviation than any other mosaic category, but with a sample size of 7, this is hardly quantifiable.

4.7.2 Comparing TC9a to TC1a, Accounting for Demographics

We now investigate to see whether different demographic groups show a change in the peak power demand in the peak period between TC1a and TC9a and in the annual consumption between the two test cells. We compare TC1a and TC9a by Dependencies and Housing Tenure; along with 14 of the 15 mosaic categories (we ignore Mosaic K as it has a sample size of 1 in TC9a). We present a monthly breakdown by weekday or weekend for peak power demand, (as in the above analysis for the test cells as a whole), only if there is a significant difference at an annual level.

As a warning to the reader at this point; it is likely that although we may see a difference in the values of μ_{TC1a} and μ_{TC9a}, we will not see a significant difference for many of the mosaic categories due to the small sample sizes. If interest does lie in the differences in TC1a and TC9a by mosaic category a secondary study would need to be carried out where significant numbers of customers for each mosaic category in TC9a are obtained, (these numbers can be calculated using sample size calculations). We will at this point investigate all demographics (for which we have an equivalent definition across TC1a and TC9a) to see where any significant differences lie.

Peak Power Demand in the 4-8pm Period

We first consider the peak power demand in the 4-8pm peak period. We begin by taking the Dependencies subset of the data, first investigating those with household members under 5 or 65+. We find that TC1a has a mean annual mean 4-8pm peak of 1.073 kW whilst TC9a has a mean annual mean 4-8pm peak of 1.036 kW, performing a two-tailed t-test with the same null and alternative hypotheses used throughout this analysis we observe a p-value of 0.327. This is not significant and as such there is no difference in the mean annual mean 4-8pm peaks of TC1a and TC9a. The mean annual max 4-8pm peaks are 3.752 kW and 3.623 kW for TC1a and TC9a respectively; the p-value associated with the test for these values is 0.249, again this is not significant and there is no difference between TC1a and TC9a. Thus for those with dependencies we see no difference in the means for TC1a and TC9a regarding their annual mean 4-8pm peak and their annual max 4-8pm peak.

We now turn our attention to those in TC1a and TC9a without dependencies. TC1a has a mean annual mean 4-8pm peak of 1.352 kW and a mean annual max 4-8pm peak of 4.584 kW; the figures for TC9a are respectively 1.202 kW and 4.181 kW. We again perform two-tailed t-tests and see a p-value of 0.000 for the annual mean 4-8pm peak and a p-value of 0.002 for the annual max 4-8pm peak (see table A5 in the appendices for a full list of p-values relating to peak power demand for those without dependencies). Both these values are significant and as such we can say there is a difference in the means of TC1a and TC9a for the annual mean and max 4-8pm peaks.

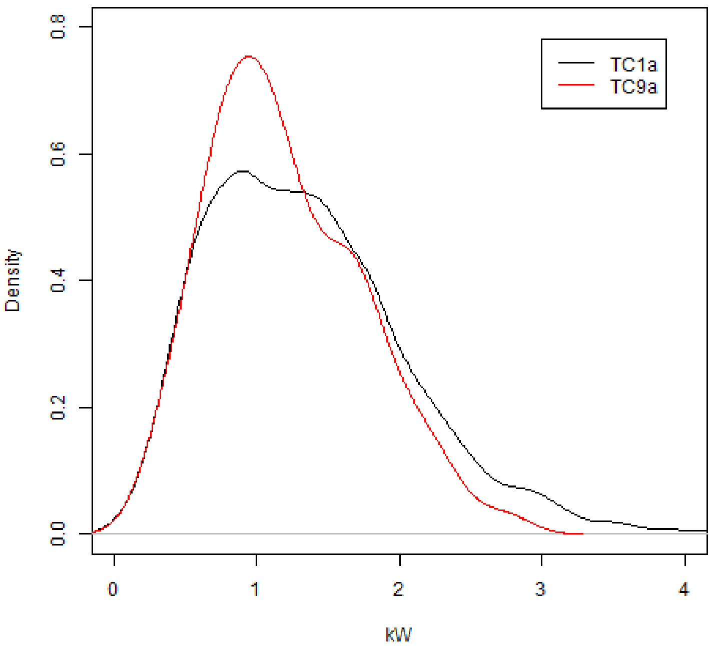

Figure 36: Distribution of the annual mean 4-8pm peak in kW for TC1a and TC9a (Without Dependencies)

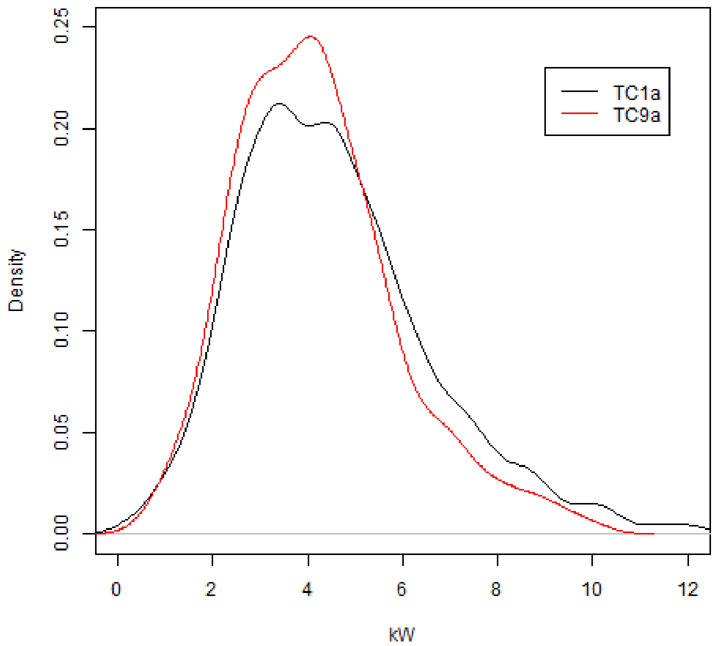

Figure 37: Distribution of the annual max4-8pm peak in kW for TC1a and TC9a (Without Dependencies)

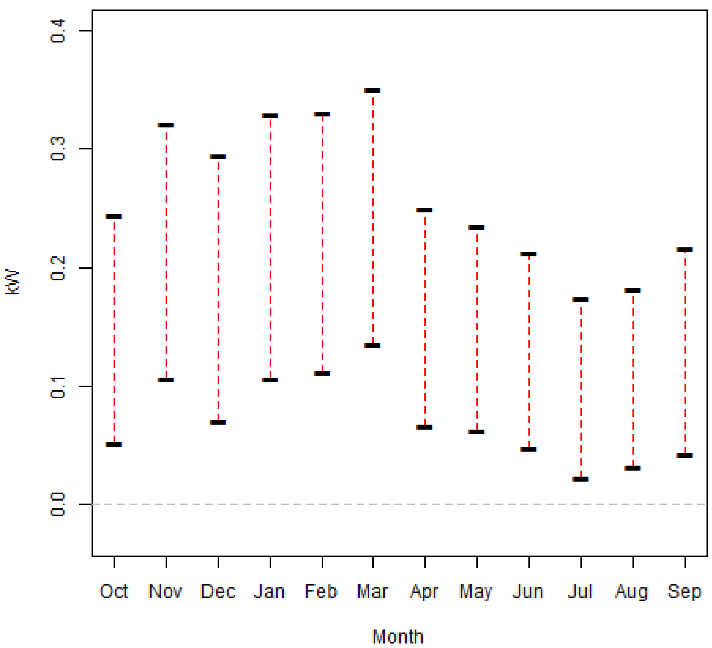

Figure 38: 95% confidence intervals for the difference in the means of the monthly weekday mean 4-8pm peak in kW for TC1a and TC9a (Without Dependencies). Positive values indicate that the mean of TC1a is greater than the mean of TC9a.

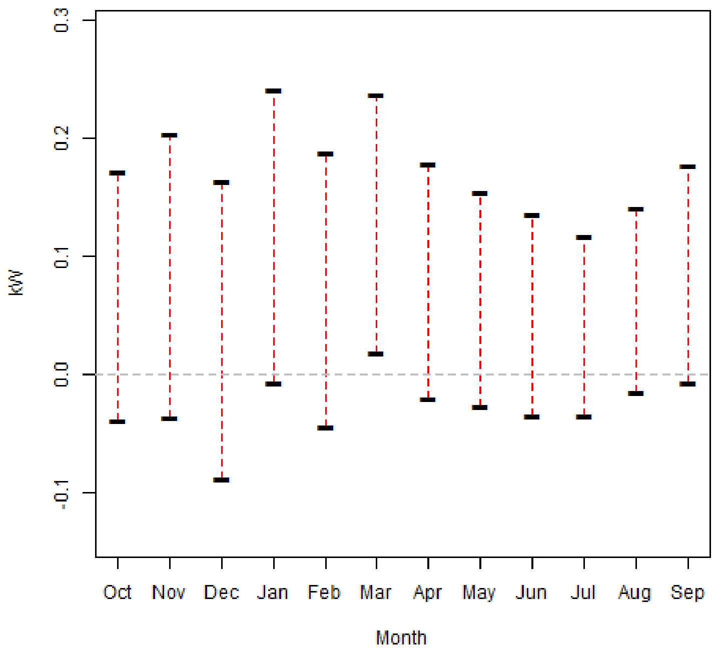

Figure 39: 95% confidence intervals for the difference in the means of the monthly weekend mean 4-8pm peak in kW for TC1a and TC9a (Without Dependencies). Positive values indicate that the mean of TC1a is greater than the mean of TC9a.

Figure 36 and Figure 37 illustrate the distributions of the annual mean 4-8pm peaks and annual max 4-8pm peaks for TC1a and TC9a respectively. From these plots we may have expected to observe a difference between TC1a and TC9a as the distribution for TC9a has a smaller tail and a higher density at smaller values in both plots. The 95% confidence intervals produced with the t-tests are (0.066, 0.234) for the annual mean 4-8pm peak and (0.149, 0.656) for the annual max 4-8pm peak. This suggests that TC1a has a mean mean 4-8pm peak which is greater by 0.066 kW to 0.234 kW and a larger mean max 4-8pm peak which is between 0.149 kW and 0.656 kW bigger. A suggestion, that for both the mean and max 4-8pm peak there has been a reduction for TC9a.

As there has been a significant difference at the annual level we further test for any differences between test cells for a specific month, given the condition of either being weekdays or weekends (see table A5). Performing two-tailed t-tests we observe significant p-values for 10 of 12 months when considering the mean weekday 4-8pm peak of TC1a and TC9a, with July – August 2013 being non-significant. We see no significant p-values when considering the mean weekend 4-8pm peaks. This is evident in Figure 38 and Figure 39 which show the 95% confidence intervals associated with the relevant t-tests.

Figure 38 shows confidence intervals consisting of purely positive numbers, indicating that for weekdays, the mean of TC9a is lower than the mean of TC1a for the months where a significant difference was observed. Figure 39 features confidence intervals containing 0 and as such we see no significant difference between the test cells. Similar patterns can be seen regarding the mean max weekday or weekend 4-8pm peaks (Figure A59 and Figure A60).

Next we subset TC1a and TC9a according to Housing Tenure. For renters TC1a has a mean annual mean 4-8pm peak of 1.097 kW whilst TC9a has a mean annual mean 4-8pm peak of 1.016 kW, the mean max 4-8pm peaks are 3.980 kW and 3.778 kW respectively. P-values associated with the t-tests for the mean 4-8pm peak and max 4-8pm peak are 0.107 and 0.205, both are not significant. As such there is no difference in the means of TC1a and TC9a for the annual mean 4-8pm peak or annual max 4-8pm peak according to a renter status.

Considering non-renters the mean annual mean 4-8pm peak of TC1a is 1.284 kW and 1.167 kW for TC9a, with mean annual max 4-8pm peaks of 4.299 kW and 3.963 kW. Performing t-tests we observe a p-value of 0.001 for both the annual mean and annual max peaks, meaning we have a significant difference in the annual mean and the annual max. The 95% confidence interval associated with the annual mean peaks is (0.048, 0.186) whilst the confidence interval for the max peaks is (0.132, 0.540). Both of these confidence intervals show that the mean of TC1a is greater than the mean of TC9a for the annual mean peaks and annual max peaks.

As we see a significant difference between the two test cells annually we investigate on a monthly by weekday or weekend level. Table A6 shows the relevant p-values and Figures A61 – A64 show associated 95% confidence intervals. The patterns we observe are near identical to those discussed above for those without dependencies. From table A6 we have significant p-values for October 2012 – May 2013 when considering the mean weekday 4-8pm peaks, with no significant values for weekends. In all cases where we observe a significant difference TC1a is greater than TC9a.

Partitioning the data by mosaic category we only observe 1 significant difference in the annual means of TC1a and TC9a, which is for Mosaic F: Suburban Mindsets. For Mosaic F we see a mean annual mean 4-8pm peak of 1.430 kW in TC1a and 1.188 kW in TC9a, this has an associated p-value of 0.001. This is significant and the 95% confidence interval is given by (0.103,0.380) indicating that the mean annual mean 4-8pm peak of TC1a is 0.103 kW to 0.380 kW greater than the mean of TC9a. For the annual max 4-8pm peaks we observe means of 4.690 kW and 4.191 kW for TC1a and TC9a respectively with a p-value of 0.016. Note that all p-values associated with Mosaic F can be found in table A7. The 95% confidence for the annual max peaks is (0.094, 0.904) indicating that the mean of TC1a is somewhere between 0.094 kW and 0.904 kW bigger than the mean annual max of TC9a. We now investigate Mosaic F by calculating mean and max peaks by month and by either weekday or weekend. We find that 10 of the 12 p-values for the monthly weekday mean 4-8pm peak are significant with only May 2013 and July 2013 being non-significant, Figure 40 shows the 95% confidence intervals associated with these test. From Figure 40 we see that TC1a has a greater mean weekday mean peak in all the 10 months which show a significant difference. Table A7 and Figure 41 show that we see no significant differences between TC1a and TC9a when considering the monthly weekend mean 4-8pm peaks. We observe significant differences in the monthly max 4-8pm peaks for 7 months when considering weekdays and 4 months when considering weekends, from Figure 42 and Figure 43 we see that where there is a significant difference there is a reduction from TC1a to TC9a.

Total Electrical Energy Use

We now consider the annual consumption of TC1a and TC9a divided up by demographic. Table 9 shows the respective means of the annual consumption for all time periods for TC1a and TC9a along with the p-value from the relevant two-tailed t-test. We see that no demographic split gives a significant p-value, meaning we see no significant difference in the annual consumption between TC1a and TC9a for any demographic.

A Note on the Sample Sizes and P-values Observed

During the above analysis of peak power demand and annual consumption by demographic it may appear strange that we observe few significant p-values, particularly for demographics where the reader may have expected to see them. This could be down to one of two things, firstly, there could be no genuine difference between the demographic in TC1a and TC9a and the reader’s hunch was unfounded; or any difference is hidden by a small sample size. For a small sample we must observe a greater difference between the two test cells to distinguish between what is noise and what is a true difference, as a smaller sample typically contains more noise. Here we may have indeed seen some differences for some demographics but this difference is clouded by our uncertainty in the sample, i.e. lost within the larger noise. If interest does lie in whether there are differences in the test cells for each demographic a second study would need to be carried out with a significant number of customers in each demographic. This approach could still lead to a conclusion of no differences between the two test cells for each demographic however.

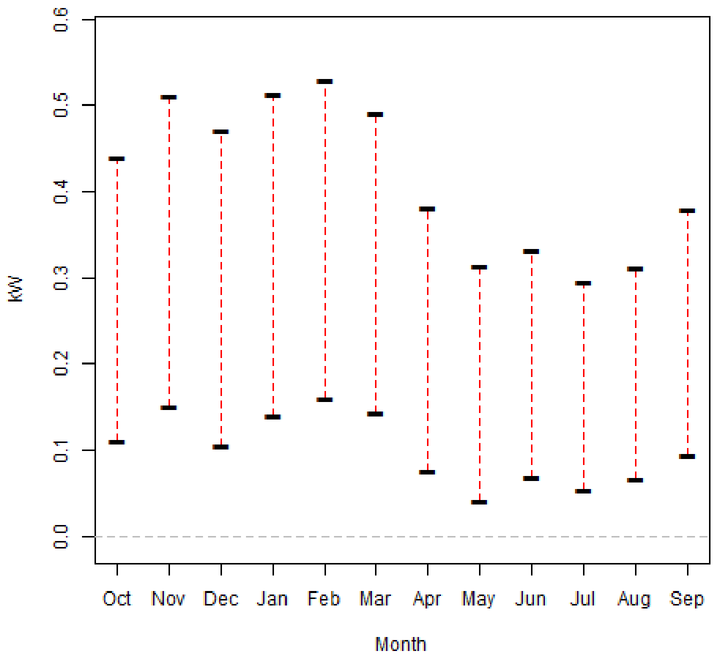

Figure 40: 95% confidence intervals for the difference in the means of the monthly weekday mean 4-8pm peak in kW for TC1a and TC9a (Mosaic F). Positive values indicate that the mean of TC1a is greater than the mean of TC9a.

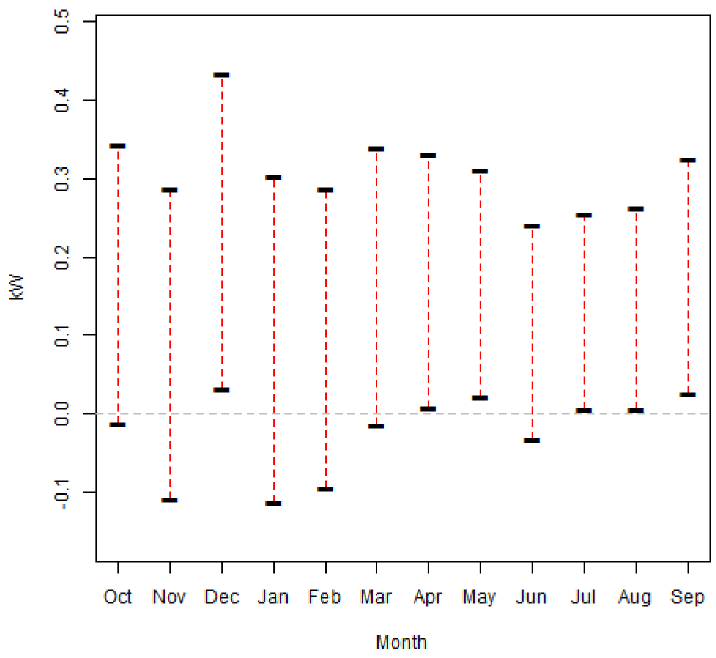

Figure 41: 95% confidence intervals for the difference in the means of the monthly weekend mean 4-8pm peak in kW for TC1a and TC9a (Mosaic F). Positive values indicate that the mean of TC1a is greater than the mean of TC9a.

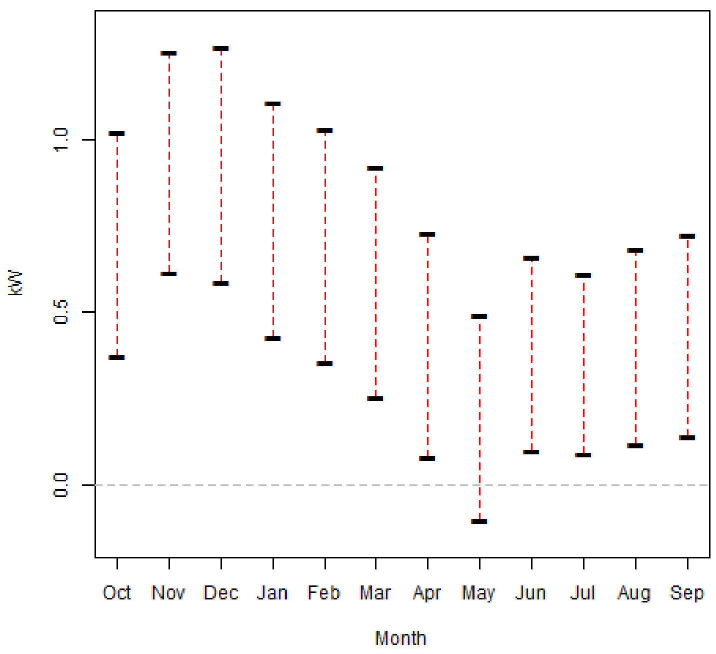

Figure 42: 95% confidence intervals for the difference in the means of the monthly weekday max 4-8pm peak in kW for TC1a and TC9a (Mosaic F). Positive values indicate that the mean of TC1a is greater than the mean of TC9a.

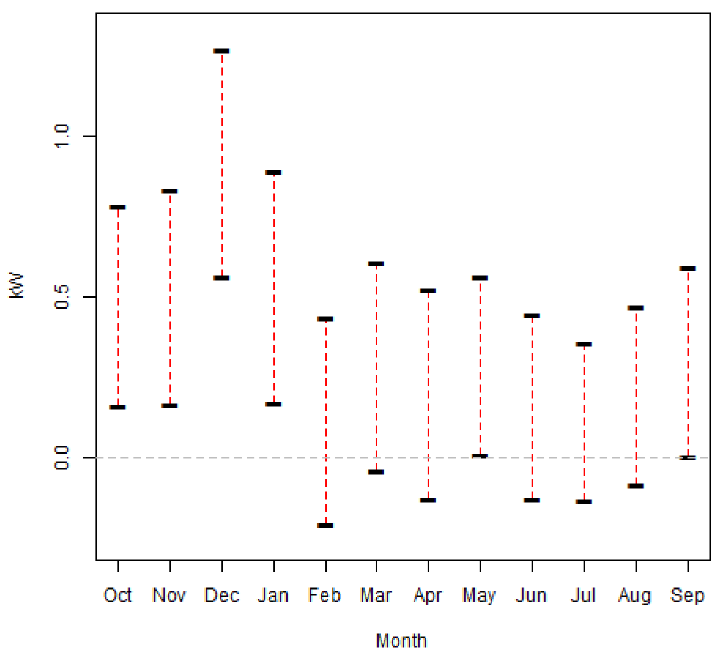

Figure 43: 95% confidence intervals for the difference in the means of the monthly weekend max 4-8pm peak in kW for TC1a and TC9a (Mosaic F). Positive values indicate that the mean of TC1a is greater than the mean of TC9a.

	Annual consumption in kWh		
Demographic	Mean of TC1a	Mean of TC9a	p-value for the difference in the mean electrical energy usage TC1a vs TC9a (3dp) [2 tailed test]
With Dependencies	3238.864	3299.980	0.615
Without Dependencies	3757.140	3636.807	0.315
Renter	3232.034	3216.212	0.919
Non-renter	3653.169	3586.584	0.515
Mosaic A	5399.123	5690.897	0.718
Mosaic B	4308.410	3935.227	0.272
Mosaic C	4677.403	4447.274	0.834
Mosaic D	3514.447	3307.956	0.401
Mosaic E	2777.237	2166.996	0.170
Mosaic F	3975.683	3638.948	0.107
Mosaic G	3966.406	5019.540	0.068
Mosaic H	2812.009	2500.181	0.520
Mosaic I	3468.685	3577.407	0.552
Mosaic J	3104.430	3075.440	0.906
Mosaic L	2343.820	2394.025	0.772
Mosaic M	3232.075	3268.780	0.839
Mosaic N	3289.976	3400.237	0.833
Mosaic O	3653.654	4020.378	0.620

Table 11: Table of means and p-values for 2-tailed t-tests assessing any differences in the mean absolute electrical energy usage during all periods for TC1a and TC9a by demographic. No category shows significant results.

4.8 Peak Day Load Profiles

Another area of interest is to consider the half hourly load profiles on the peak day for each test cell. The peak day for TC1a in the period 1st October 2012 – 30th September 2013 is Friday 18th January 2013 with the corresponding peak day for TC9a being Sunday 20th January 2013. We therefore look to construct load profiles for Friday 18th January, Saturday 19th January and Sunday 20th January 2013 along with the monthly average in each half hourly period for January 2013. This means we have half hourly load profiles for both TC1a and TC9a for the peak day in each test cell along with the intermediate Saturday and monthly average. Figures 44 -59 illustrate the means and standard deviations for TC1a and TC9a for each day for all customers in each test cell and the comparable DEI demographics (renters, non-renters, those with dependencies and those without dependencies). Looking at the figures we note that TC1a produces smoother load profiles when compared with TC9a, this is evidence of the higher number of customers in TC1a. Only 77 renter customers with non-zero readings where available in TC9a on Friday 18th January, however other days are slightly better represented with customer numbers typically somewhere between 120 and 200 in TC9a for any demographic on a given day, these values are still considerably smaller than those for TC1a.

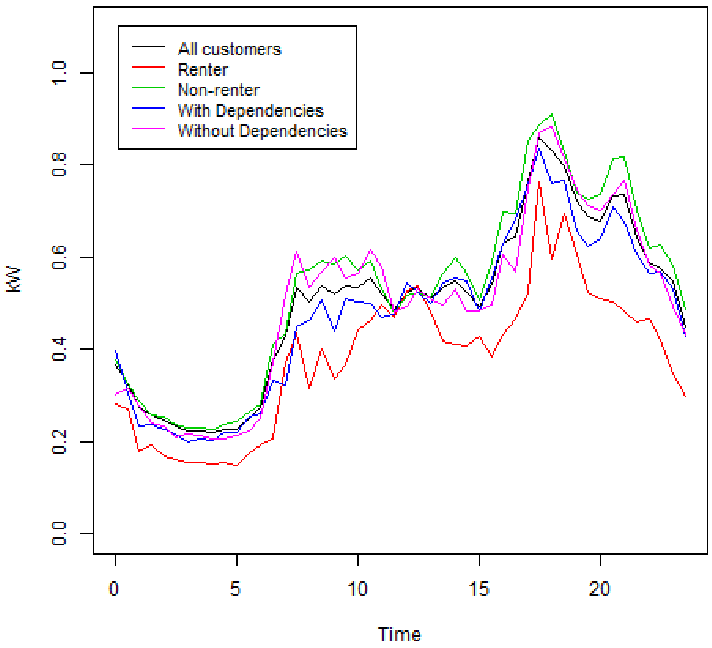

Figure 44: Load profiles for the mean of each half hourly period on Friday 18th January 2013 in TC9a.

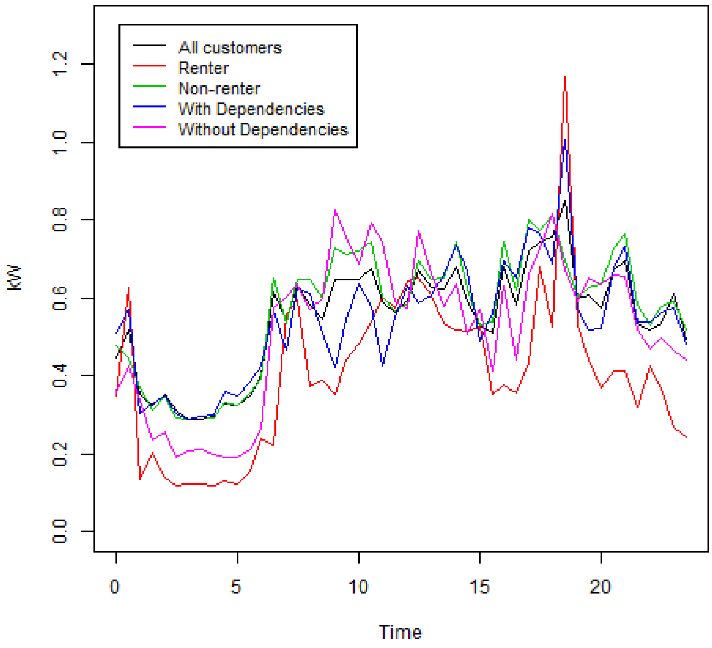

Figure 45: Load profiles for the standard deviation of each half hourly period on Friday 18th January 2013 in TC9a.

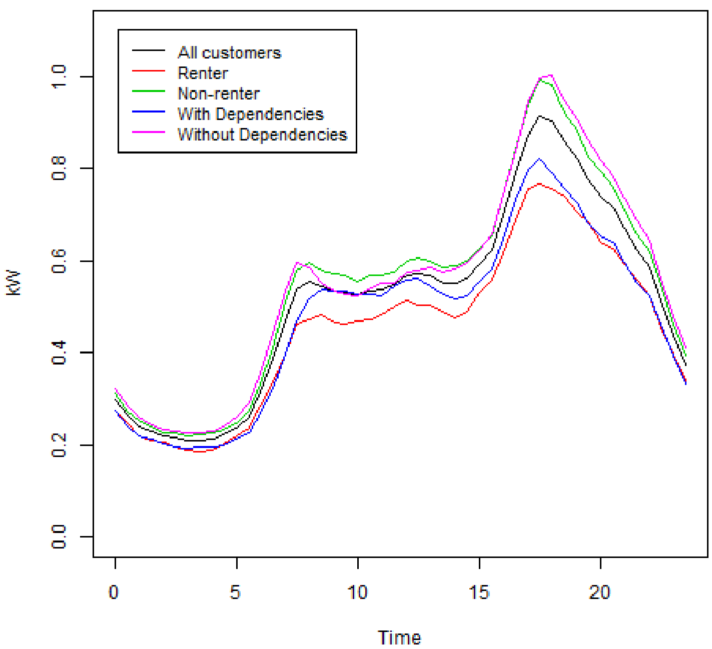

Figure 46: Load profiles for the mean of each half hourly period on Friday 18th January 2013 in TC1a.

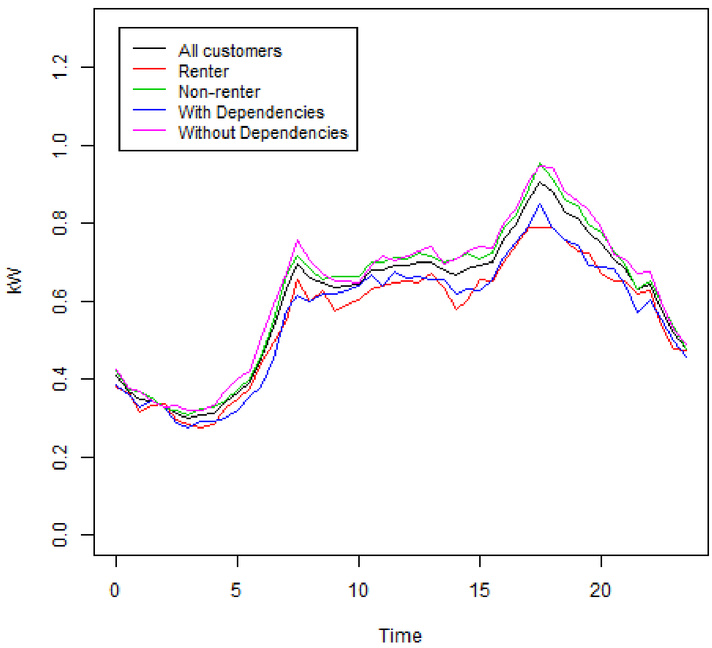

Figure 47: Load profiles for the standard deviation of each half hourly period on Friday 18th January 2013 in TC1a.

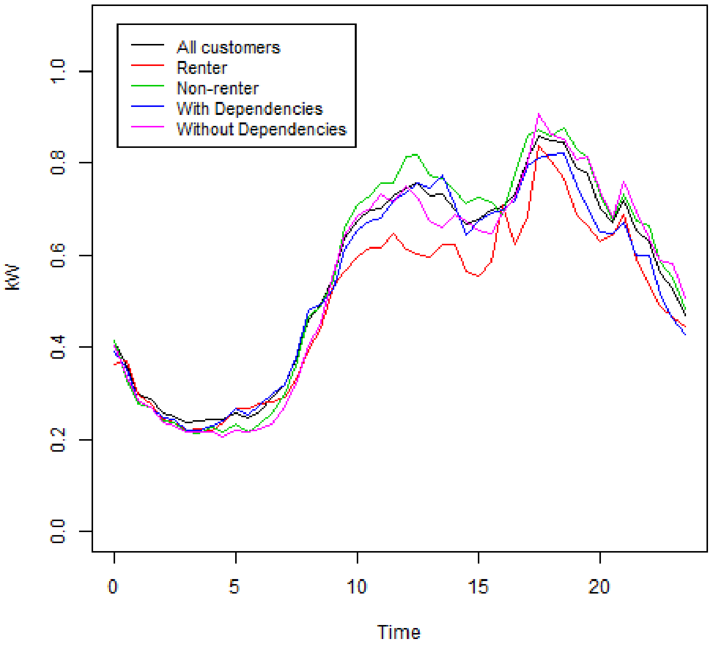

Figure 48: Load profiles for the mean of each half hourly period on Saturday 19th January 2013 in TC9a.

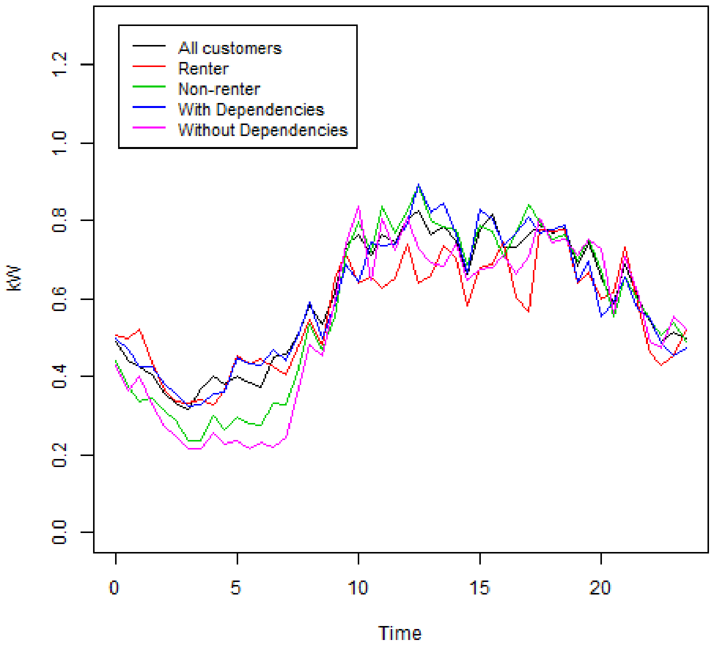

Figure 49: Load profiles for the standard deviation of each half hourly period on Saturday 19th January 2013 in TC9a.

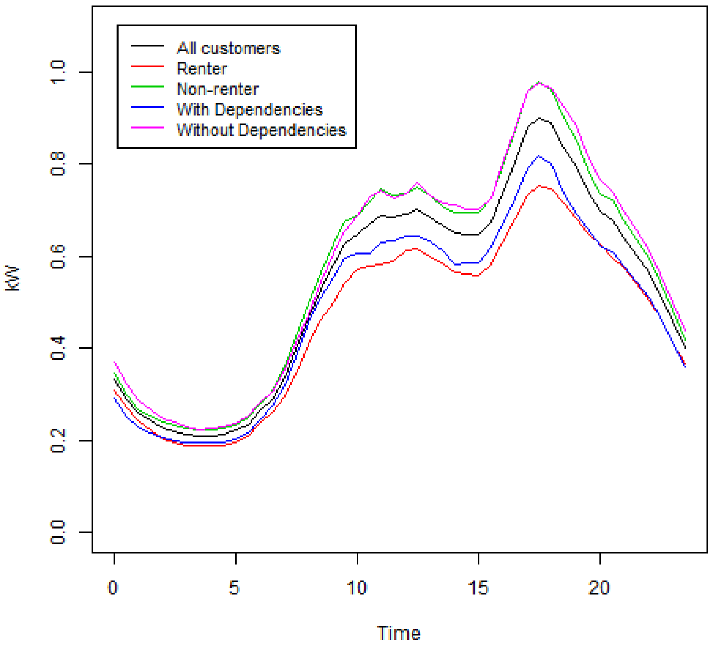

Figure 50: Load profiles for the mean of each half hourly period on Saturday 19th January 2013 in TC1a.

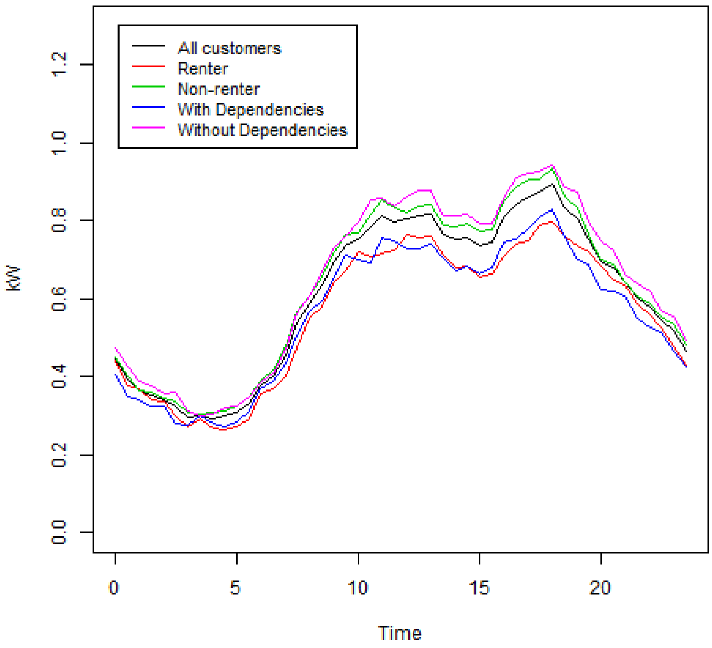

Figure 51: Load profiles for the standard deviation of each half hourly period on Saturday 19th January 2013 in TC1a.

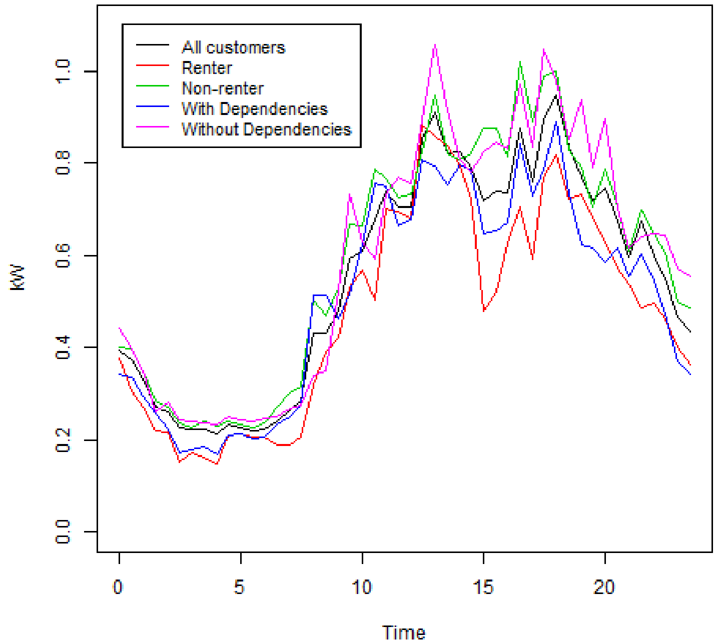

Figure 52: Load profiles for the mean of each half hourly period on Sunday 20th January 2013 in TC9a.

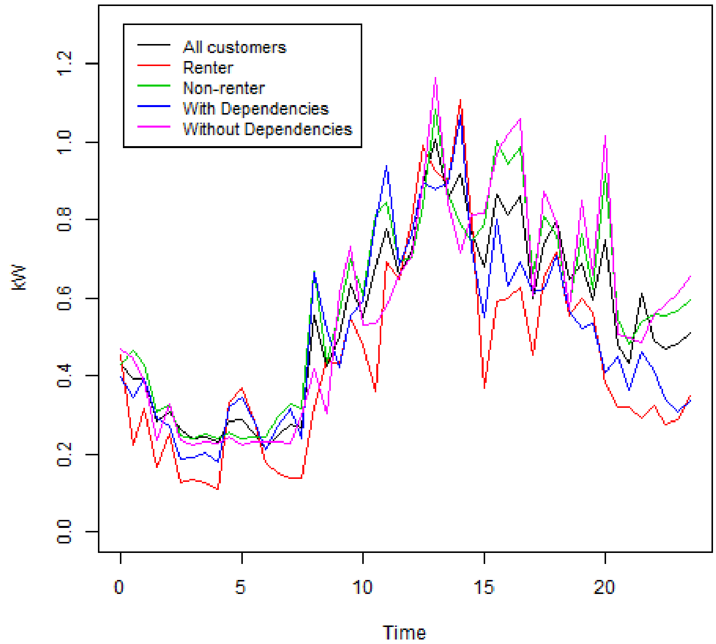

Figure 53: Load profiles for the standard deviation of each half hourly period on Sunday 20th January 2013 in TC9a.

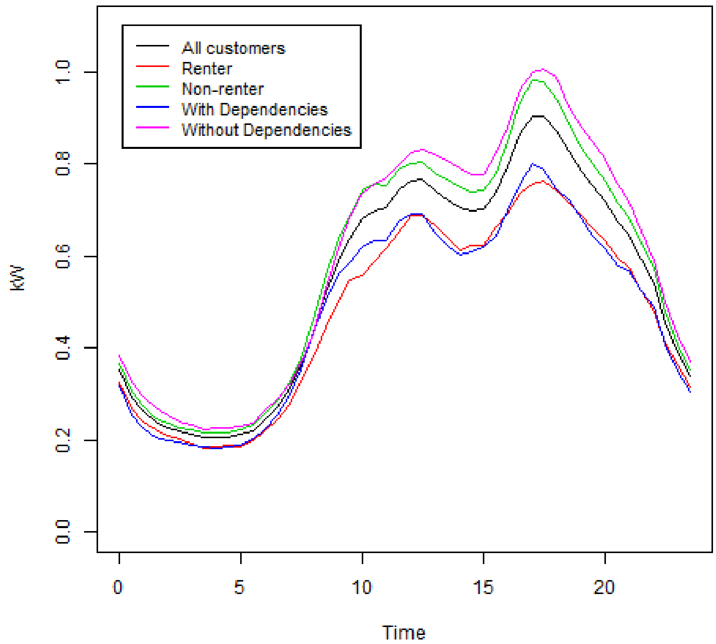

Figure 54: Load profiles for the mean of each half hourly period on Sunday 20th January 2013 in TC1a.

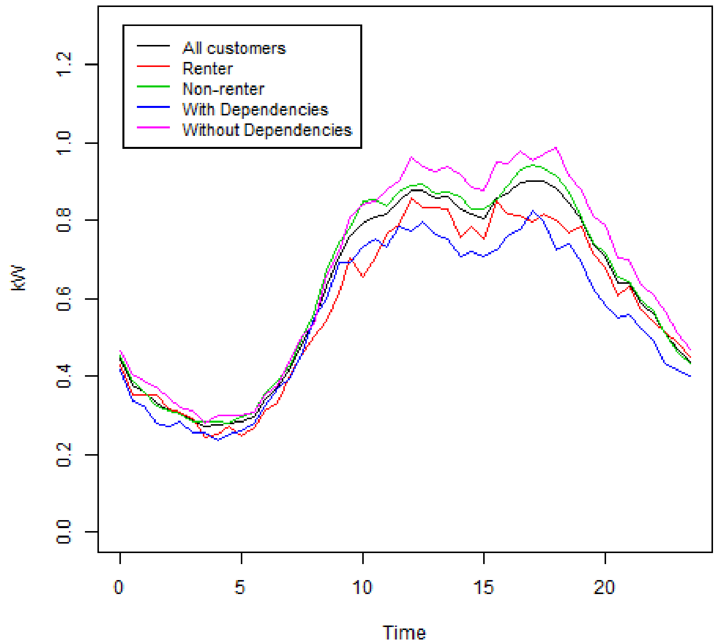

Figure 55: Load profiles for the standard deviation of each half hourly period on Sunday 20th January 2013 in TC1a.

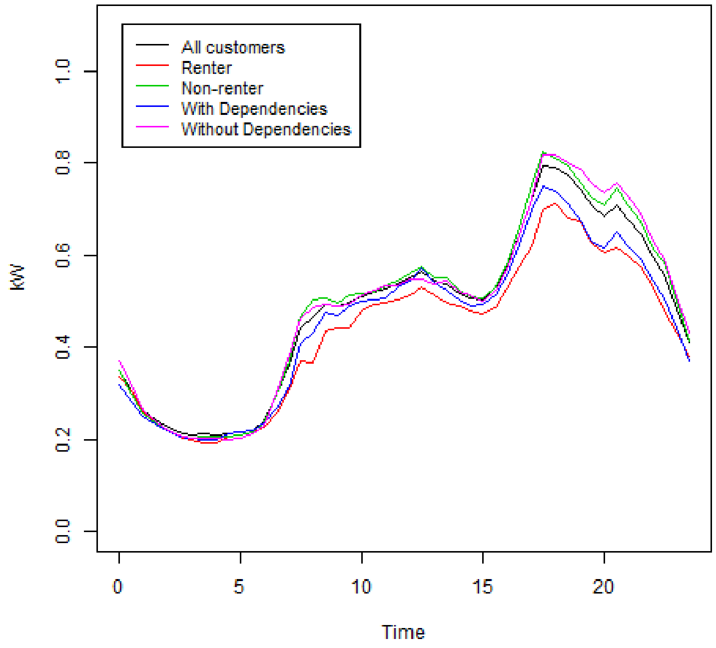

Figure 56: Load profiles for the mean of each half hourly period of the January 2013 average in TC9a.

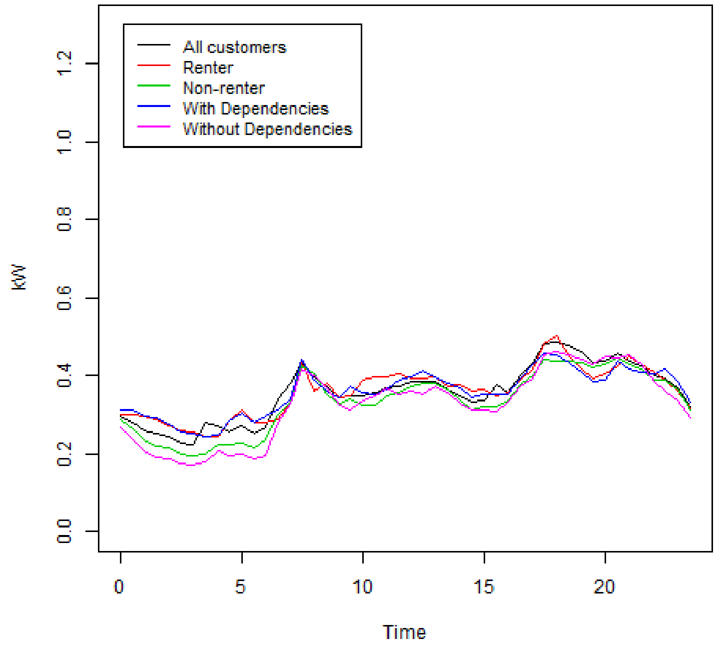

Figure 57: Load profiles for the standard deviation of each half hourly period of the January 2013 average in TC9a.

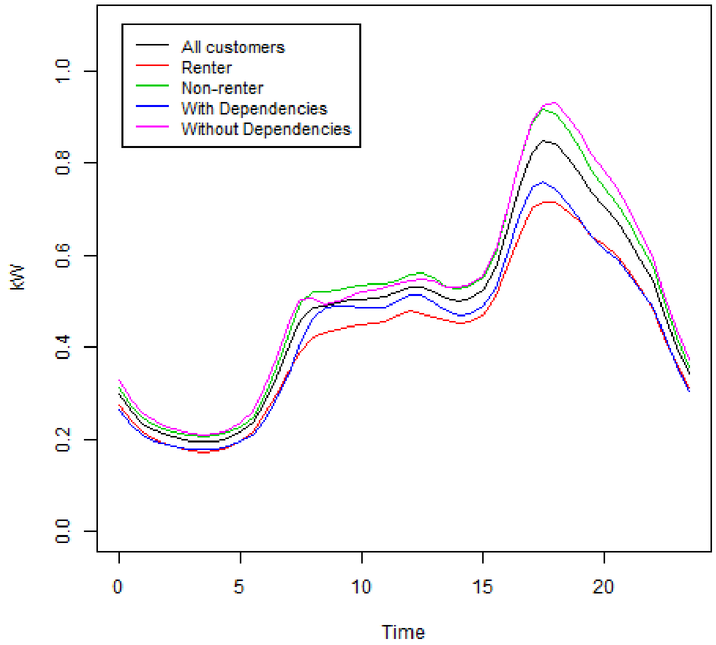

Figure 58: Load profiles for the mean of each half hourly period of the January 2013 average in TC1a.

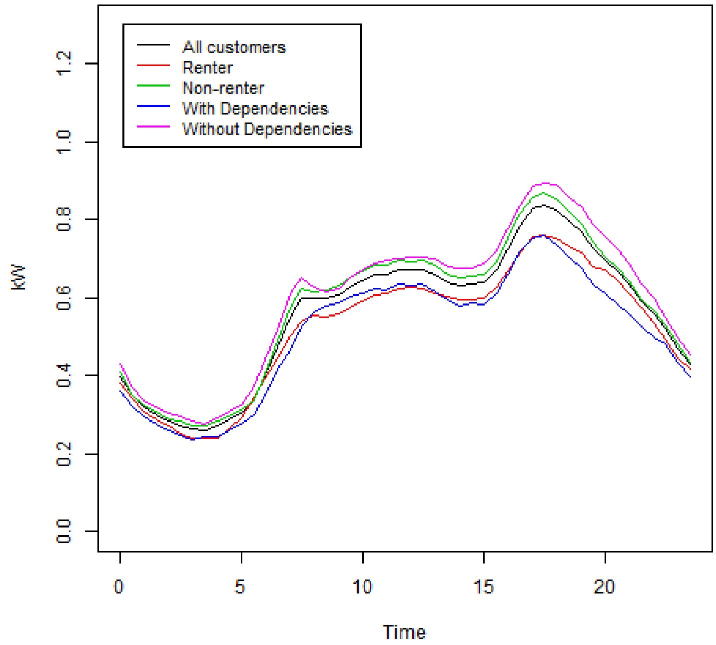

Figure 59: Load profiles for the standard deviation of each half hourly period of the January 2013 average in TC1a.

Both test cells are reasonably similar across any given day, especially when you combine the means and standard deviations, however there is a slight indication that TC1a may be slightly higher on Friday 18th January with TC9a possibly being higher on Sunday 20th January. This is unsurprising given that these dates are regarded as the peak day for the respective test cells, although there is still little difference between the test cells on these days. There is some suggestion that renters and those with dependencies have slightly lower load profiles, however there is little difference between the load profiles of any demographics and if we combine the means and standard deviations we find that confidence intervals for all demographics overlap, showing no difference between the demographic splits. Note that no formal testing occurred here and these conclusions have been drawn from visual inspection. As a final note, from the figures it appears that TC9a and TC1a follow the same rough pattern in the mean and standard deviation across any given day with the differences in TC9a attributable to the smaller sample size in TC9a, with the possible exception of the January average standard deviations. It is interesting to note that we observe smaller standard deviations during the night when houses are likely to be similar but greater standard deviations during the day, with the largest standard deviations appearing during the morning and evening peaks when houses can differ dramatically.

Table 12 shows the mean peak, the standard deviation of the peak and the end of the half hour in which the peak occurs for the peak day in TC1a (Friday 18th January 2013) and the monthly average in which the peak day occurs (January 2013), for all customers in TC1a and TC9a. We see that for both test cells on the 18th January and for the monthly average the peak occurred between 17:30 and 18:00. There is little difference in the mean peak values between TC1a and TC9a, with a slight suggestion that TC9a may have a lower peak. However the difference is not statistically significant and as such the mean peaks in TC1a and TC9a are not different on the 18th January or across the monthly average. This difference was assessed in each case using a two-tailed t-test with the same null and alternative hypotheses as used throughout this analysis.

TC1a peak day analysis for all customers in TC1a and TC9a			
Period analysed	**Value of the mean peak (kW)**	**Standard deviation of the peak (kW)**	**End of the half hour in which the peak occurs (hh:mm)**
TC1a peak day, 18th Jan. 2013	0.913	0.907	18:00
TC9a 18th Jan. 2013	0.859	0.745	18:00
TC1a Jan. 2013 average	0.847	0.837	18:00
TC9a Jan. 2013 average	0.793	0.480	18:00

Table 12: TC1a peak day (Friday 18th January 2013) analysis, with monthly averages and corresponding TC9a analysis

4.9 Customers who did not save on the tariff

We conclude our analysis by investigating the electricity usage of the 40% of customers in TC9a who lost money after switching to the tariff. These were calculated through shadow billing at a flat rate.

It should be noted that it was possible for TC9a customers to have saved money even without a change in behaviour, these would be customers who already had a lower than average proportion of their consumption during peak hours. The shadow billing was carried out for the whole observation period and these dates extend beyond those which are analysed here. As such, those who lost money may not have necessarily lost money over the date range studied for this analysis. Of the total 243 customers who lost money, 199 customers fell within the date range of this analysis (1st October 2012 – 30th September 2013).

It should be noted that by only considering those that lost money, we are manipulating the data and possibly engineering the behaviour we wish to see. As such the numbers given here are subject to bias and may not be truly representative of a population where all customers lost money. The aim here is to identify any abnormal behaviour in those that lost out under the tariff, from which we can offer possible anecdotes about the general population if those that lost out under the tariff are presumably removed from the tariff for the following year.

An area for further study on those who saved/lost money under the tariff could be an experiment to investigate the following:

1. Observe everyone for 1 year unrestricted.
2. Place everyone on the tariff and observe for a further year.
3. Calculate who saved money and who lost money. Those that saved money stay on the tariff. Those that lost money would transfer back to the flat rate. Observe for a final year to distinguish any further changes in behaviour (e.g. those that saved money may relax and lose money for the second year under the tariff. Do those that lost money stay constant over the 3 years? Etc.)
   * Point 3 could be recursively implemented until the maximum number of observational years has been completed.

We begin by considering the distribution of the money lost for all TC9a customers, illustrated in Figure 60. This shows a distribution with a long positive tail, with most density found between 0 and 75. The minimum customer loss was 1p and the maximum loss by one customer was £190.78. The mean loss for TC9a customers was £30.78 however this value is affected by the long positive tail of the distribution; we find the median loss to be £18.40 with a standard deviation of £36.66. Given a customer's natural yearly bill variation there is a question of whether a customer who only lost 1p should be classified as a customer who lost out under the tariff; these customers have the potential to introduce further bias into the study. However as this is the only data available into whether a customer lost money under the tariff, and we have no information about a customer's bill variation, we include all customers who lost money in our analysis for as much transparency as possible.

If we consider the demographic makeup of those in TC9a who lost money under the tariff we find that all mosaic categories are represented, along with all DEI demographic categories. By visual

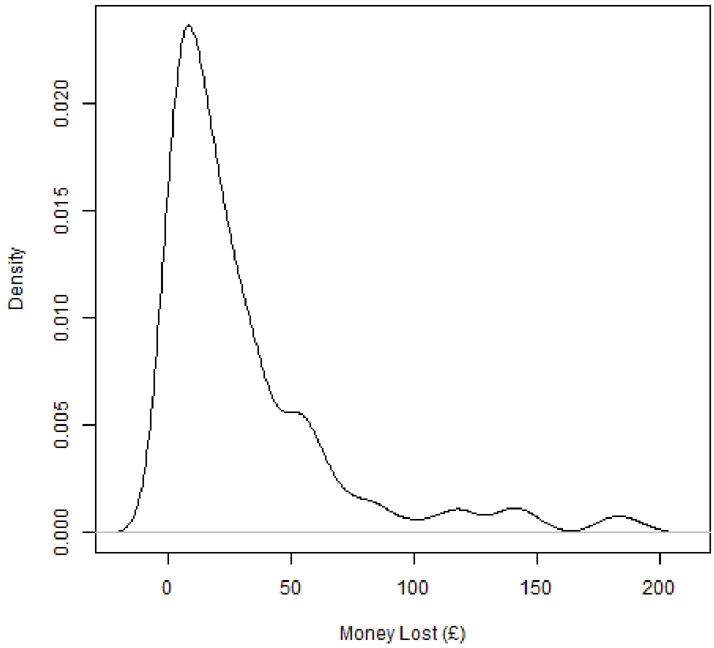

Figure 60: Total money (£) lost for all TC9a customers who lost money under the tariff (243 customers).

inspection the proportions of these demographics are representative of TC9a (no statistical testing has taken place to confirm this). From this we proposition that no specific demographic group or mosaic category lost money under the tariff, and that those who did lose money are overall representative of the TC9a population.

For those that lost money we now consider their peak power demand by investigating their annual mean 4-8pm peak and annual max 4-8pm peak, comparing against the whole population in TC1a. Figure 61 shows the distributions of the annual mean 4-8pm peaks for TC1a and for those that lost money in TC9a, with Figure 62 showing the distributions for the annual max 4-8pm peaks. Both figures show little difference in the distributions of TC1a and TC9a, with any apparent differences likely heightened by the smaller sample size of those that lost money in TC9a (199 customers). There is the slightest suggestion that those customers who lost money in TC9a may have a higher mean peak demand, although this requires further analysis to quantify if this is a significant change (see below). The tails of all distributions appear fairly similar. As reported earlier, TC1a has a mean annual mean 4-8pm peak of 1.219 kW with a standard deviation of 0.674 kW and a mean annual max 4-8pm peak of 4.188 kW with a standard deviation of 2.015 kW. Those who lost money in TC9a have a mean annual mean 4-8pm peak of 1.302 kW with a standard deviation of 0.542 kW and a mean annual max 4-8pm peak of 4.131 kW with a standard deviation of 1.756 kW.

To quantify if there has been any change in the means of these distributions we perform a two-tailed t-test, with the same null and alternative hypotheses as used throughout this whole analysis. First we consider the distributions of the annual mean 4-8pm peak for TC1a and TC9a (for those that lost money) which gives a p-value of 0.086 (see Table A8 in the appendices for a full list of p-values relating to those in TC9a who lost money). This is not significant and as such we can say there has

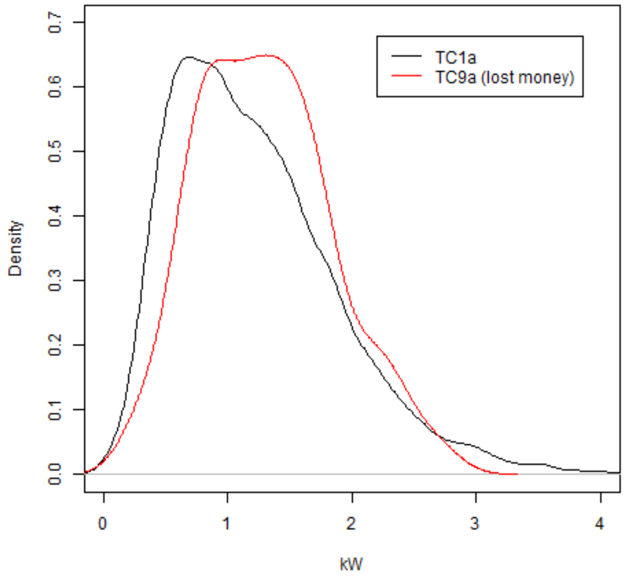

Figure 61: Distribution of the annual mean 4-8pm peak in kW for TC1a and TC9a (those that lost money).

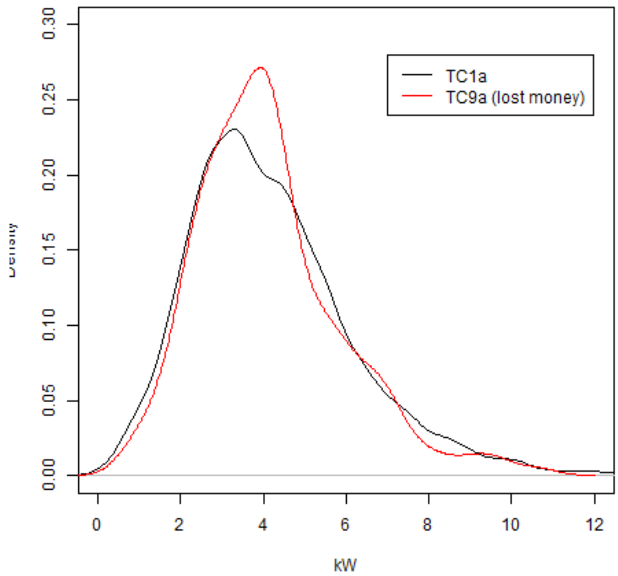

Figure 62: Distribution of the annual max 4-8pm peak in kW for TC1a and TC9a (those that lost money).

been no change in the means of these distributions, the 95% confidence interval produced with the test is (-0.179, 0.012). Considering the distributions of the annual max 4-8pm peak we observe a p-value of 0.697 which again is not significant, the 95% confidence interval associated with this test is given by (-0.229,0.342). We can therefore conclude that there is no difference between TC1a and those that lost money in TC9a for the annual mean 4-8pm peak and the annual max 4-8pm peak.

Thus at an annual level it is possible that those that lost money under the tariff in TC9a are similar to the average customer in TC1a, considering just their mean and max 4-8pm peak.

We can also take a subset and calculate these mean and max 4-8pm peaks by month and by weekday or weekend. This method produces 24 mean 4-8pm peaks for each customer (and indeed 24 max 4-8pm peaks); see table A8 for all p-values.

We observe a significant difference in the mean monthly weekday mean 4-8pm peak for June 2013, July 2013 and September 2013 with a significant difference in the mean monthly weekend max 4-8pm peaks for December 2012; all other tests produced non-significant p-values. The 95% confidence intervals associated with the two-tailed t-tests are presented in Figures 63-66.

From Figure 63 we can see that for the months where we observe a significant difference, those that lost under the tariff in TC9a have a greater mean weekday mean 4-8pm peak than the mean weekday mean 4-8pm peak in TC1a for that given month.

Figure 66 shows that TC1a has a greater mean weekend max 4-8pm peak than those who lost money under the tariff in TC9a for December 2012.

The above suggests that those who lost money under the tariff in TC9a look similar to the average TC1a customer, with the possible exception of a higher mean weekday mean 4-8pm peak for 3 months (although this increase may be minimal). Therefore if those who lost money under the tariff in TC9a were removed from TC9a, we could find that the means of the various metrics calculated would indeed be lower in TC9a. This gives the impression that we may possibly see a greater reduction in the peak power demand of a TC9a customer if these customers are removed, along with the possibility that we may now witness a significant difference in the annual consumption. This is unsurprising as we would expect a greater reduction if we only consider those customers who saved money under the tariff, and therefore changed their behaviour to exploit the tariffs price structure in their favour

Exploring this concept in more detail we can assume that those customers in TC9a who did not lose money under the tariff, did in fact save money. We further assume that those customers in TC9a who saved money, were most likely those who engaged with the tariff, and thus are likely to see greater reductions when compared to the average customer in TC1a.

We find that those who saved money have a mean annual mean 4-8pm peak of 1.029 kW and a mean annual max 4-8pm peak of 3.820 kW with standard deviations of 0.491 kW and 1.708 kW respectively. Both of these values are significantly different from TC1a, with those customers who saved money in TC9a having lower means in both cases.

However it should be noted that these results are caveated by the assumptions above. The 95% confidence interval for the difference in the annual mean 4-8pm peak between TC1a and those who saved money in TC9a is given by (0.120,0.260), suggesting that the mean annual mean 4-8pm peak is between 0.120 kW and 0.260 kW bigger in TC1a. This is a possible reduction in the mean annual mean 4-8pm peak demand of between 10.008% and 21.452% for those who saved money under the tariff.

That is, those who were placed on the tariff and engaged with the tariff see a greater reduction than those who were placed on the tariff and lost money, and all customers who were placed on the tariff. The last comparison is unsurprising given the above, as those customers who did not engage with the tariff increase the mean of the whole population within the test cell, meaning we do not see as great a reduction when comparing the populations as a whole.

We see significant differences in the mean 4-8pm peak for all months considering weekdays but for no months when considering weekends; for all cases where we witness a significant difference the mean is greater in TC1a.

If we compare the annual consumption of those who saved money under the tariff in TC9a against the average customer in TC1a we find no significant difference, that is, the annual consumption for those who saved money is the same as the annual consumption of the average customer in TC1a.

However these claims need further investigation before they can be statistically verified. A further experiment, such as the one outlined at the beginning of this sub-section, is needed in order to provide robust analysis in answering these questions.

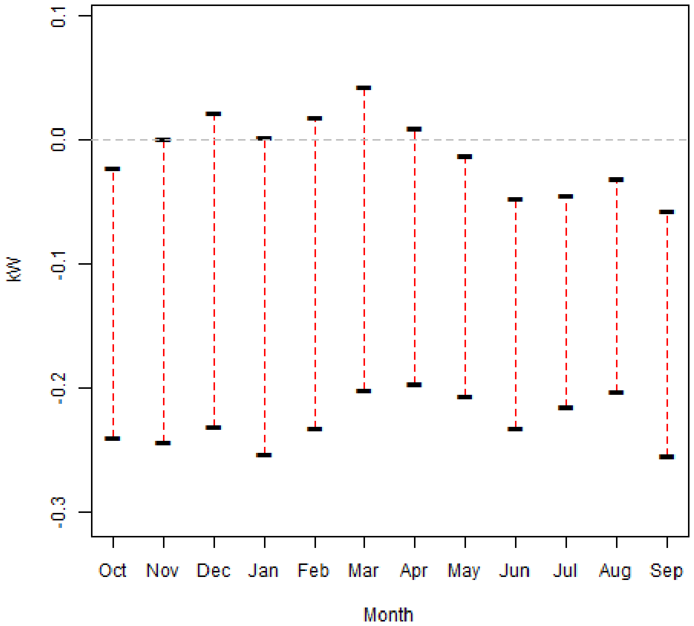

Figure 63: 95% confidence intervals for the difference in the means of the monthly <u>weekday mean</u> 4-8pm peak in kW for TC1a and TC9a (those that lost money). Positive values indicate that the mean of TC1a is greater than the mean of TC9a.

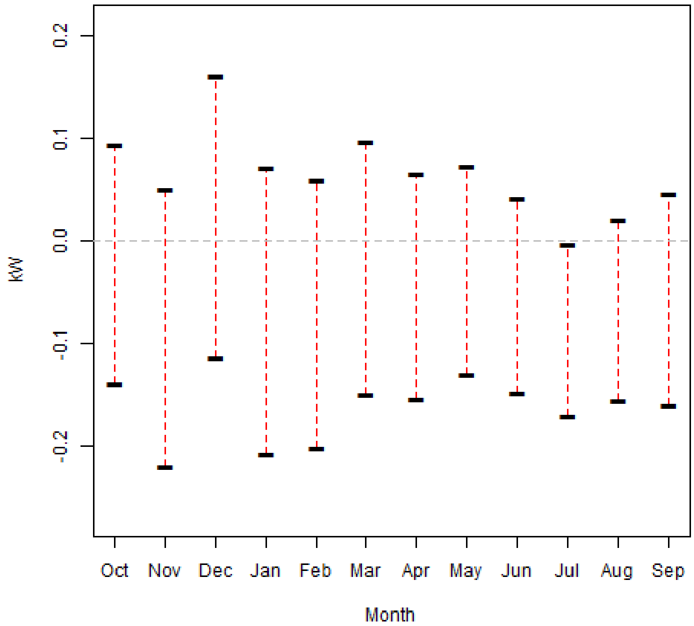

Figure 64: 95% confidence intervals for the difference in the means of the monthly <u>weekend mean</u> 4-8pm peak in kW for TC1a and TC9a (those that lost money). Positive values indicate that the mean of TC1a is greater than the mean of TC9a.

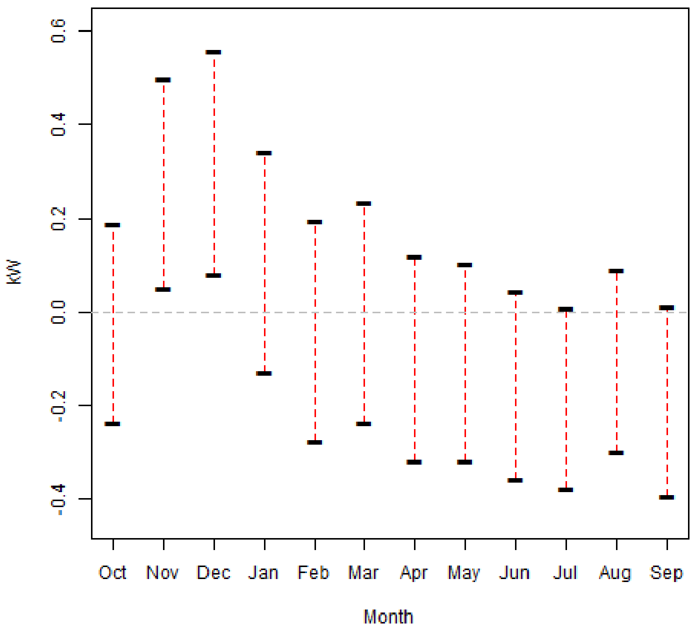

Figure 65: 95% confidence intervals for the difference in the means of the monthly <u>weekday max</u> 4-8pm peak in kW for TC1a and TC9a (those that lost money). Positive values indicate that the mean of TC1a is greater than the mean of TC9a.

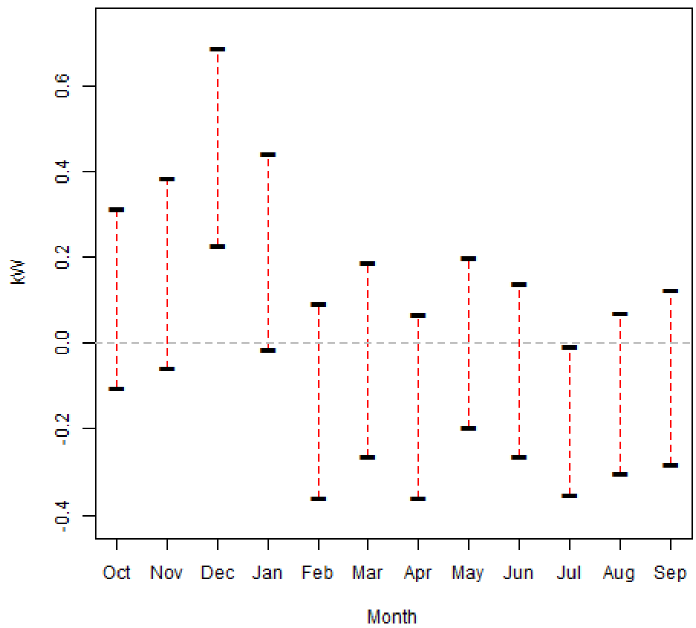

Figure 66: 95% confidence intervals for the difference in the means of the monthly <u>weekend max</u> 4-8pm peak in kW for TC1a and TC9a (those that lost money). Positive values indicate that the mean of TC1a is greater than the mean of TC9a.

5 Summary

This analysis has investigated the behaviour of TC9a customers in relation to TC1a customers with specific interest paid to the peak and shoulder periods. The populations of the test cells were first considered as a whole before being broken down by demographics. Taking the populations as a whole we showed that there is a difference in the mean annual mean peak power demand and in the mean annual max peak in the 4-8pm period. In both cases we found that TC9a gave lower values than TC1a. Looking at the mean monthly weekday mean peaks in the same period we view significant reductions between TC1a and TC9a, particularly during the winter months, however we observe no significant difference when considering the weekends, see Section 4.2 for more detail.

In Section 4.3 we show that we observe no differences between TC1a and TC9a in the 8-10pm period when considering both the mean annual mean peak and the mean annual max peak. Considering the 2-4pm period we again see no difference in the mean annual mean peak of TC1a and TC9a but we do find a difference in the mean annual max peak, where TC1a is greater than TC9a. At a monthly level by weekday or weekend we witness significant differences when considering the mean max peaks; October 2012 – January 2013 are significantly different for both weekdays and weekends with TC1a having a greater mean than TC9a, for more details see Section 4.4. Sections 4.3 and 4.4 lead us to the conclusion that there is no overall difference between the two test cells in the shoulder period, meaning there has been no new peak created for TC9a. However it is worth noting that exceptions exist at a monthly weekday and weekend level.

We investigate the absolute electricity consumption of both test cells in Section 4.6.We discover that there is no significant difference between the test cells in their mean annual electricity consumption when considering the day as a whole, even when only considering the customers who saved money under the tariff. Looking at the peak (4-8pm) and off-peak periods individually we find that there is a significant difference between the mean annual 4-8pm electrical energy consumption of both test cells, where the mean of TC9a is lower than the mean of TC1a. We find that 4 of the 12 months show a significant difference when considering weekdays, where again TC9a is lower than TC1a, however we see no difference when considering the weekends of each month. The off-peak period shows no difference in the means of TC1a and TC9a at any level, that is annually or monthly by weekday or weekend. We refer the reader to Section 4.6 for further discussion on these findings.

Splitting the two test cells by demographics we find significant differences in the mean annual mean peak and in the mean annual max peak in the 4-8pm period of TC1a and TC9a for those without dependencies, non-renters and Mosaic F. For all three demographics we find that TC1a has greater values than TC9a for its mean annual mean peak and mean annual max peak. These three demographics were also investigated at a monthly by weekday or weekend level and full details can be found in Section 4.7.2. We found no significant differences between TC1a and TC9a for any demographic when considering the annual consumption for all time periods.

Comparing our results to the findings in previous reports regarding TC9a (see table 3) we must first acknowledge that we are unable to comment on the results relating to TC9a customers pre- and post- tariff. Previous reports consisted of small samples where a reduction in the peak period was observed, although no formal testing occurred. [8] found a reduction in the early evening peak, our results in Section 4.2 agree with these findings; however [8] discusses a reduction during summer months which we do not particularly see here given we observe no significant p-values for the mean annual mean 4-8pm peaks in summer months, although we witness significant p-values when considering the mean annual max 4-8pm peaks for summer months. Overall our analysis appears to agree with [8] when comparing TC9a customers to TC1a customers.

The authors of [9] estimate that customers have reduced their weekday peak consumption by 10.4% and their weekend peak consumption by 5.8%. Unfortunately this analysis does not consider the annual split by weekdays or weekends, although we can offer some comparison to the annual peak consumption. It is found in Section 4.6 that a 95% confidence interval for the difference in the mean of the annual peak consumption for TC1a and TC9a shows a reduction in TC9a of between 1.494% and 11.284%. Therefore, whilst we can give no single value for the percentage reduction, and that our confidence interval shows a reasonably wide range for the reduction, we do agree with [9] that there has been a reduction in the peak consumption of a TC9a customer. Our confidence interval includes both the values 10.4% and 5.8% suggesting we may see a similar level of reduction to that remarked upon in [9], although we point out that the findings in [7] were observational. Section 4.2 shows that a 95% confidence interval for the difference in the mean of the annual mean 4-8pm peak for TC1a and TC9a shows a reduction for TC9a of between 3.199% and 12.469%, further evidence to support the observations of [9], although on a slightly different measurement.

Overall consumption is also discussed in [9], finding a reduction of 3.3% and 1.4% for TC9a customers for weekdays and weekends respectively. This report did not consider overall consumption by weekdays or weekends but we can offer some comparison to the annual absolute electricity consumption, see Section 4.5. We found no significant difference between TC1a and TC9a considering the annual consumption, suggesting TC1a and TC9a customers use the same amount of electricity; this is in contradiction to [9]. If we consider the 95% confidence interval for the two-tailed t-test performed in Section 4.2 the upper confidence limit suggests a possible reduction for TC9a of 5.511%, however the lower limit suggests an increase for TC9a of 4.051%. Therefore it is possible to see a reduction as detailed in [9], however there is no statistical evidence to support the claim that the reduction is significant.

Overall our findings agree with those detailed in previous reports, with the exception of overall consumption in [9]. Further statistical analysis would need to be carried out on the datasets of previous reports to test whether any true differences were observed or not.

In short we believe this report has shown that there are reductions for TC9a customers compared to TC1a customers during the peak period, with no new peak created in the shoulder periods for TC9a customers as a consequence, although no statistically significant reduction in the peak was observed between TC1a and TC9a on the day of greatest network stress.

6 References

[1] "CLNR-L006: Domestic and SME tariff development for the Customer-Led Network Revolution," Frontier Economics, 2012.

[2] M. Blell, "DEI-CLNR-R008: Customer Led Network Revolution: Revised Selection Criteria for Domestic Test Cells," 2011.

[3] Experian, "Mosaic_UK_2009_brochure.pdf," 2009. [Online]. Available: http://www.experian.co.uk/assets/business-strategies/brochures/Mosaic_UK_2009_brochure.pdf . [Accessed October 2014].

[4] Rebekah Phillips, Gill Owen, Judith Ward (Sustainability First), "CLNR-L036: Project Lessons Learned from Trial Recruitment," 2013.

[5] Experian Marketing Services Ltd, "Endless Possibilities. One Mosaic.," Experian Marketing Services Ltd, London, 2014.

[6] L. Sidebotham, "CLNR-L020: Customer Led Network Revolution: Progress Report 7," 2014.

[7] British Gas, "CLNR-L015: Customer Led Network Revolution: Initial Time of Use Tariff Trial Analysis," 2013.

[8] C. B.-H. D. M. E. S. Robin Wardle, "CLNR-L012: Customer Led Network Revolution: Initial Load Profiles from CLNR Intervention Trials," 2013.

[9] P. F. E. L. D. M. Chris Thompson, "CLNR-L071: Customer Led Network Revolution: A guide to the load and generation profile datasets," 2014.

[10] Experian Merketing Services Ltd, "Mosaic UK Grand Index," Experian Marketing Services Ltd, Lodon, 2009.

[11] A. T. Druckman, "Household energy consumption in the UK: A highly geographically and socio-economically disaggregated model," *Energy Policy,* vol. 36, no. 8, pp. 3177-3192, 2008.

7 Appendices

7.1 T-tests for Peak Power Demand

	Month	p-value for the difference in the mean peaks (4-8pm) for TC1a vs TC9a (3dp) [2-tailed test]	p-value for the difference in the max peaks (4-8pm) for TC1a vs TC9a (3dp) [2-tailed test]
Weekday	October 2012	0.005	**0.000**
	November 2012	**0.001**	**0.000**
	December 2012	**0.002**	**0.000**
	January 2013	**0.001**	**0.000**
	February 2013	**0.000**	**0.000**
	March 2013	**0.000**	**0.000**
	April 2013	**0.001**	**0.003**
	May 2013	**0.001**	**0.004**
	June 2013	0.006	**0.002**
	July 2013	0.038	0.028
	August 2013	0.012	0.013
	September 2013	0.007	**0.002**
Weekend	October 2012	0.359	0.005
	November 2012	0.737	**0.000**
	December 2012	0.259	**0.000**
	January 2013	0.366	**0.000**
	February 2013	0.975	0.737
	March 2013	0.269	0.702
	April 2013	0.216	0.638
	May 2013	0.053	0.031
	June 2013	0.375	0.388
	July 2013	0.782	0.974
	August 2013	0.270	0.162
	September 2013	0.109	0.104
	All year	**0.001**	**0.003**

Table A1: Table of p-values for 2-tailed t-tests assessing any differences in the mean mean and max peaks during the 4-8pm period (peak period). Significant results are highlighted in bold.

	Month	p-value for the difference in the mean peaks (8-10pm) for TC1a vs TC9a (3dp) [2-tailed test]	p-value for the difference in the max peaks (8-10pm) for TC1a vs TC9a (3dp) [2-tailed test]
Weekday	October 2012	0.454	0.991
	November 2012	0.042	0.178
	December 2012	0.007	**0.002**
	January 2013	0.048	0.178
	February 2013	0.071	0.061
	March 2013	0.123	0.023
	April 2013	0.426	0.211
	May 2013	0.893	0.409
	June 2013	0.808	0.224
	July 2013	0.988	0.383
	August 2013	0.877	0.495
	September 2013	0.746	0.528
Weekend	October 2012	0.557	0.181
	November 2012	0.065	**0.004**
	December 2012	0.041	**0.000**
	January 2013	0.311	0.038
	February 2013	0.077	0.068
	March 2013	0.179	0.144
	April 2013	0.597	0.948
	May 2013	0.652	0.421
	June 2013	0.325	0.502
	July 2013	0.370	0.934
	August 2013	0.361	0.512
	September 2013	0.976	0.996
	All year	0.561	0.664

Table A2: Table of p-values for 2-tailed t-tests assessing any differences in the mean mean and max peaks during the 8-10pm period (shoulder period). Significant results are highlighted in bold.

	Month	p-value for the difference in the mean peaks (2-4pm) for TC1a vs TC9a (3dp) [2-tailed test]	p-value for the difference in the max peaks (2-4pm) for TC1a vs TC9a (3dp) [2-tailed test]
Weekday	October 2012	0.076	**0.002**
	November 2012	0.044	**0.000**
	December 2012	0.945	**0.000**
	January 2013	0.136	**0.000**
	February 2013	0.567	0.193
	March 2013	0.220	0.253
	April 2013	0.275	0.167
	May 2013	0.078	0.096
	June 2013	0.109	0.307
	July 2013	0.159	0.256
	August 2013	0.159	0.130
	September 2013	0.172	0.124
Weekend	October 2012	0.248	**0.001**
	November 2012	0.754	**0.000**
	December 2012	0.737	**0.000**
	January 2013	0.328	0.006
	February 2013	0.166	0.347
	March 2013	0.603	0.942
	April 2013	0.212	0.097
	May 2013	0.997	0.564
	June 2013	0.868	0.512
	July 2013	0.694	0.179
	August 2013	0.437	0.191
	September 2013	0.983	0.437
	All year	0.103	**0.012**

Table A3: Table of p-values for 2-tailed t-tests assessing any differences in the mean mean and max peaks during the 2-4pm period (shoulder period). Significant results are highlighted in bold.

7.2 Additional Figures for Peak Power Demand

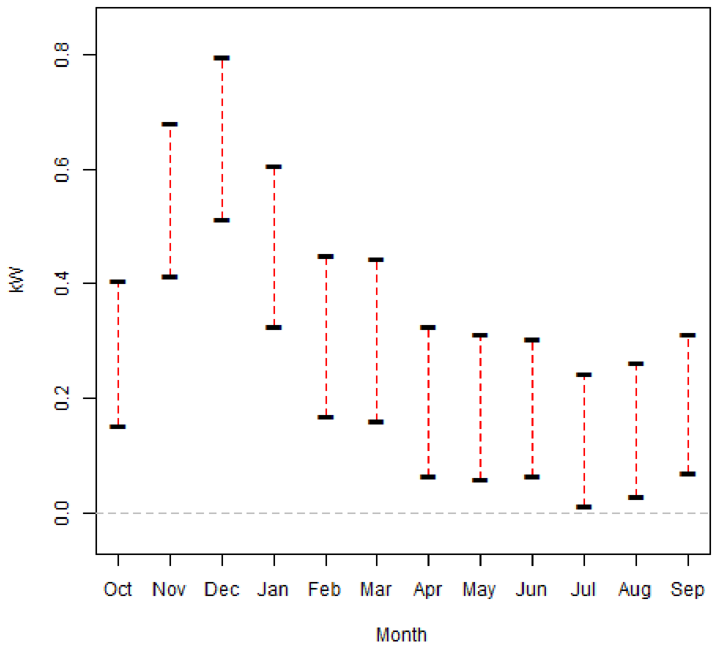

Figure A1: 95% confidence intervals for the difference in the means of the monthly weekday max 4-8pm peak in kW for TC1a and TC9a. Positive values indicate that the mean of TC1a is greater than the mean of TC9a.

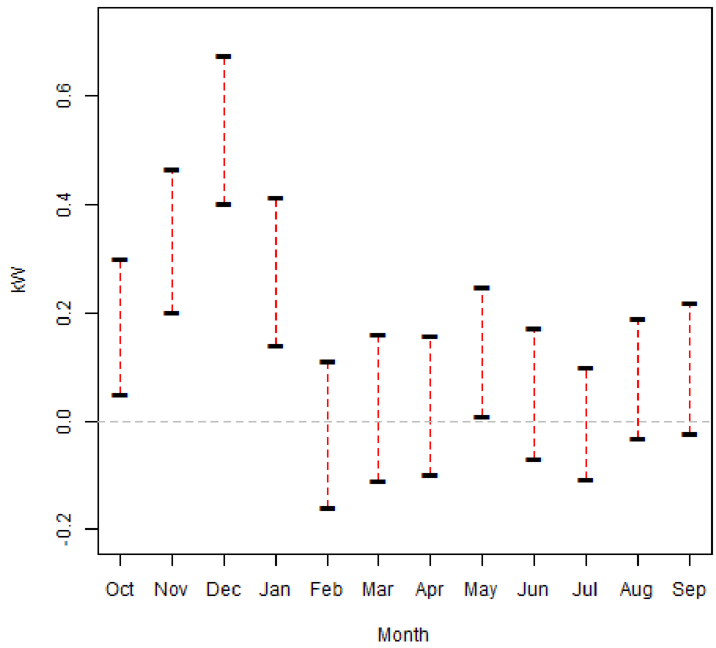

Figure A2: 95% confidence intervals for the difference in the means of the monthly weekend max 4-8pm peak in kW for TC1a and TC9a. Positive values indicate that the mean of TC1a is greater than the mean of TC9a.

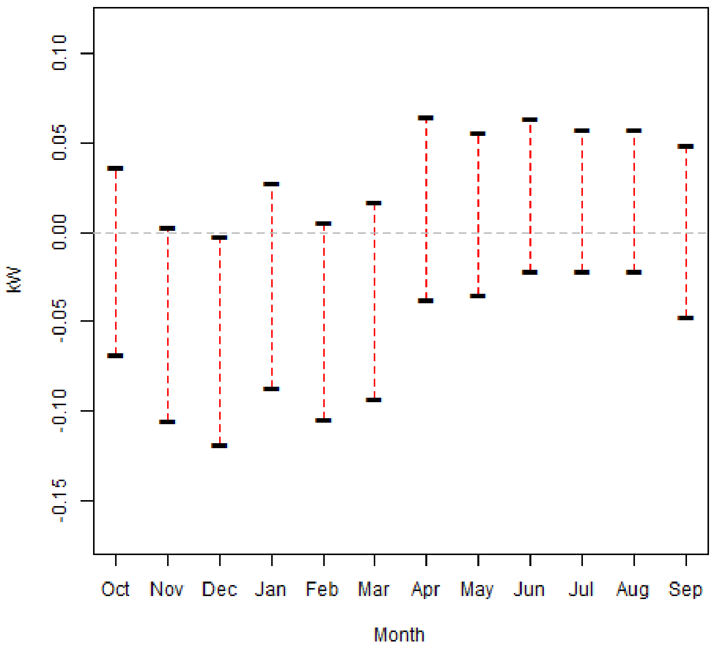

Figure A3: 95% confidence intervals for the difference in the means of the monthly weekend mean 8-10pm peak in kW for TC1a and TC9a. Positive values indicate that the mean of TC1a is greater than the mean of TC9a.

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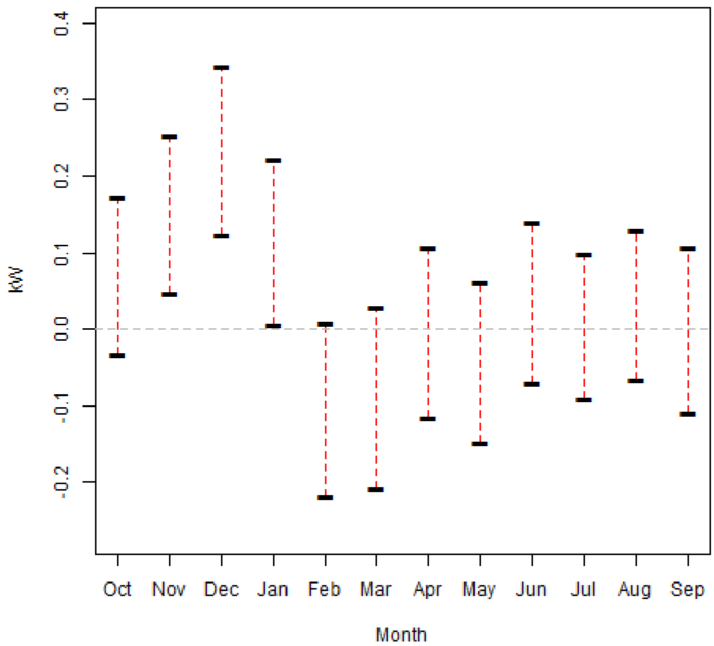

Figure A4: 95% confidence intervals for the difference in the means of the monthly weekend max 8-10pm peak in kW for TC1a and TC9a. Positive values indicate that the mean of TC1a is greater than the mean of TC9a.

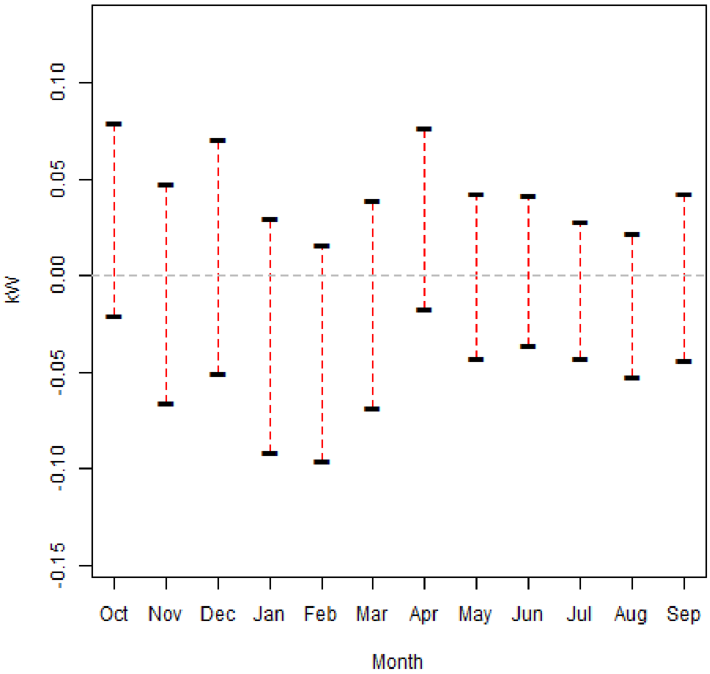

Figure A5: 95% confidence intervals for the difference in the means of the monthly weekend mean 2-4pm peak in kW for TC1a and TC9a. Positive values indicate that the mean of TC1a is greater than the mean of TC9a.

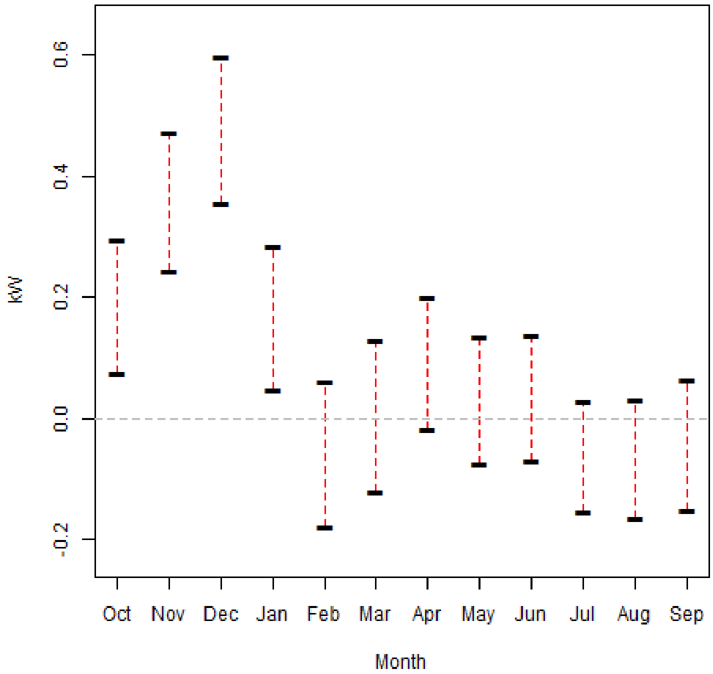

Figure A6: 95% confidence intervals for the difference in the means of the monthly weekend max 2-4pm peak in kW for TC1a and TC9a. Positive values indicate that the mean of TC1a is greater than the mean of TC9a.

7.3 T-tests for Absolute Electrical Energy Usage

	Month	p-value for the difference in the mean electrical energy usage i n the peak period for TC1a vs TC9a (3dp) [2 tailed test]	p-value for the difference in the mean electrical energy usage in the off-peak period for TC1a vs TC9a (3dp) [2 tailed test]
Weekday	October 2012	0.017	0.953
	November 2012	**0.001**	0.463
	December 2012	0.021	0.267
	January 2013	**0.001**	0.420
	February 2013	**0.001**	0.276
	March 2013	**0.000**	0.401
	April 2013	0.013	0.736
	May 2013	0.005	0.864
	June 2013	0.011	0.852
	July 2013	0.055	0.918
	August 2013	0.032	0.881
	September 2013	0.009	0.963
Weekend	October 2012	0.321	0.422
	November 2012	0.198	0.353
	December 2012	0.418	0.544
	January 2013	0.213	0.155
	February 2013	0.565	0.109
	March 2013	0.127	0.186
	April 2013	0.191	0.681
	May 2013	0.134	0.745
	June 2013	0.387	0.821
	July 2013	1.000	0.496
	August 2013	0.661	0.652
	September 2013	0.123	0.392
	All year	**0.011**	0.589

Table A4: Table of p-values for 2-tailed t-tests assessing any differences in the mean absolute electrical energy usage during the 4-8pm peak period and the off-peak period. Significant results are highlighted in bold.

7.4 Additional Figures for Absolute Electrical Energy Usage

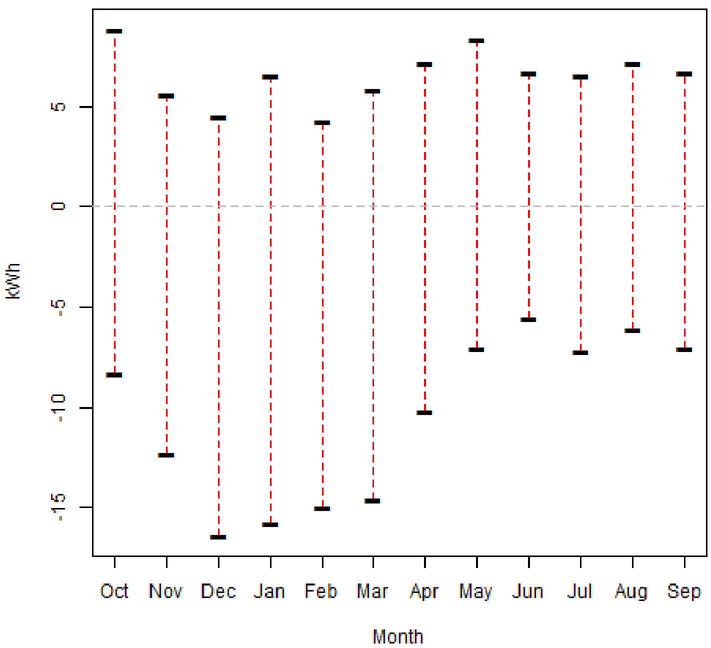

Figure A7: 95% confidence intervals for the difference in the means of the monthly weekday off-peak usage in kWh for TC1a and TC9a. Positive values indicate that the mean of TC1a is greater than the mean of TC9a.

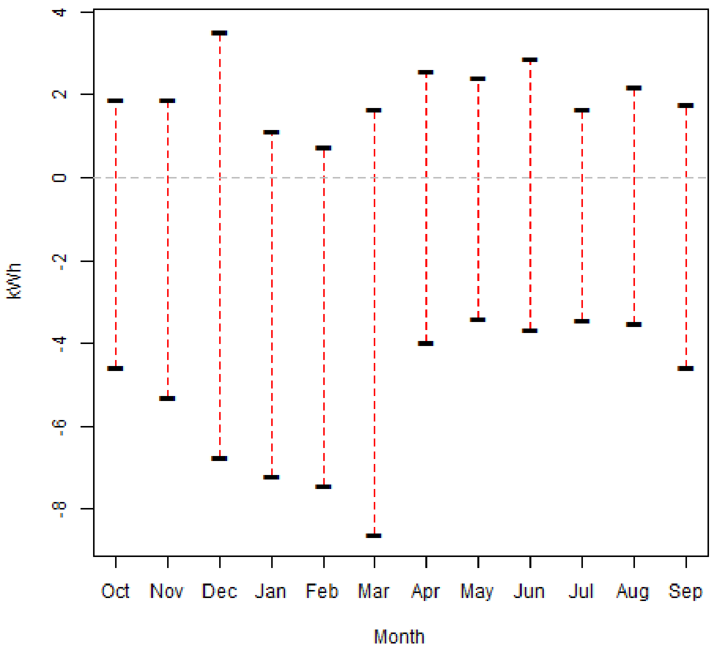

Figure A8: 95% confidence intervals for the difference in the means of the monthly weekend off-peak usage in kWh for TC1a and TC9a. Positive values indicate that the mean of TC1a is greater than the mean of TC9a.

7.5 Additional Figures by Demographic

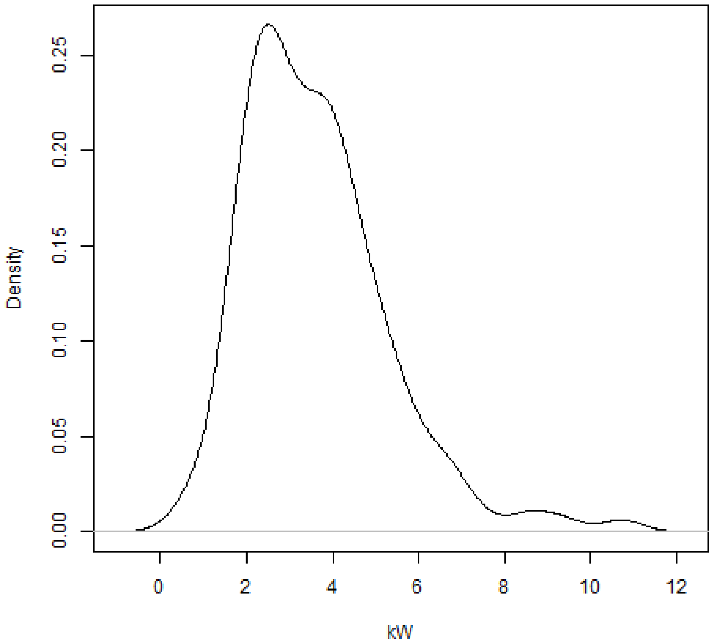

Figure A13: Distribution of the annual max 4-8pm peak in kW for TC9a (With Dependencies)

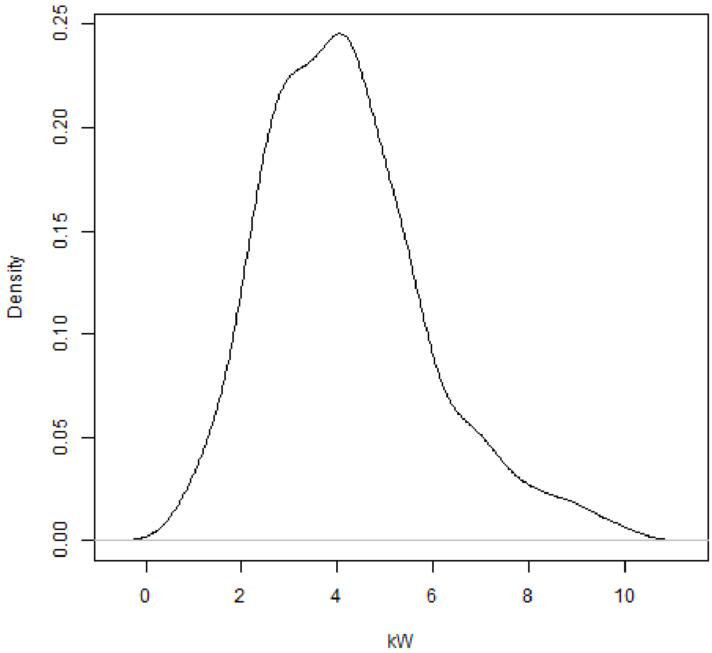

Figure A14: Distribution of the annual max 4-8pm peak in kW for TC9a (Without Dependencies)

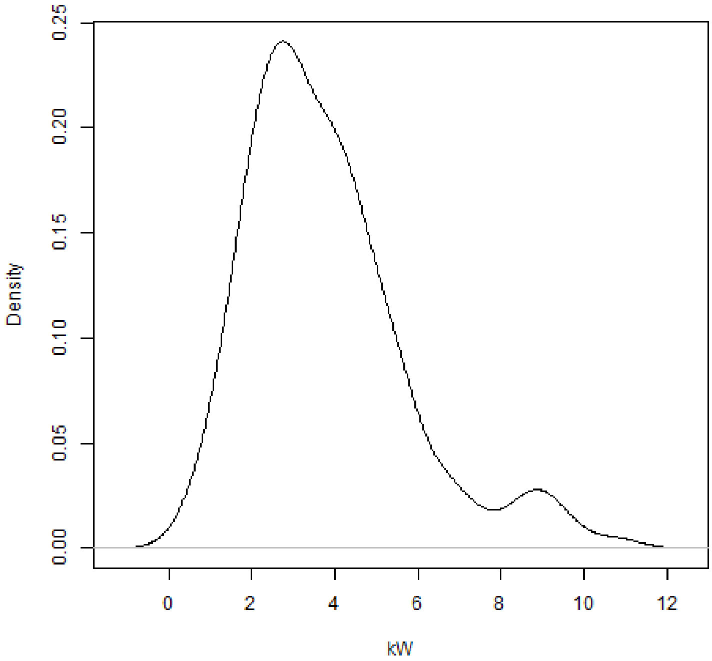

Figure A15: Distribution of the annual max 4-8pm peak in kW for TC9a (Renter)

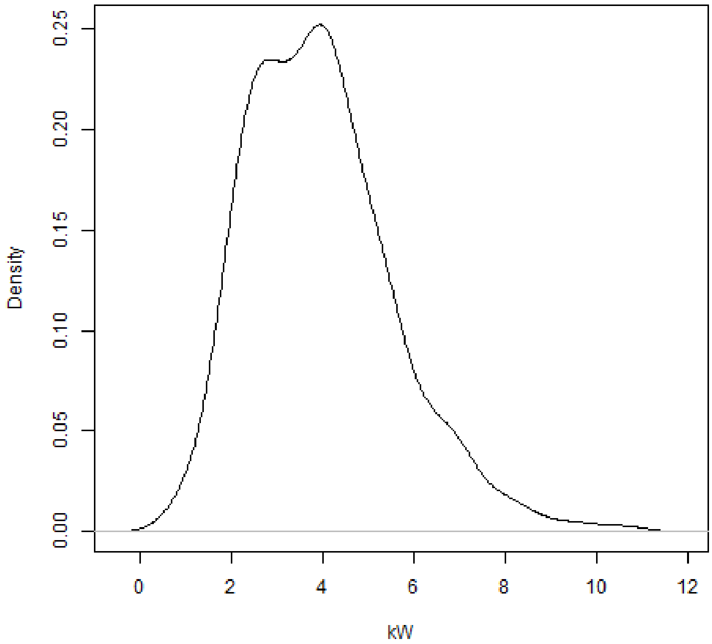

Figure A16: Distribution of the annual max 4-8pm peak in kW for TC9a (Non-renter)

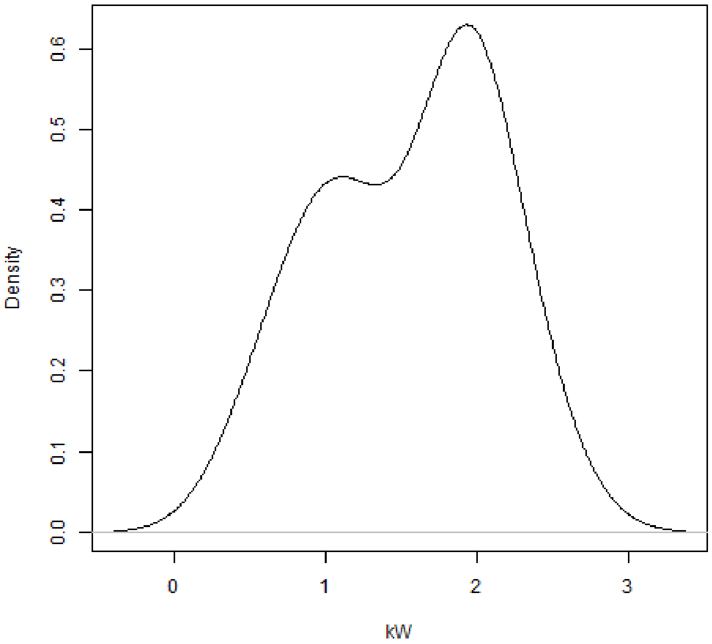

Figure A17: Distribution of the annual mean 4-8pm peak in kW for TC9a (Mosaic A)

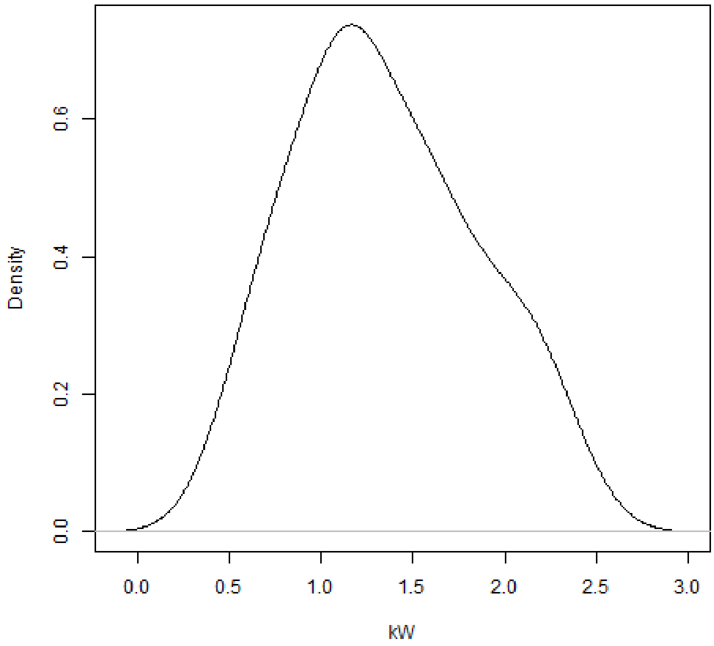

Figure A18: Distribution of the annual mean 4-8pm peak in kW for TC9a (Mosaic B)

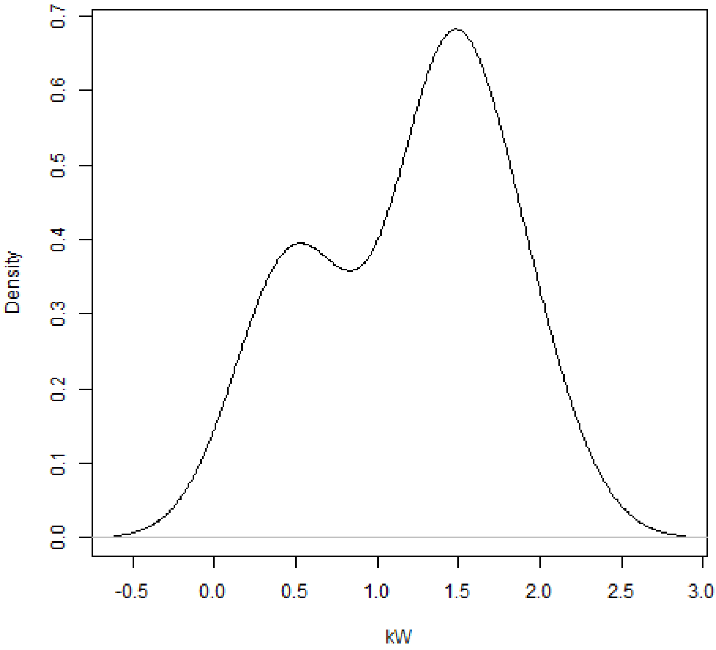

Figure A19: Distribution of the annual mean 4-8pm peak in kW for TC9a (Mosaic C)

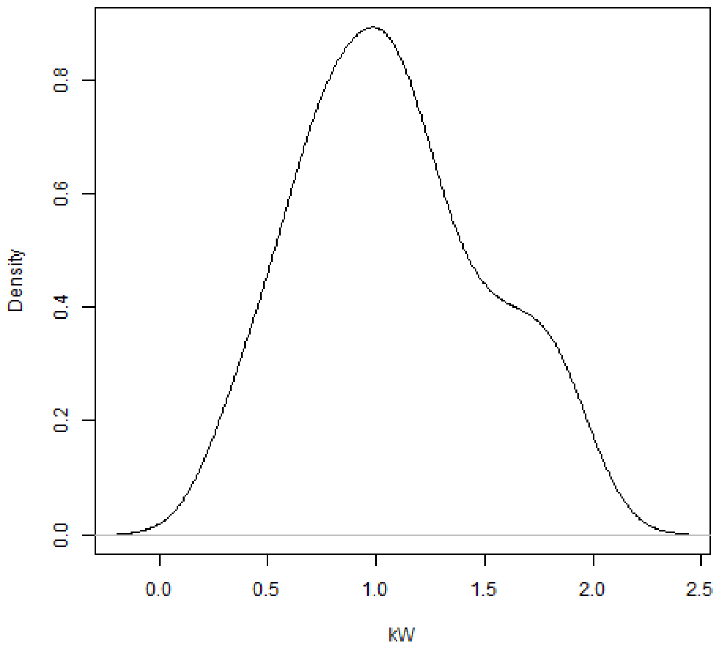

Figure A20: Distribution of the annual mean 4-8pm peak in kW for TC9a (Mosaic D)

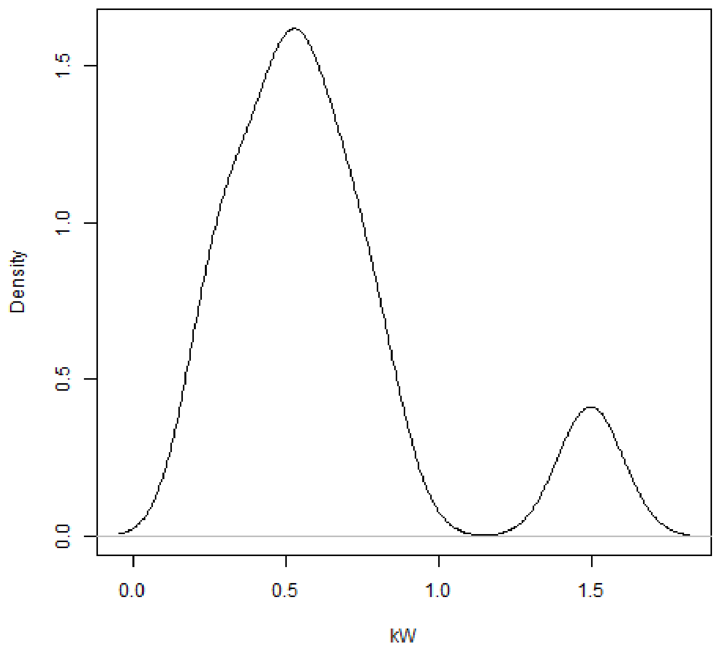

Figure A21: Distribution of the annual mean 4-8pm peak in kW for TC9a (Mosaic E)

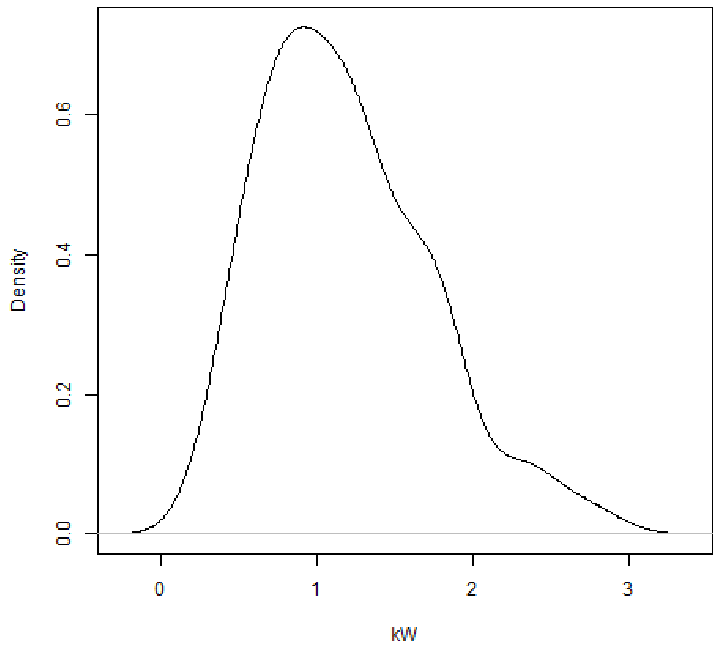

Figure A22: Distribution of the annual mean 4-8pm peak in kW for TC9a (Mosaic F)

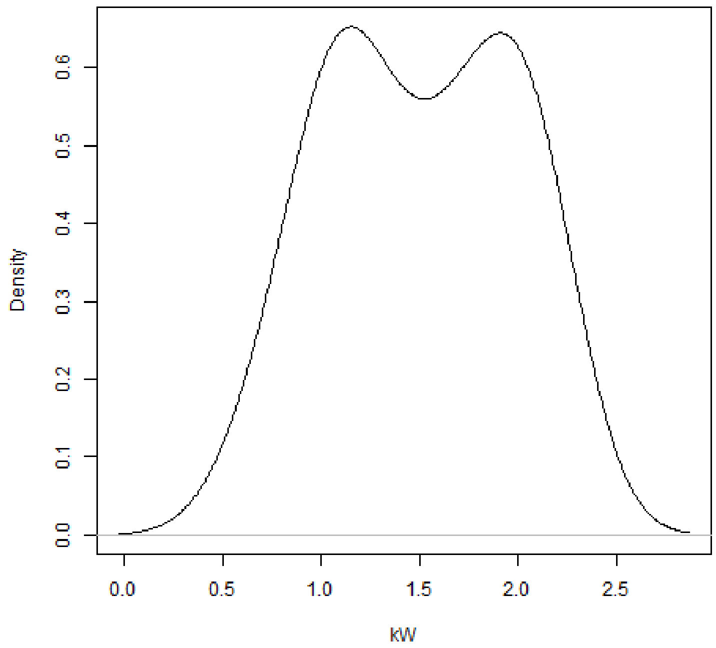

Figure A23: Distribution of the annual mean 4-8pm peak in kW for TC9a (Mosaic G)

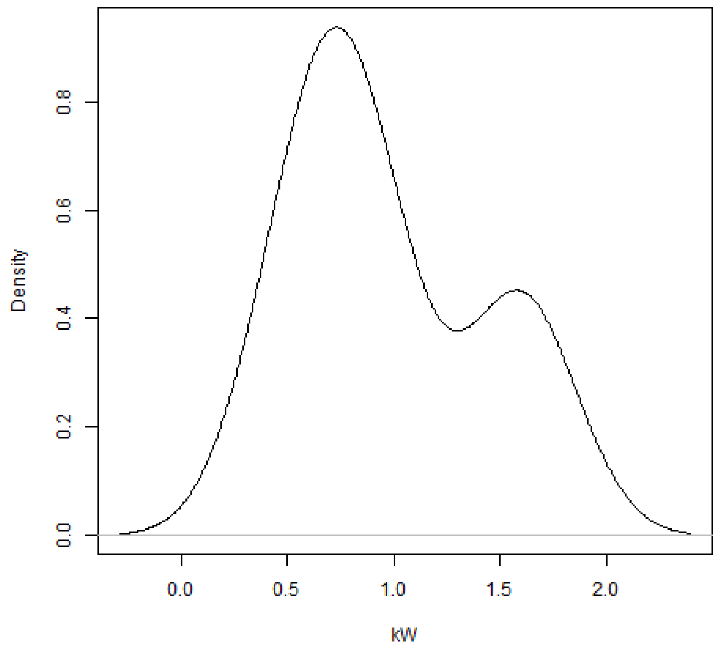

Figure A24: Distribution of the annual mean 4-8pm peak in kW for TC9a (Mosaic H)

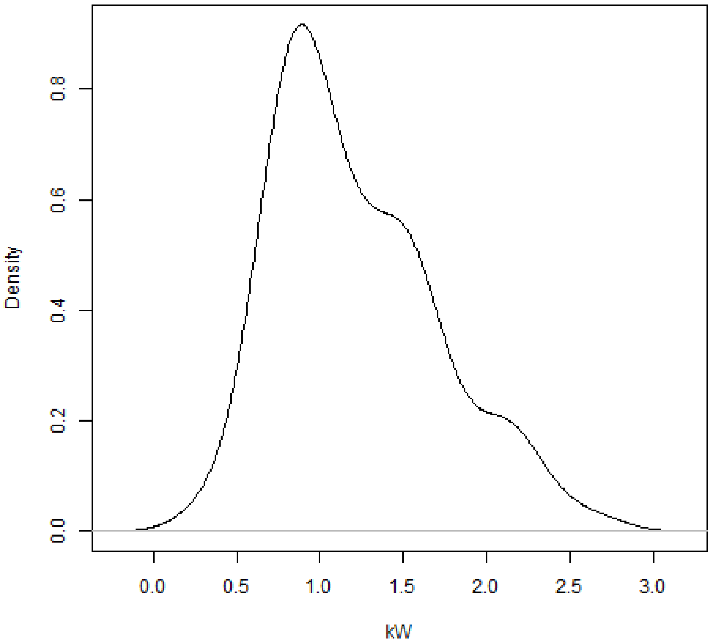

Figure A25: Distribution of the annual mean 4-8pm peak in kW for TC9a (Mosaic I)

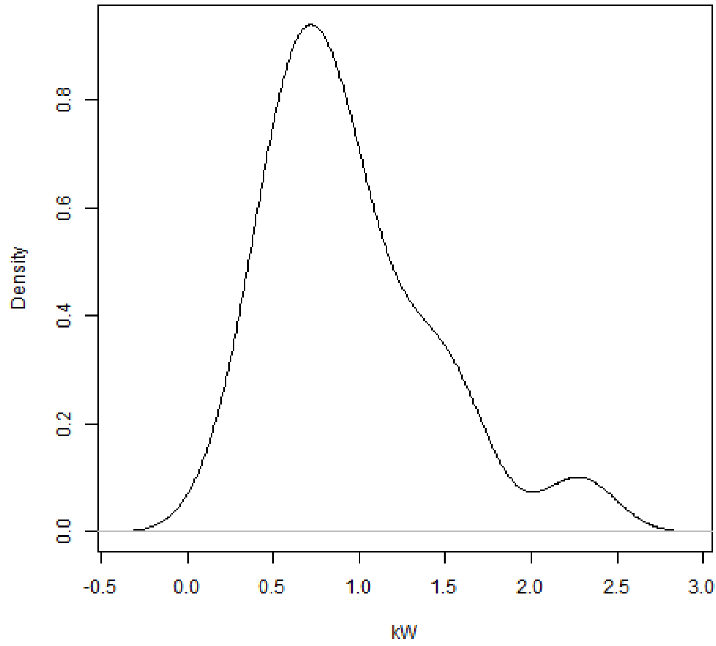

Figure A26: Distribution of the annual mean 4-8pm peak in kW for TC9a (Mosaic J)

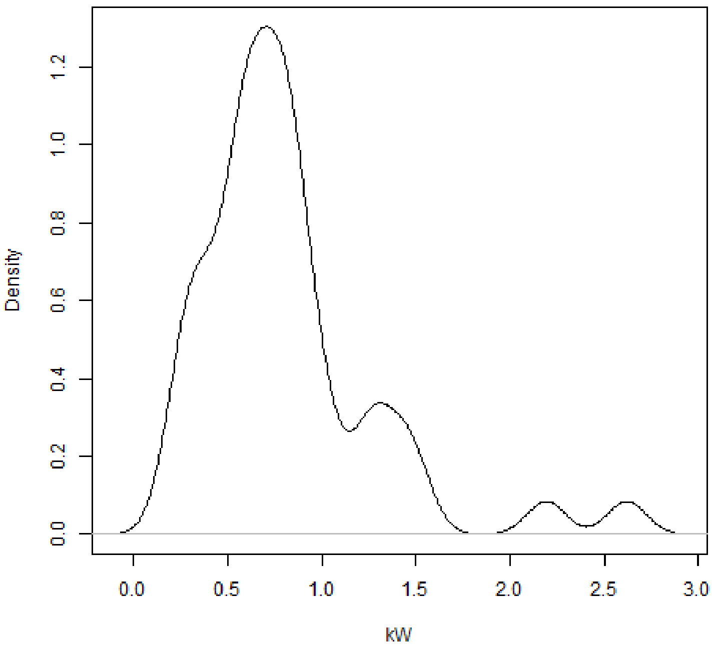

Figure A27: Distribution of the annual mean 4-8pm peak in kW for TC9a (Mosaic L)

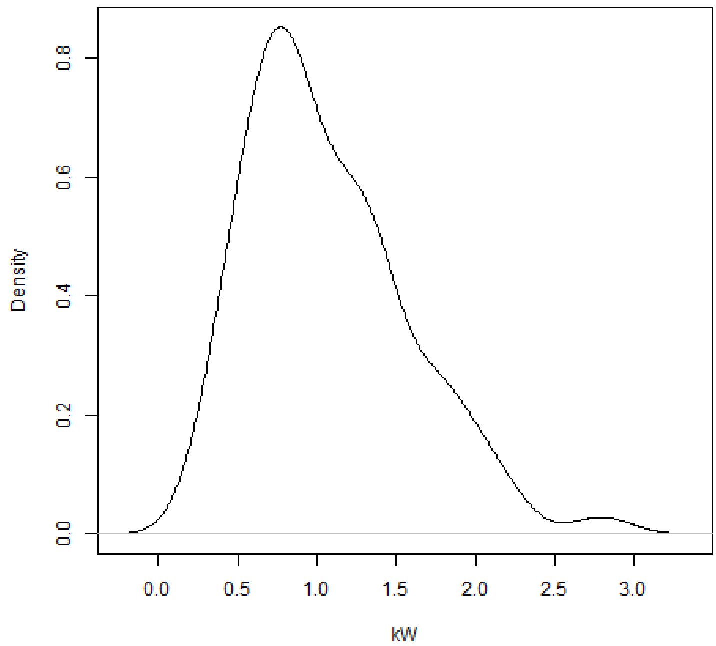

Figure A28: Distribution of the annual mean 4-8pm peak in kW for TC9a (Mosaic M)

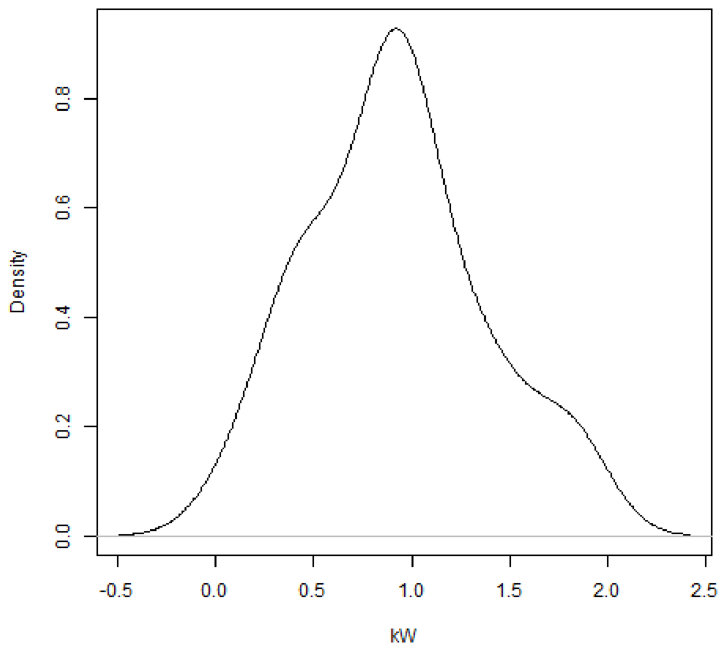

Figure A29: Distribution of the annual mean 4-8pm peak in kW for TC9a (Mosaic N)

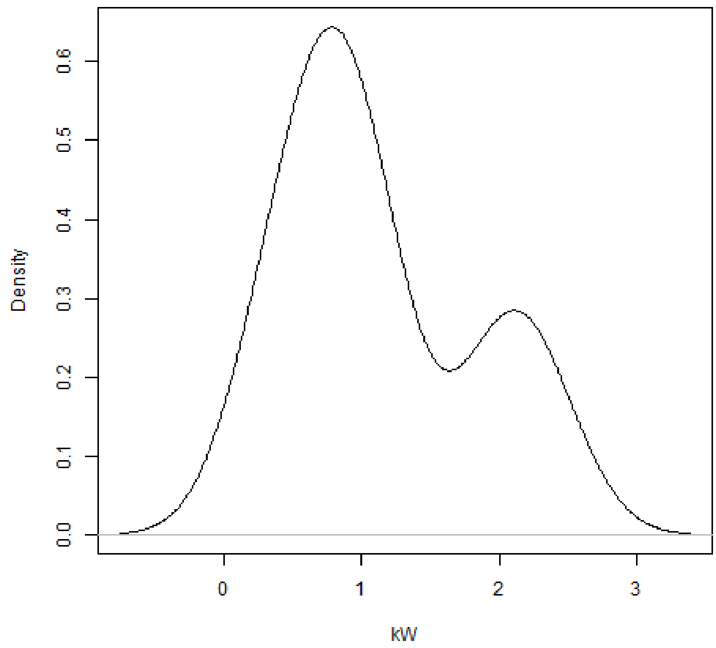

Figure A30: Distribution of the annual mean 4-8pm peak in kW for TC9a (Mosaic O)

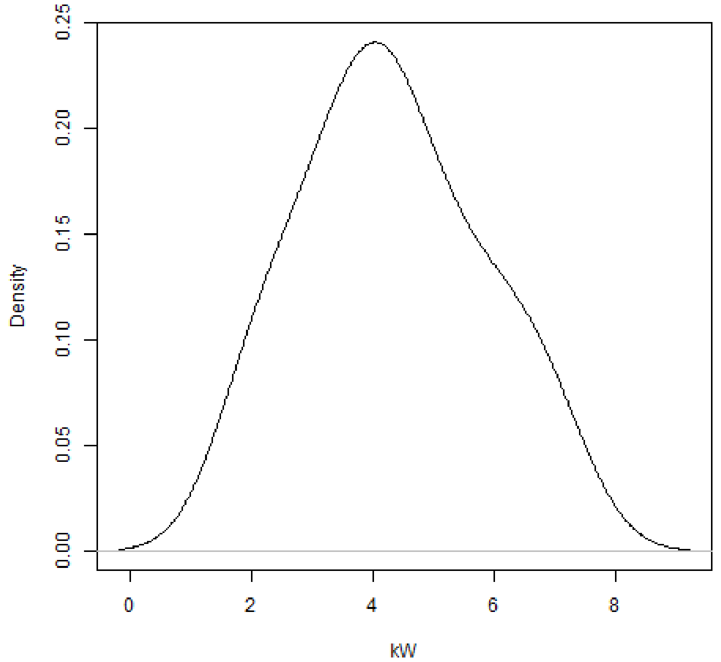

Figure A31: Distribution of the annual max 4-8pm peak in kW for TC9a (Mosaic A)

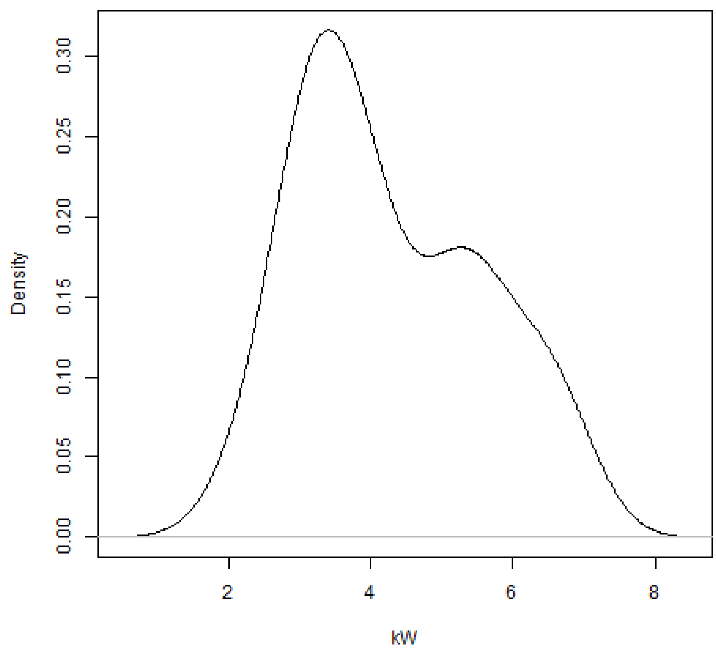

Figure A32: Distribution of the annual max 4-8pm peak in kW for TC9a (Mosaic B)

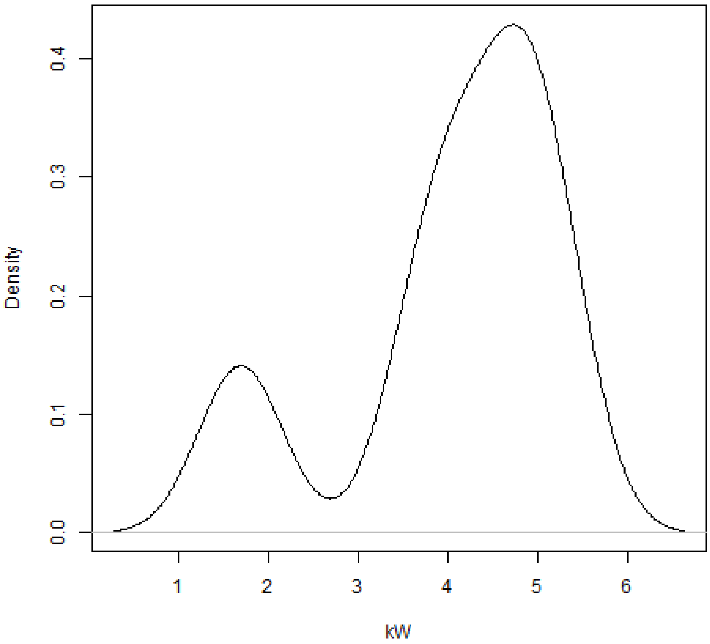

Figure A33: Distribution of the annual max 4-8pm peak in kW for TC9a (Mosaic C)

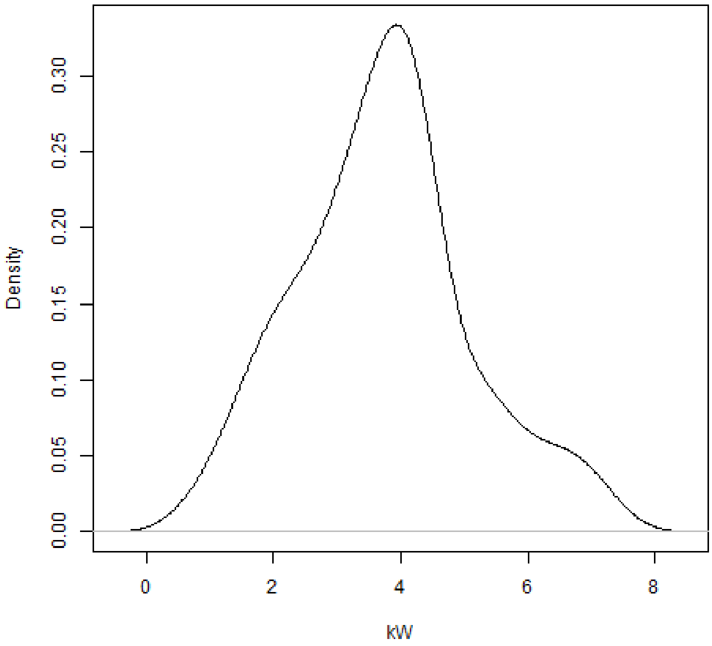

Figure A34: Distribution of the annual max 4-8pm peak in kW for TC9a (Mosaic D)

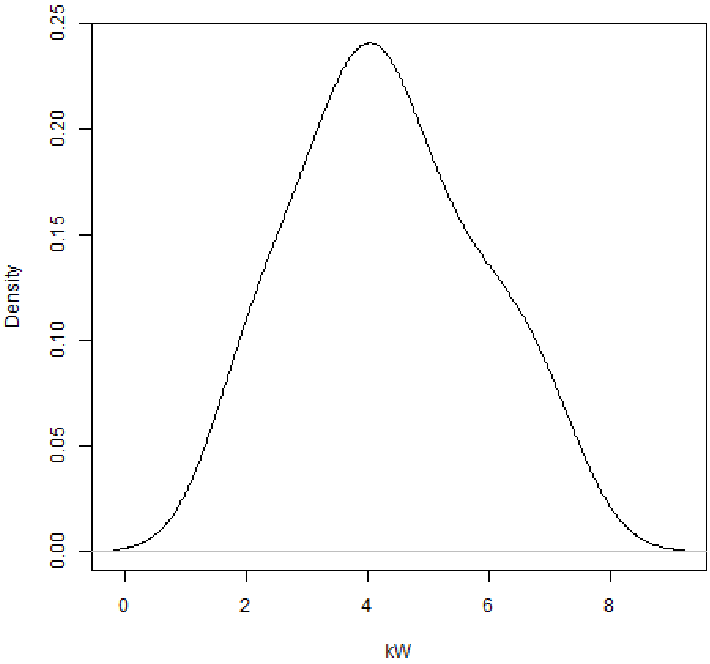

Figure A35: Distribution of the annual max 4-8pm peak in kW for TC9a (Mosaic E)

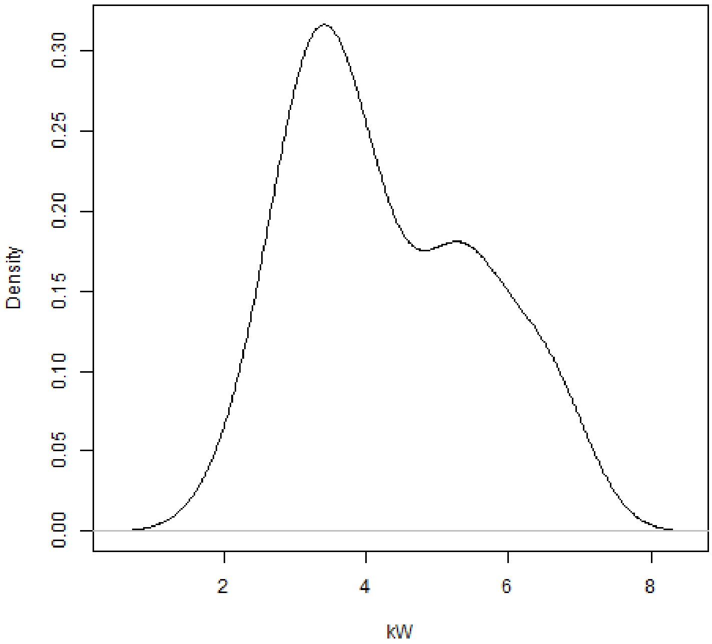

Figure A36: Distribution of the annual max 4-8pm peak in kW for TC9a (Mosaic F)

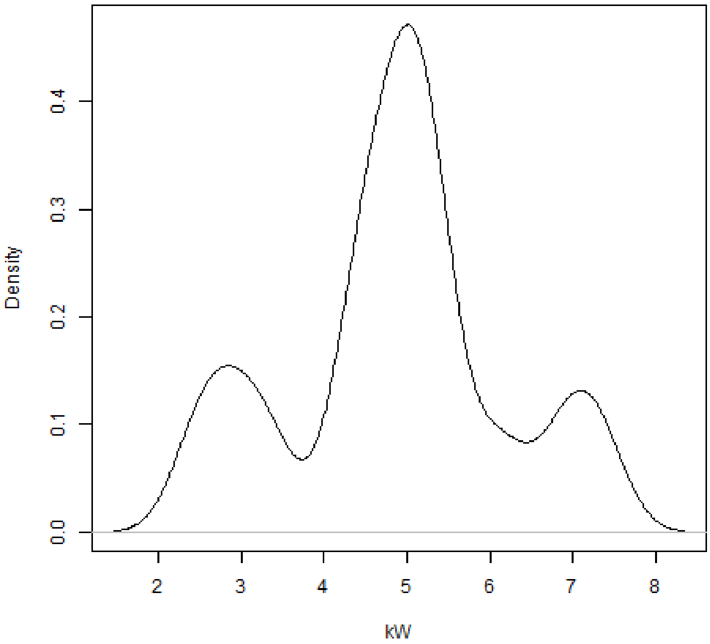

Figure A37: Distribution of the annual max 4-8pm peak in kW for TC9a (Mosaic G)

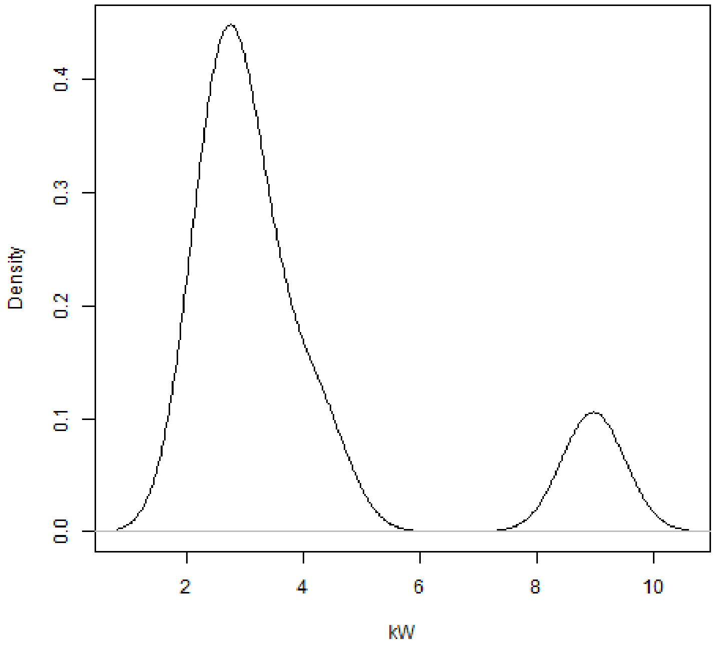

Figure A38: Distribution of the annual max 4-8pm peak in kW for TC9a (Mosaic H)

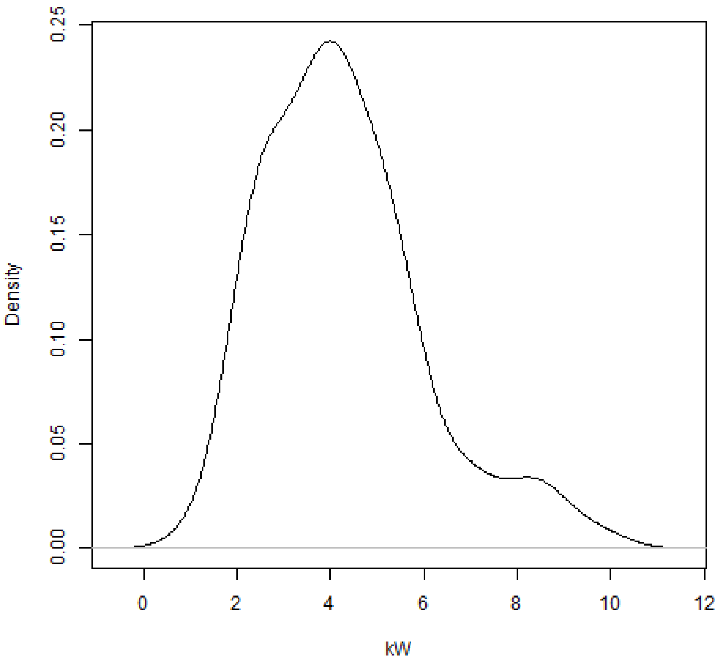

Figure A39: Distribution of the annual max 4-8pm peak in kW for TC9a (Mosaic I)

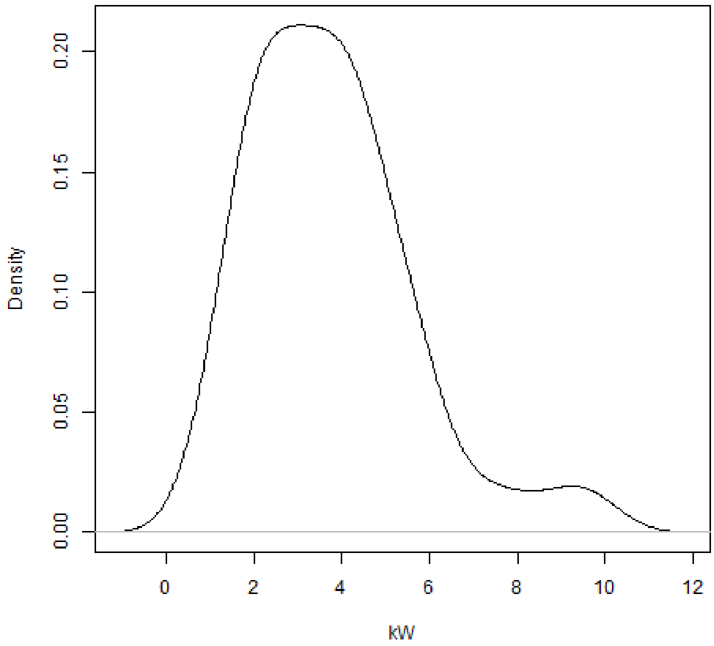

Figure A40: Distribution of the annual max 4-8pm peak in kW for TC9a (Mosaic J)

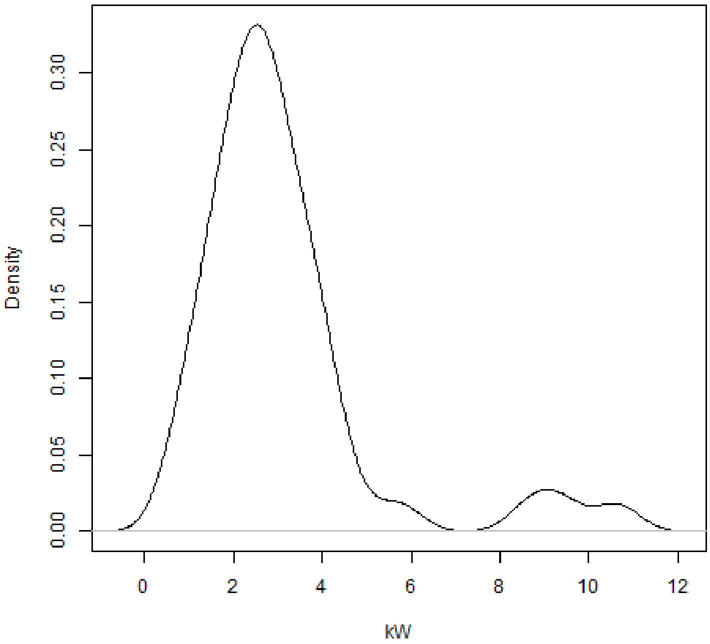

Figure A41: Distribution of the annual max 4-8pm peak in kW for TC9a (Mosaic L)

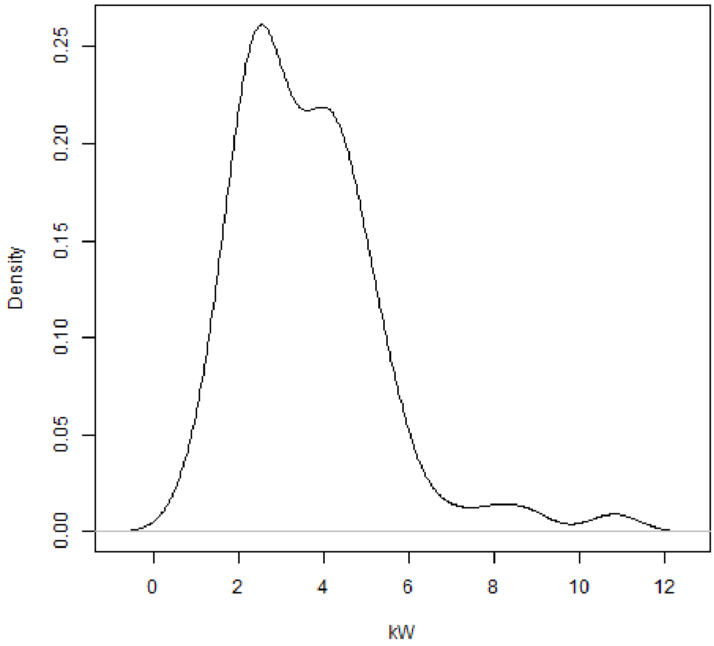

Figure A42: Distribution of the annual max 4-8pm peak in kW for TC9a (Mosaic M)

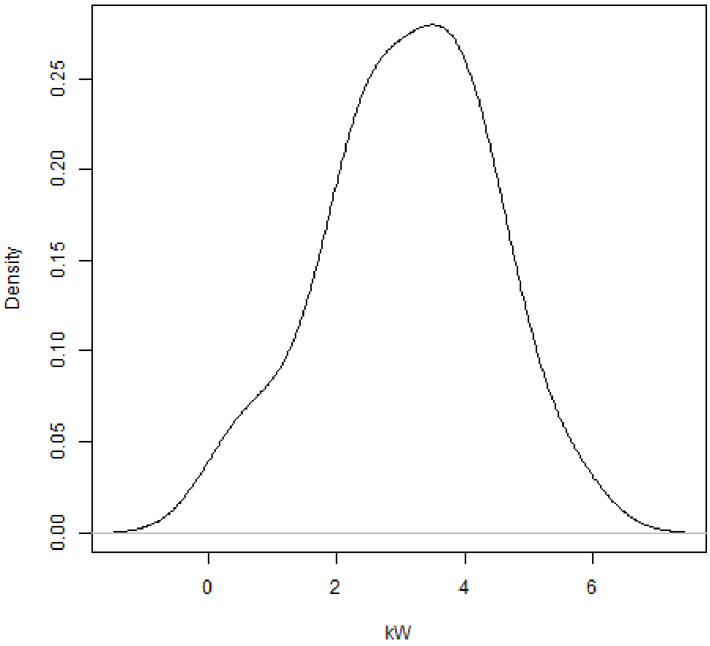

Figure A43: Distribution of the annual max 4-8pm peak in kW for TC9a (Mosaic N)

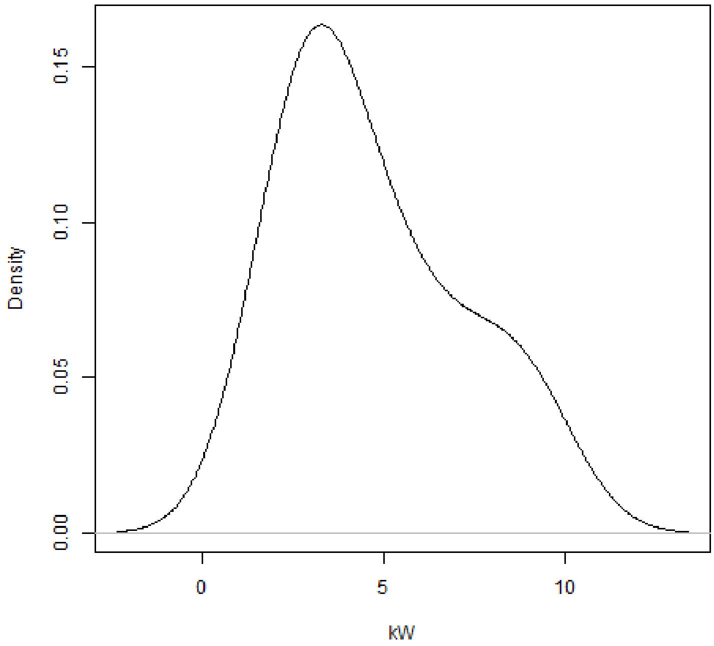

Figure A44: Distribution of the annual max 4-8pm peak in kW for TC9a (Mosaic O)

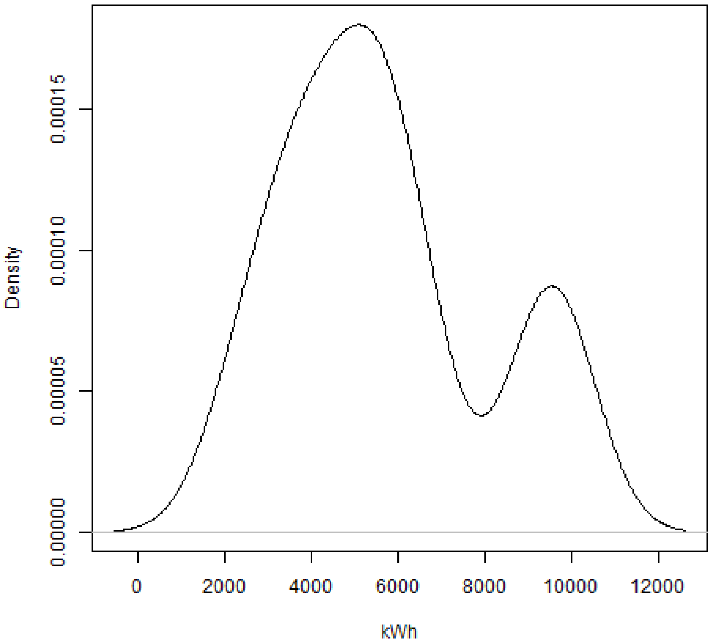

Figure A45: Distribution of the annual energy consumption in kWh for TC9a (Mosaic A)

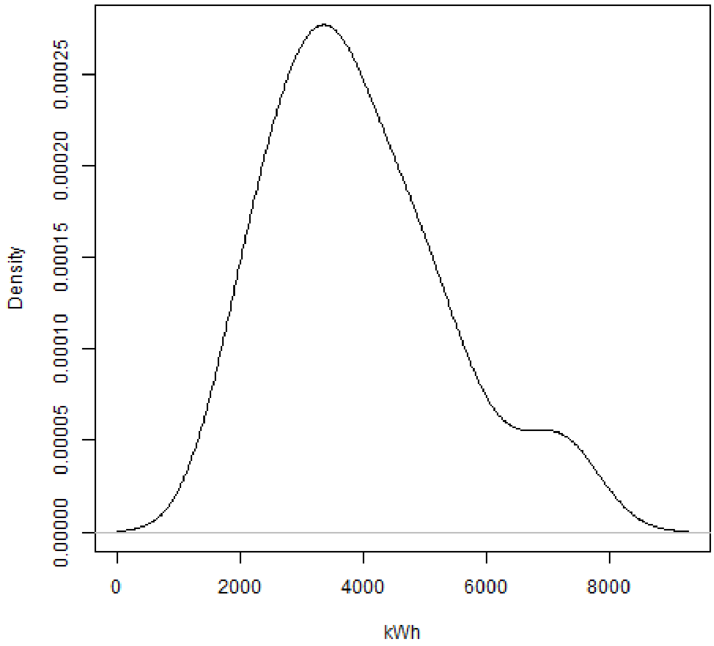

Figure A46: Distribution of the annual energy consumption in kWh for TC9a (Mosaic B)

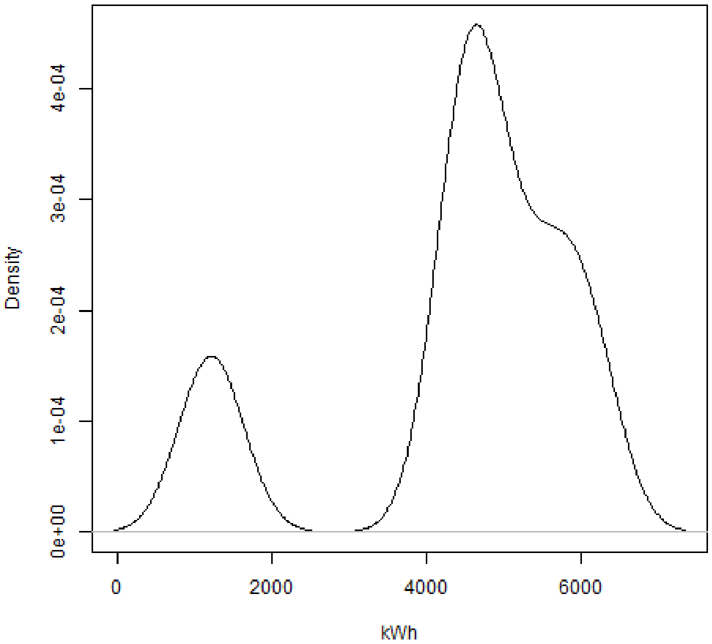

Figure A47: Distribution of the annual energy consumption in kWh for TC9a (Mosaic C)

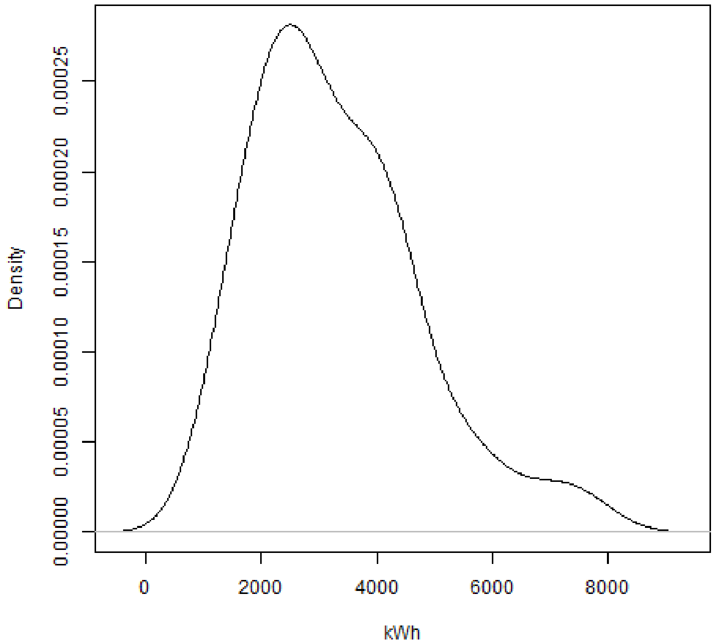

Figure A48: Distribution of the annual energy consumption in kWh for TC9a (Mosaic D)

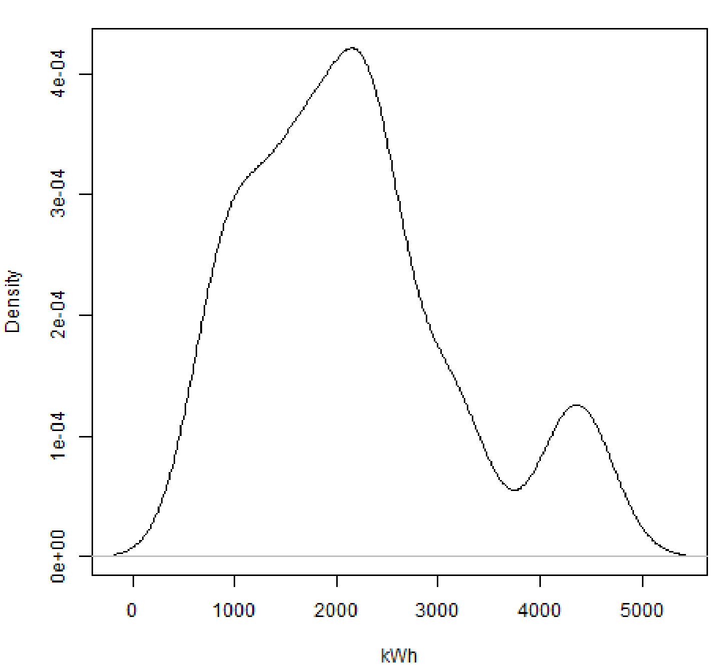

Figure A49: Distribution of the annual energy consumption in kWh for TC9a (Mosaic E)

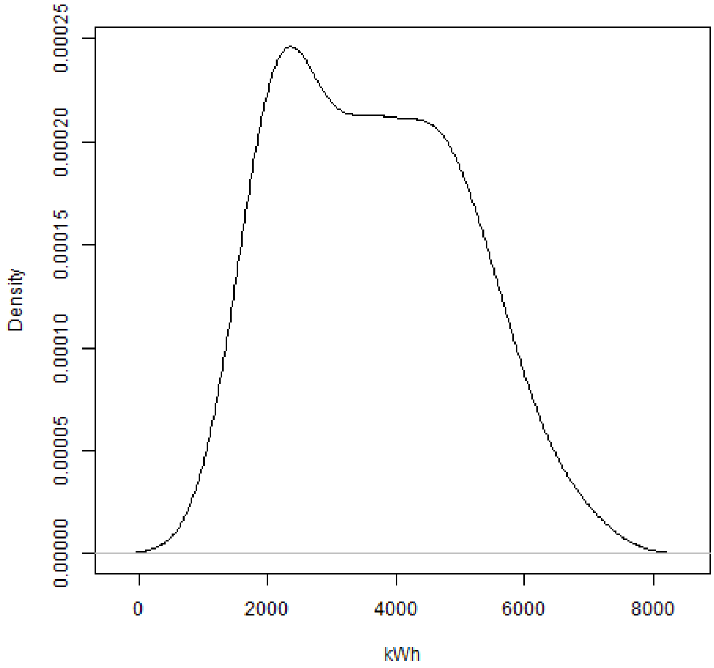

Figure A50: Distribution of the annual energy consumption in kWh for TC9a (Mosaic F)

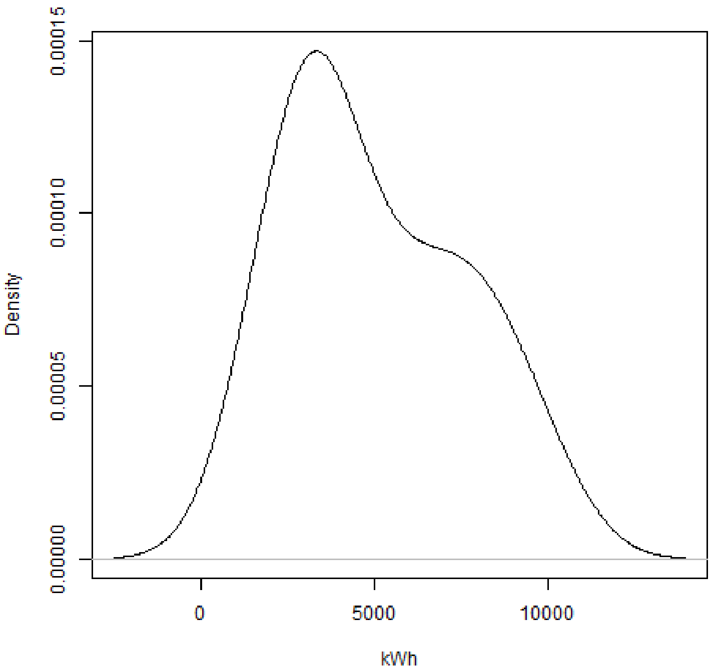

Figure A51: Distribution of the annual energy consumption in kWh for TC9a (Mosaic G)

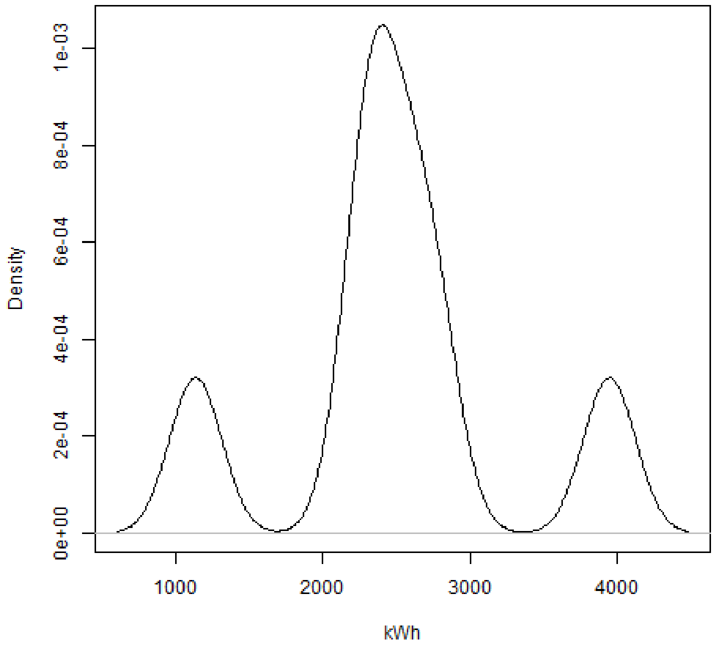

Figure A52: Distribution of the annual energy consumption in kWh for TC9a (Mosaic H)

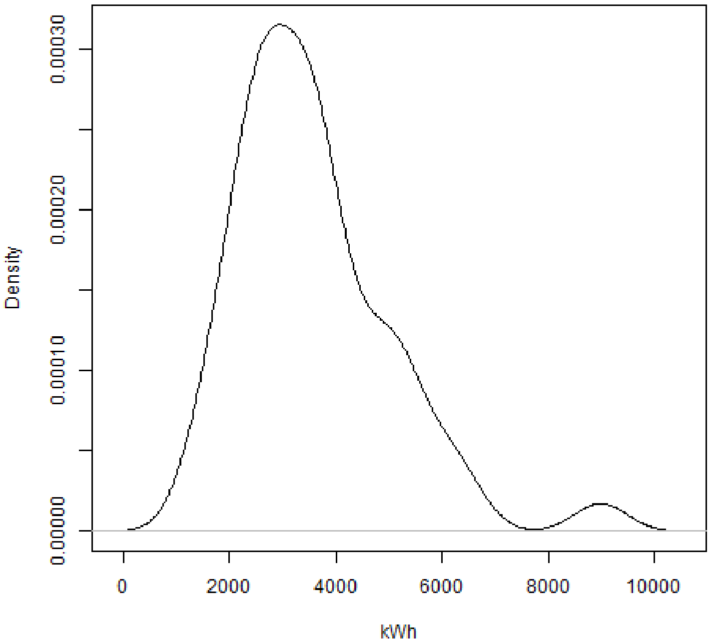

Figure A53: Distribution of the annual energy consumption in kWh for TC9a (Mosaic I)

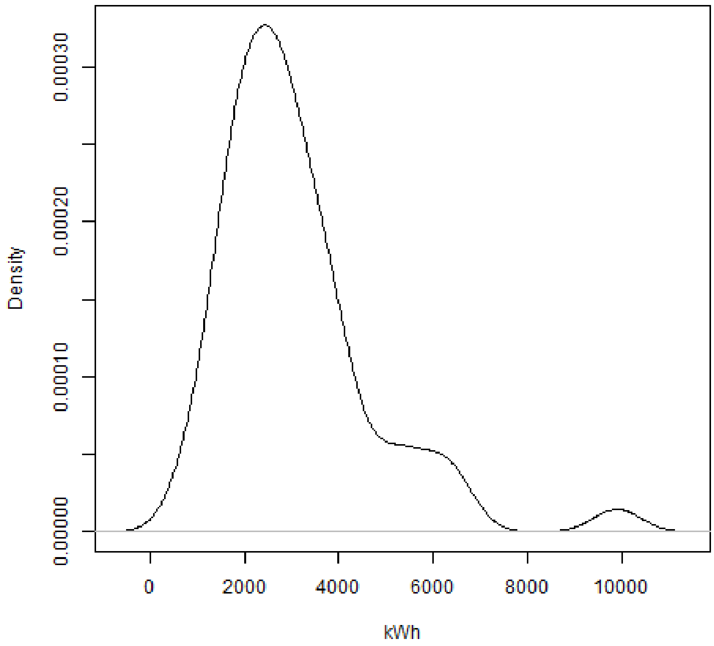

Figure A54: Distribution of the annual energy consumption in kWh for TC9a (Mosaic J)

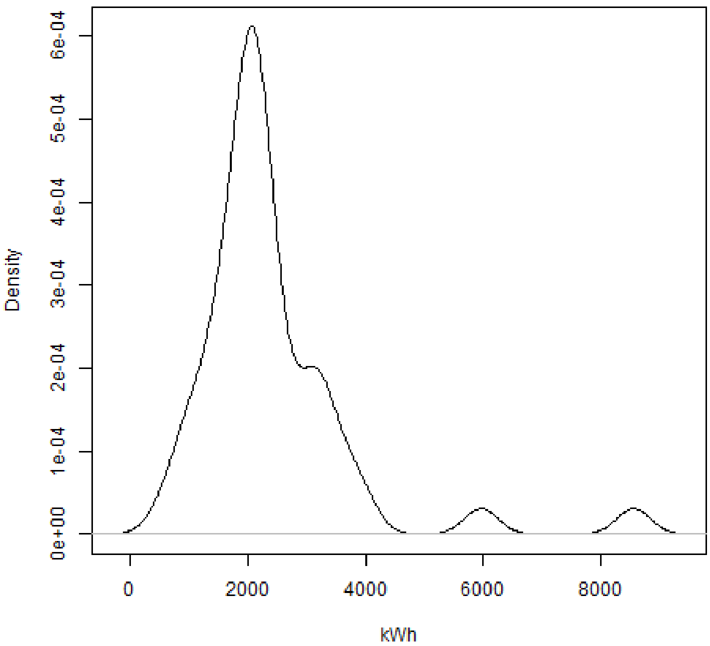

Figure A55: Distribution of the annual energy consumption in kWh for TC9a (Mosaic L)

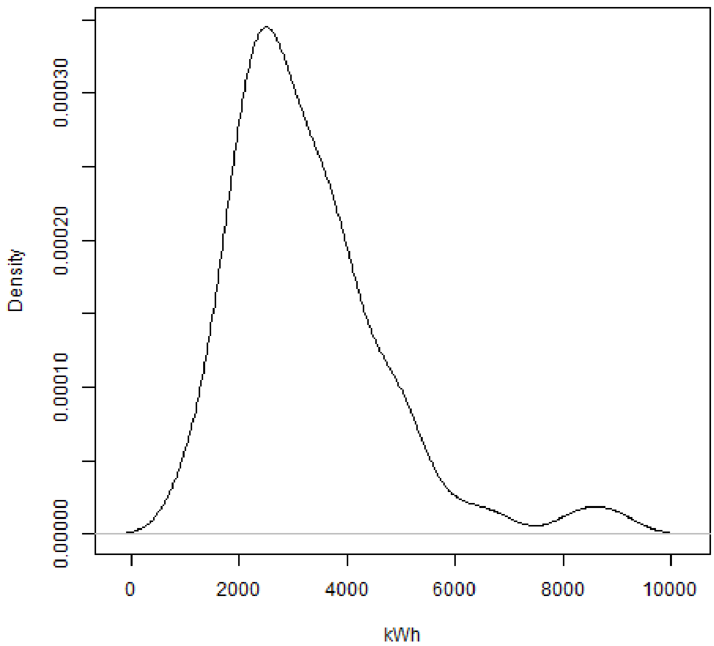

Figure A56: Distribution of the annual energy consumption in kWh for TC9a (Mosaic M)

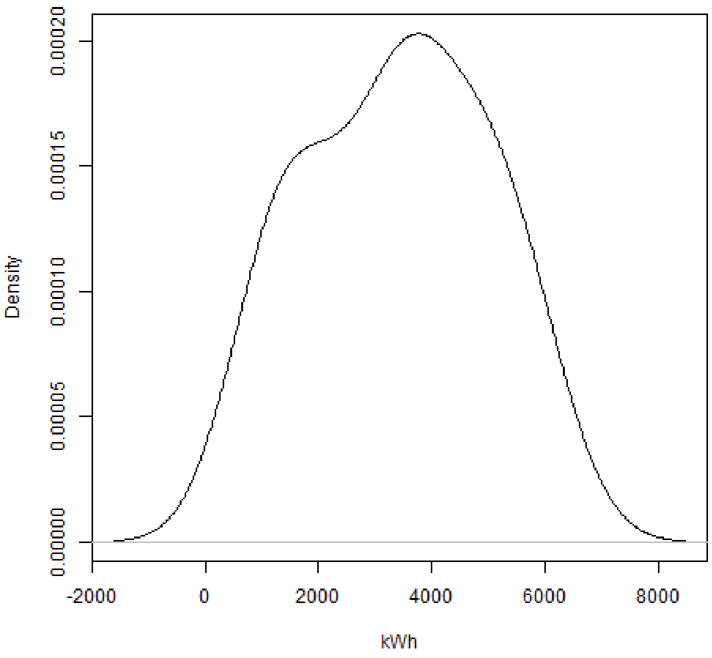

Figure A57: Distribution of the annual energy consumption in kWh for TC9a (Mosaic N)

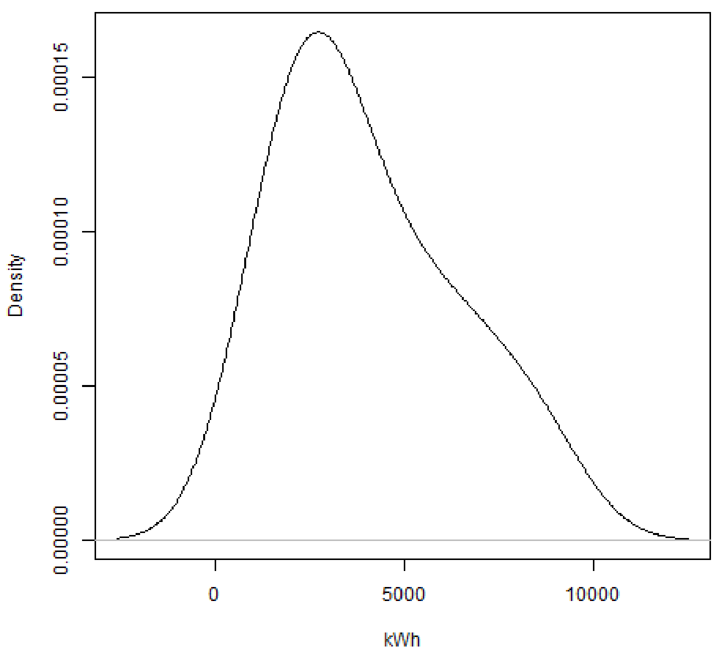

Figure A58: Distribution of the annual energy consumption in kWh for TC9a (Mosaic O)

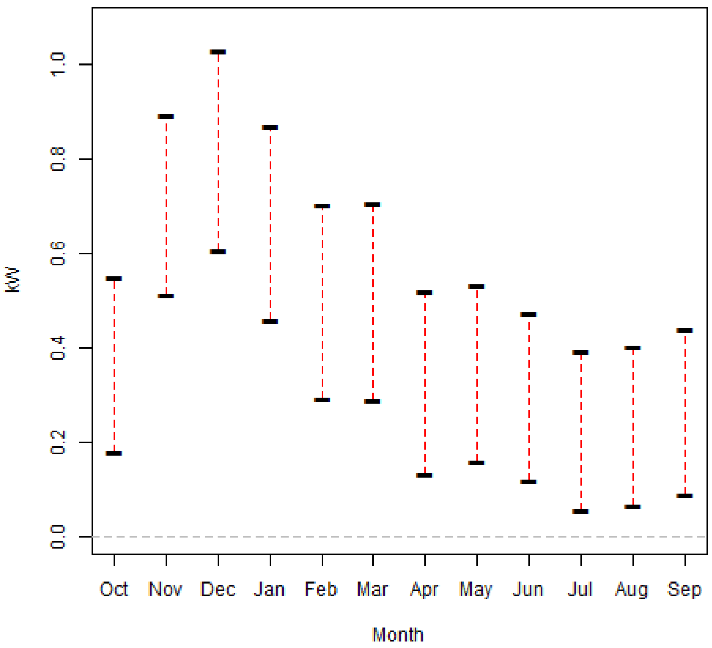

Figure A59: 95% confidence intervals for the difference in the means of the monthly weekday max 4-8pm peak in kW for TC1a and TC9a (Without Dependencies). Positive values indicate that the mean of TC1a is greater than the mean of TC9a.

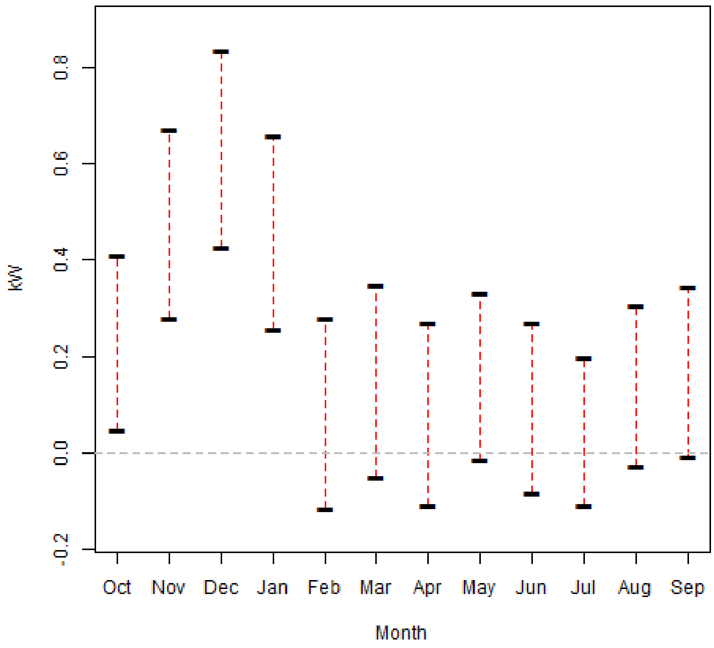

Figure A60: 95% confidence intervals for the difference in the means of the monthly weekday max 4-8pm peak in kW for TC1a and TC9a (Without Dependencies). Positive values indicate that the mean of TC1a is greater than the mean of TC9a.

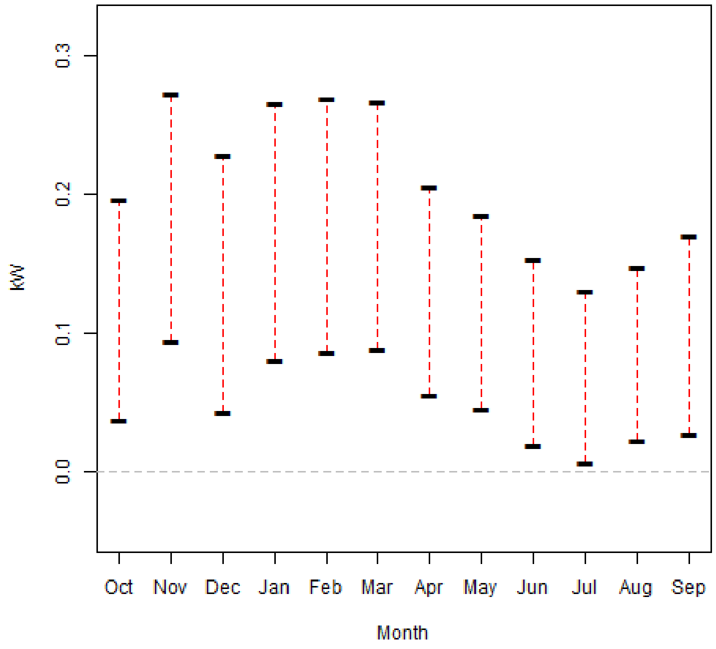

Figure A61: 95% confidence intervals for the difference in the means of the monthly weekday mean 4-8pm peak in kW for TC1a and TC9a (Non-renter). Positive values indicate that the mean of TC1a is greater than the mean of TC9a.

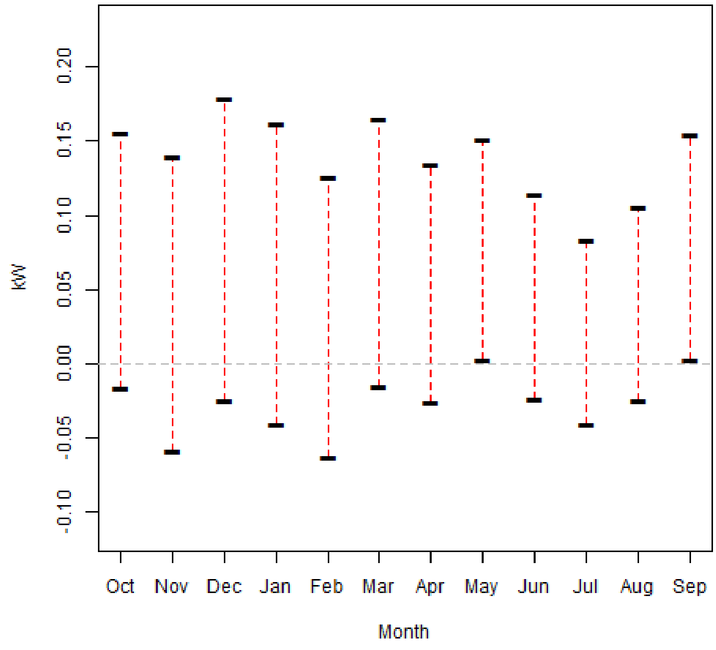

Figure A62: 95% confidence intervals for the difference in the means of the monthly weekend mean 4-8pm peak in kW for TC1a and TC9a (Non-renter). Positive values indicate that the mean of TC1a is greater than the mean of TC9a.

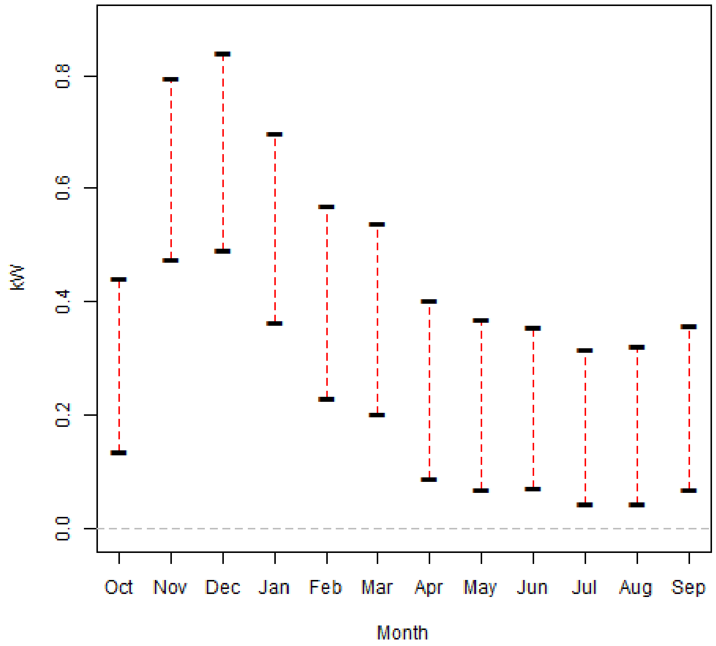

Figure A63: 95% confidence intervals for the difference in the means of the monthly weekday max 4-8pm peak in kW for TC1a and TC9a (Non-renter). Positive values indicate that the mean of TC1a is greater than the mean of TC9a.

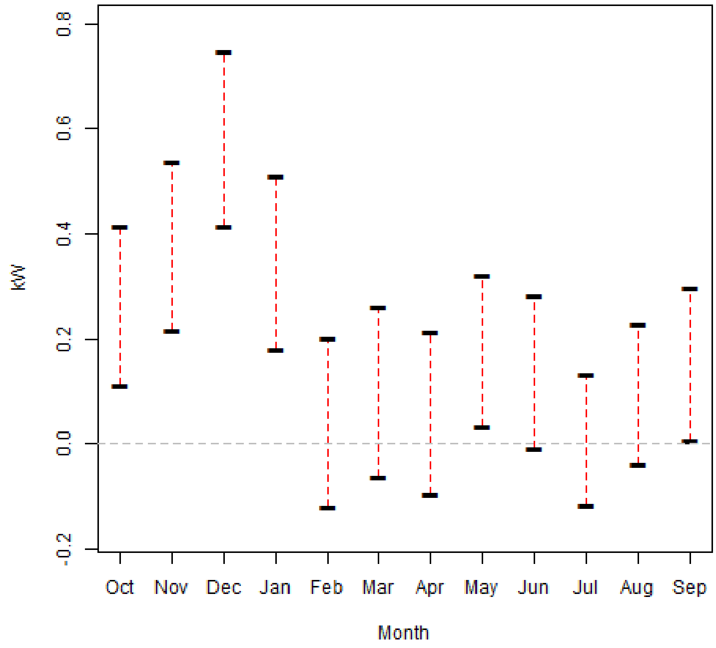

Figure A64: 95% confidence intervals for the difference in the means of the monthly weekday max 4-8pm peak in kW for TC1a and TC9a (Non-renter). Positive values indicate that the mean of TC1a is greater than the mean of TC9a.

7.6 T-tests for TC1a vs TC9a by Demographic

	Month	p-value for the difference in the mean peaks (4-8pm) for TC1a vs TC9a (3dp) (without dependants) [2 tailed test]	p-value for the difference in the max peaks (4-8pm) for TC1a vs TC9a (3dp) (without dependants) [2 tailed test]
Weekday	October 2012	**0.003**	**0.000**
	November 2012	**0.000**	**0.000**
	December 2012	**0.001**	**0.000**
	January 2013	**0.000**	**0.000**
	February 2013	**0.000**	**0.000**
	March 2013	**0.000**	**0.000**
	April 2013	**0.001**	**0.001**
	May 2013	**0.001**	**0.000**
	June 2013	**0.002**	**0.001**
	July 2013	0.010	0.009
	August 2013	0.005	0.007
	September 2013	**0.003**	**0.003**
Weekend	October 2012	0.216	0.013
	November 2012	0.172	**0.000**
	December 2012	0.554	**0.000**
	January 2013	0.063	**0.000**
	February 2013	0.226	0.409
	March 2013	0.023	0.138
	April 2013	0.119	0.396
	May 2013	0.165	0.072
	June 2013	0.246	0.302
	July 2013	0.283	0.557
	August 2013	0.116	0.097
	September 2013	0.068	0.061
	All year	**0.000**	**0.002**

Table A5: Table of p-values for 2-tailed t-tests assessing any differences in the mean mean and max peaks during the 4-8pm period for those without dependencies. Significant results are highlighted in bold.

	Month	p-value for the difference in the mean peaks (4-8pm) for TC1a vs TC9a (3dp) (Non-renter) [2 tailed test]	p-value for the difference in the max peaks (4-8pm) for TC1a vs TC9a (3dp) (Non-renter) [2 tailed test]
Weekday	October 2012	**0.004**	**0.000**
	November 2012	**0.000**	**0.000**
	December 2012	**0.004**	**0.000**
	January 2013	**0.000**	**0.000**
	February 2013	**0.000**	**0.000**
	March 2013	**0.000**	**0.000**
	April 2013	**0.001**	**0.002**
	May 2013	**0.001**	**0.004**
	June 2013	0.011	**0.003**
	July 2013	0.031	0.010
	August 2013	0.008	0.010
	September 2013	0.007	**0.004**
Weekend	October 2012	0.111	**0.001**
	November 2012	0.422	**0.000**
	December 2012	0.140	**0.000**
	January 2013	0.241	**0.000**
	February 2013	0.512	0.609
	March 2013	0.103	0.225
	April 2013	0.186	0.458
	May 2013	0.042	0.015
	June 2013	0.202	0.065
	July 2013	0.492	0.908
	August 2013	0.222	0.163
	September 2013	0.041	0.039
	All year	**0.001**	**0.001**

Table A6: Table of p-values for 2-tailed t-tests assessing any differences in the mean mean and max peaks during the 4-8pm period for non-renters. Significant results are highlighted in bold.

	Month	p-value for the difference in the mean peaks (4-8pm) for TC1a vs TC9a (3dp) (Mosaic F) [2 tailed test]	p-value for the difference in the max peaks (4-8pm) for TC1a vs TC9a (3dp) (Mosaic F) [2 tailed test]
Weekday	October 2012	**0.001**	**0.000**
	November 2012	**0.000**	**0.000**
	December 2012	**0.002**	**0.000**
	January 2013	**0.001**	**0.000**
	February 2013	**0.000**	**0.000**
	March 2013	**0.000**	**0.001**
	April 2013	**0.003**	0.014
	May 2013	0.011	0.198
	June 2013	**0.003**	0.008
	July 2013	0.005	0.008
	August 2013	**0.002**	0.005
	September 2013	**0.001**	**0.004**
Weekend	October 2012	0.069	**0.003**
	November 2012	0.375	**0.003**
	December 2012	0.024	**0.000**
	January 2013	0.371	**0.004**
	February 2013	0.323	0.477
	March 2013	0.070	0.084
	April 2013	0.040	0.233
	May 2013	0.024	0.042
	June 2013	0.135	0.271
	July 2013	0.041	0.367
	August 2013	0.040	0.164
	September 2013	0.021	0.047
	All year	**0.001**	**0.016**

Table A7: Table of p-values for 2-tailed t-tests assessing any differences in the mean mean and max peaks during the 4-8pm period for Mosaic F. Significant results are highlighted in bold.

7.7 T-tests for TC1a vs Those That Lost Money in TC9a

	Month	p-value for the difference in the mean peaks (4-8pm) for TC1a vs TC9a (those that lost money) (3dp) [2 tailed test]	p-value for the difference in the max peaks (4-8pm) for TC1a vs TC9a (those that lost money) (3dp) [2 tailed test]
Weekday	October 2012	0.018	0.826
	November 2012	0.051	0.015
	December 2012	0.105	0.009
	January 2013	0.055	0.373
	February 2013	0.093	0.741
	March 2013	0.204	0.998
	April 2013	0.075	0.380
	May 2013	0.027	0.323
	June 2013	**0.003**	0.132
	July 2013	**0.003**	0.063
	August 2013	0.007	0.300
	September 2013	**0.002**	0.068
Weekend	October 2012	0.714	0.315
	November 2012	0.220	0.144
	December 2012	0.733	**0.000**
	January 2013	0.341	0.065
	February 2013	0.291	0.247
	March 2013	0.682	0.745
	April 2013	0.427	0.182
	May 2013	0.588	0.977
	June 2013	0.274	0.546
	July 2013	0.045	0.041
	August 2013	0.139	0.224
	September 2013	0.286	0.448
	All year	0.086	0.697

Table A8: Table of p-values for 2-tailed t-tests assessing any differences in the mean mean and max peaks during the 4-8pm period for those who lost money under the tariff in TC9a. Significant results are highlighted in bold.

Customer-Led Network Revolution

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