Customer-Led Network Revolution

Insight Report: Domestic Solar PV Customers

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1 Executive Summary

The transition to a low carbon energy network is likely to include a higher proportion of distributed renewable energy generation, in which domestic solar photovoltaic (PV) technology is likely to play an important role. As the electricity network was not designed to accommodate distributed energy generation such as PV, it is important to understand the impacts that might arise on the energy network as a result of widespread PV deployment. In the Customer Led Network Revolution project, households with PV installations were monitored to understand their electricity generation and consumption patterns.

This report considers two household groups or test cells (TCs): TC5 is comprised of 143 households with solar PV, and TC20 (IHD) of an additional 149 households which in addition to solar PV had an in-home display (IHD) notifying users when electricity generation exceeded household demand and was therefore being exported to the grid. The IHD was intended as a prompt to users who could then choose to utilise this excess generation within the home which could reduce PV export at times of peak PV energy generation. These two test cells were compared against the baseline (or "control") group TC1a, which is described elsewhere.

When making comparisons between the test cells, in general it is only possible to state the trends observed averaged across groups of customers. It is not possible to make definitive and accurate statements about specific customers, because the distribution of behaviour tends to be quite large, even within a customer group.

Compared to TC1a (the base domestic profile and control group), households with solar PV were found to show:

- **Lower net annual electricity consumption** (by 32% for TC5 and 22% for TC20(IHD))
- However, excluding PV generation they showed *higher gross annual electricity consumption* than TC1a (between 10% and 30% greater for TC5, and 24%-43% greater for TC20 (IHD)).
- **Higher peaks in demand during the 4-8pm period** (when compared to TC1a, the mean of customers' daily evening peaks, averaged across the year and across all households in the test cell was 14%-33% greater for TC5 and 24-31% greater for TC20 (IHD)).
- **A greater fraction of electricity use during the 10am-4pm period** (mean of 30% of daily use for TC5 and TC20 (IHD) compared to 27% for TC1a).

However, it was not possible to account for demographic factors in the comparison. Therefore it is not clear to what extent the above are a result of behaviour change arising directly from the PV installations, or PV take-up being more highly correlated with some customer groups where the above behaviour was pre-existing to some extent.

On average, the households in the solar PV test cells generated per annum an amount of electricity equivalent to just over 40% of their annual electricity consumption. While some electricity was exported, especially in the summer months around midday, around 80% of the electricity generated was used on site.

Throughout the analysis, TC5 and TC20 (IHD) showed no statistically significant differences to each other; the in-home display was not observed to improve households' utilisation of PV generation.

Findings from the qualitative research[1] which demonstrated that people without an in-home display found other means to monitor and assess the amounts of electricity they imported and exported, offer some explanation of this effect. These methods included record keeping, collecting and interpreting monthly statistics and regularly checking meters. Participants with the in-home-display commonly became enthusiastic users of the illuminated green-red signalling system which prompted householders to change the timing of household practices, particularly those employing wet white-goods.

Regarding impact on the grid, peak export took place at times when demand of the PV households – and the homes around them – was low, meaning that with modest levels of PV penetration entire distribution areas may tend to become net exporters of electricity. This may pose challenges to networks in the future, either in terms of increased voltage rise, or exceeding the thermal capacity of the local network.

Finally, further research and analysis into customer demographics could provide insight into the extent to which the electricity consumption patterns observed here are due to the installation of the PV arrays. This is important to network operators because:

- The rollout of domestic PV could lead to increased pressure on the network at the times of greatest network stress (winter evening peak)
- Domestic PV could be less effective in decarbonising energy supply because its generation is partly countered by an increase in electricity consumption within the household.

[1] CLNR-L244: High Level Summary of Learning: Domestic Solar PV Customers (2014)

2 Trial Overview

2.1 Description

This report details the analysis of the two domestic solar PV test cells (5 and 20 (IHD)), which provide profiles of electricity consumption and generation for a range of households with solar photovoltaic (PV) panels.

- **Test cell 5** involved monitoring of 143 domestic customers' electrical energy demand and solar PV generation.
- **Test cell 20 (IHD)**[2] involved monitoring of 149 domestic customers' electrical energy demand and solar PV generation, for households with an In-home Display (IHD) which notified customers when PV generation exceeded household consumption and therefore electricity was being exported to the grid. This was intended as a prompt to encourage customers to manually adapt their electricity consumption to reduce PV export to the grid.

A separate test cell, TC20 (Auto), investigates households with solar PV and automatic means of balancing generation and consumption. Unfortunately challenges with data quality in that test cell could not be resolved and reliable outputs could not be generated with the TC20 (Auto) data.

Where necessary, Test Cell 1a (Basic profiling of domestic smart meter customers), is used in this report as the baseline group against which the results of TC5 and TC20 (IHD) are compared.

In addition to the metered consumption and generation data, 46 separate interviews were carried out across 31 households within the Solar PV trials to investigate current practices and participants' perceptions on their electricity use. The qualitative analysis is reported on in more detail in the Synthesis Report in [1].

2.2 Purpose

These trials were designed to support Learning Outcomes 1 and 2. Specifically, they provide the data needed to understand:

- PV owners' patterns of electricity generation, in-home use and export to the grid;
- Whether real-time information on energy generation and consumption can make customers more likely to use a greater proportion the energy generated by their PV systems and prevent mass-export in times of high generation and low demand.

[2] This may occasionally be referred to as TC20man, meaning that the participants were expected to manually balance electricity generation and consumption.

3 Trial Design

3.1 Participation and recruitment

Test cell 5 comprised 143 domestic customers and test cell 20(IHD) another 149, both of which included non-British Gas customers. Participants 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.

The existence of a solar PV installation was a pre-requisite for participation in test cells 5 and 20, which narrowed the potential target group for recruitment. However, the recruitment success rate for these test cells was unexpectedly high (11%, compared to an industry average for direct-marketing in the region of 1.5%), which is in line with reports by staff involved in the recruitment process regarding customers showing interest in how they could make the most of their existing low carbon technologies.

A high number of households originally recruited were found to be part of “rent a roof” schemes[3], which then had to be discarded due to the added complexity involved in interacting with the scheme owners. The resulting shortfall in numbers was made up mainly working with social housing providers which already had PV installations in place [1].

The factors above are likely to have an impact on the demographic make-up of test cells 5 and 20(IHD), i.e. being a mixture of owner occupiers and social housing renters. However, no demographic data is available for these test cells.

3.2 Equipment and tariff

TC5 and TC20 (IHD) customers had pre-existing solar PV installations, varying in capacity and date of installation. Where not already present, the following equipment was installed for both test cells:

- **Mains isolation switch** to allow isolation of mains power and safe installation of the secondary meter;
- **Metering:** a secondary meter on the mains electrical supply to monitor electricity import and export, and an in-line meter to monitor the energy generation of the PV system;
- **Communications:** a hub was installed to collect the metering data.

In addition, TC20 (IHD) customers were provided with an in-home display which indicates when electricity is being exported back to the grid.

No change was made to customers’ existing tariffs, although the installation of a smart meter may have had an effect on the calculation of remuneration under the Feed-in Tariff (see section 4.4.3).

[3] In this type of scheme, companies lease roof space from homeowners for the installation of solar PV panels. Customers can typically make use of the electricity generated by the panels and thus reduce energy bills, although the scheme operator receives the Feed in Tariff subsidy related to the generation of renewable energy.

4 Trial Results

4.1 Data available

Table 1 below shows the number of customers and date ranges for which metered data is available for the solar PV test cells 5 and 20(IHD) and the baseline test cell 1. The months of October to December are not directly comparable between the solar PV test cells and the baseline test cell, which needs to be taken into account when considering possible conclusions in these months.

Test Cell	Number of customers	Date range
TC1a	8415	October 2012 – September 2013
TC5	143	January – December 2013
T20(IHD)	149	January – December 2013

Table 1: Data available in each test cell

There is no information available about electricity consumption patterns for the participants before the start of the trial, or prior to installation of the panels, and so it is not possible to compare the results against electricity use before the installation of the PV panels.

4.2 Load and generation profiles

Customers in both test cells 5 and 20 (IHD) show familiar electricity consumption profiles. Figure 1 shows the daily gross consumption (i.e. excluding PV generation) profiles for TC5 and 20(IHD), with TC1a included for comparison. Although the shape of all three profiles is broadly similar, the baseline test cell 1a plateaus around 9am whereas the solar PV test cells show consumption continuing to increase after this point. This difference could be due to underlying or pre-existing differences in consumption patterns between the TC1a group and the TC5 and 20 groups. An alternative explanation is that the TC5 and 20 groups attempted to match electricity demand to solar PV generation, and this is explored further in section 4.4.

As expected, PV generation varied across the year, with the summer months showing more power generated and longer generation hours. Figure 2 shows the daily generation profiles for each month for test cell 5. The seasonal effect is particularly clear, with average peak generation in July more than trebling that of January. In hours without generation there are small energy losses due to the operation of the inverters, although these are negligible in comparison to overall household electricity use. Interestingly, most months show some form of energy generation during the 4-8pm period, which in general corresponds with the times of greatest domestic electricity use.

The net result of electricity generation and consumption for TC5 and 20 (IHD) is shown in **Figure 3** as an average across the year. There is a clear dip in the net demand during the day leading to net export around midday, with a peak in net demand in the evening. Net load profiles vary considerably across the year (see Figure 11 in the Appendices), with no or little export in the winter months, and peak export exceeding peak demand at the height of summer. Average net load profiles for each month can be found in Figure 11 in the appendices.

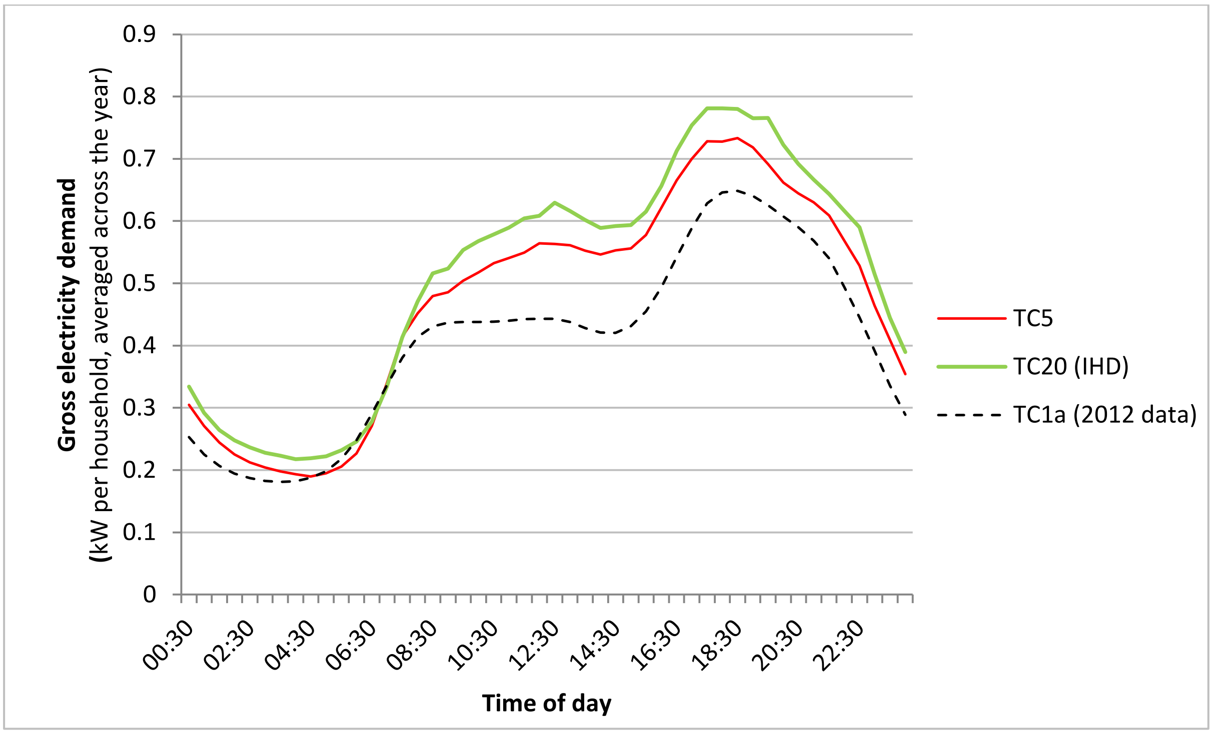

Figure 1: Daily load profiles for all three test cells, averaged across the year. This excludes any PV generation.

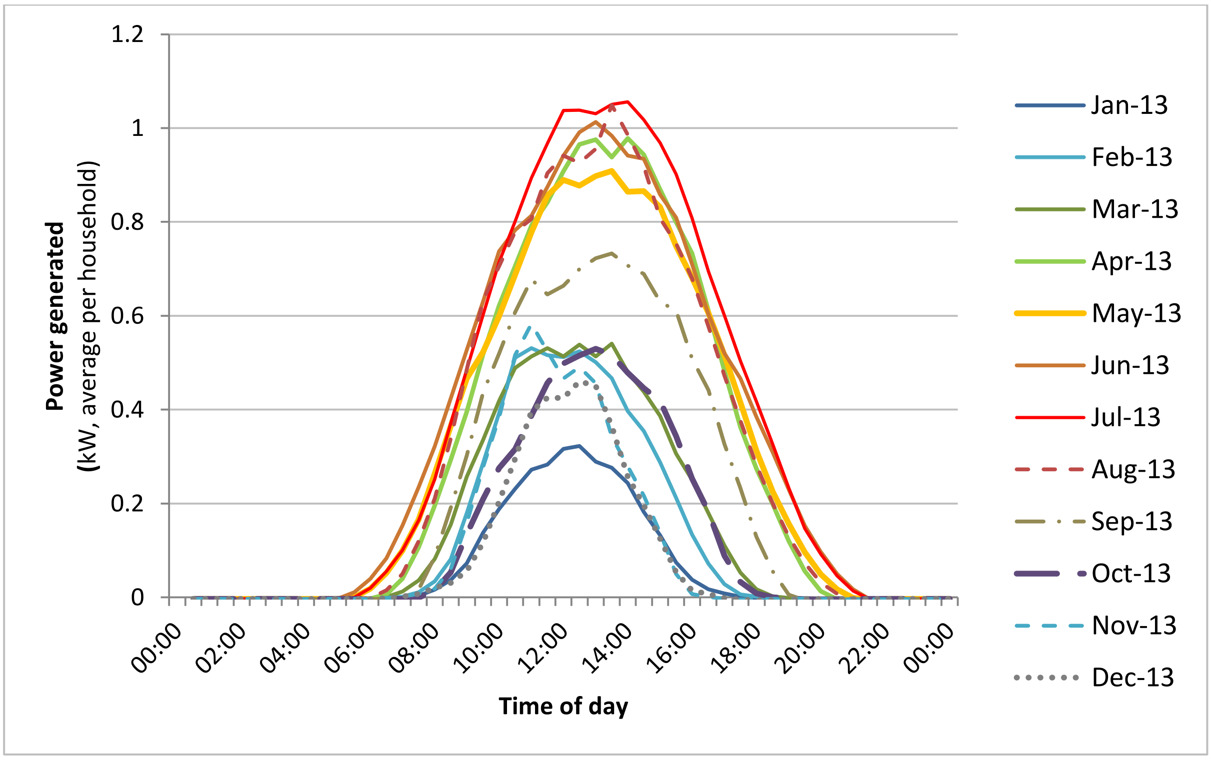

Figure 2: Daily PV generation profiles for test cell 5, averaged across each month

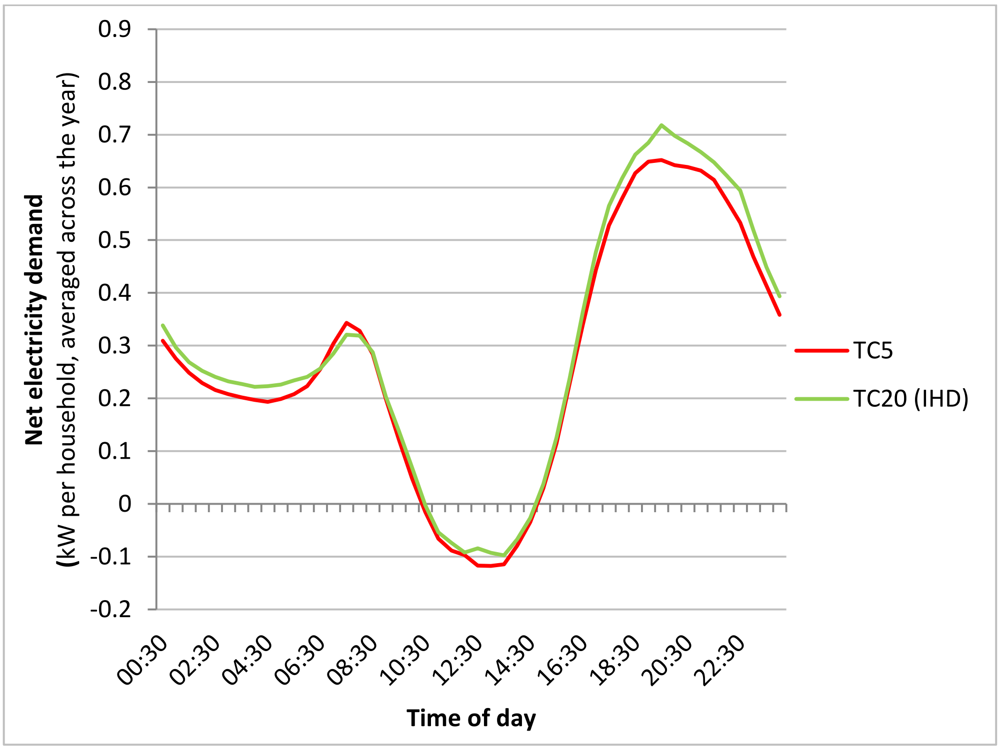

Figure 3: Net electricity demand for the solar PV test cells, averaged across the year.

4.3 Annual electricity consumption

The total electricity consumed by TC5 and TC20 (IHD) households was found to be higher than in TC1a households. Figure 4 shows the distribution of annual gross electricity consumption (excluding any PV generation) for all three test cells. The mean value for TC5 is between 10 and 30% higher than for TC1a, with the mean for TC20 (IHD) being 24-43% higher than TC1a. However, the difference between TC5 and TC20 (IHD) is not statistically significant (see Table 2 and Table 3 in the appendices).

Note that in TC1a[4] mean annual electricity consumption was found to vary by up to 40% between different demographic groups, meaning that without further demographic insight the differences identified here cannot be attributed exclusively to the solar PV.

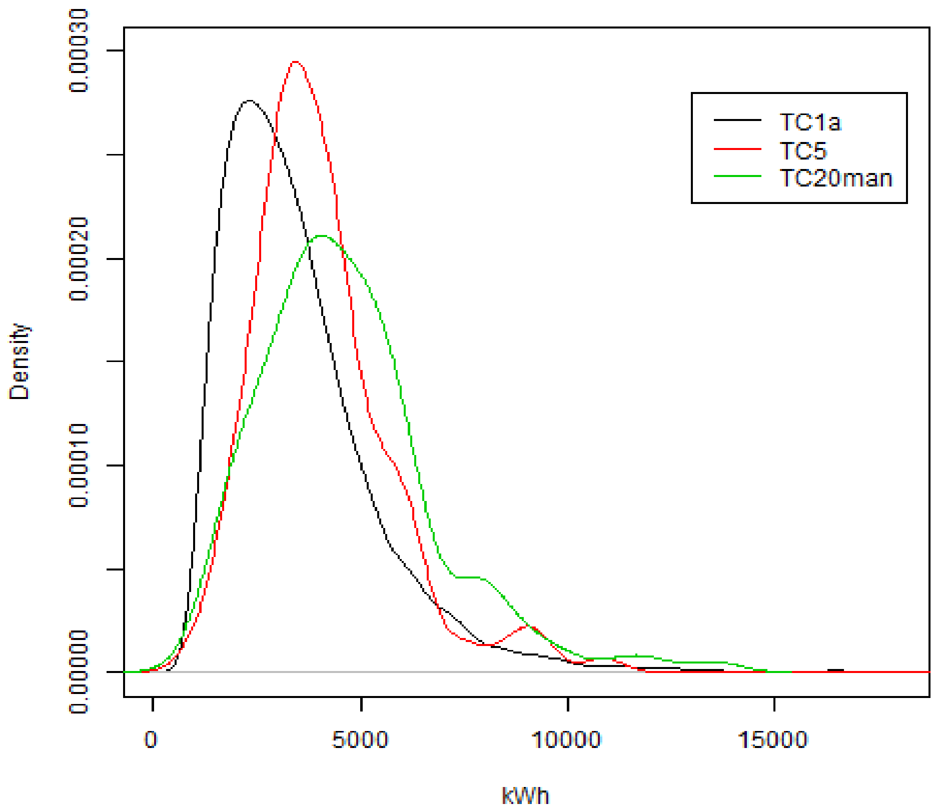

Figure 4: Distribution of the annual gross electricity consumption for all three test cells.

Figure 5 below shows the average overall annual consumption for each of the three test cells alongside the energy generated by the solar PV test cells. The electricity generation by TC20 (IHD) households is equivalent to 41% of their annual electricity consumption, this proportion rising to 43% in the case of TC5 households.

[4] CLNR-L216 - Insight Report: Baseline domestic profiles

Therefore, although TC5 and 20(IHD) show higher gross electricity use, the PV generation more than offsets this. The result is a net annual electricity demand by the solar PV households 22% – 32% lower than the baseline test cell.

It is important to note that not all of the electricity generated is used directly on-site. As shown in section 4.2, electricity generation and consumption have very different daily and seasonal profiles – therefore in some occasions electricity generated is a much smaller proportion of electricity use than described here, whereas at other times generation exceeds consumption. Section 4.4 below looks into the extent to which the solar PV test cells are able to make use of their own generation.

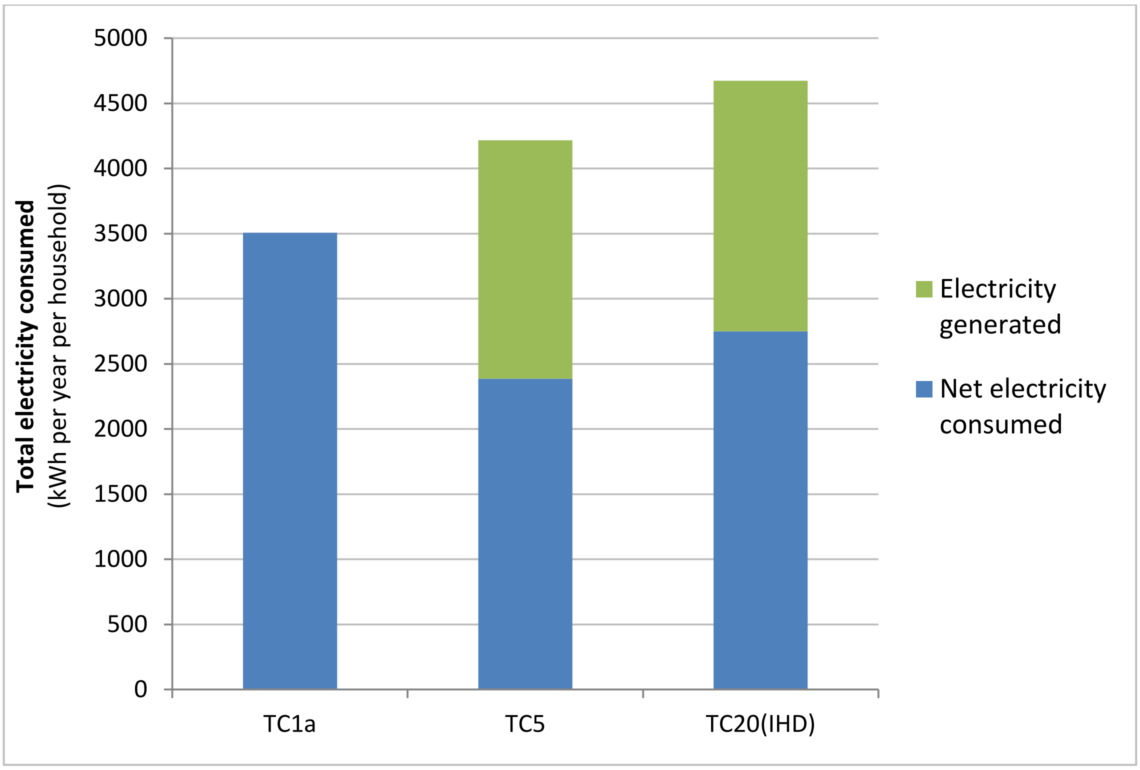

Figure 5: Net and gross annual electricity consumption (household average for each test cell)

4.4 Load balancing

4.4.1 Daytime electrical energy use

Throughout the year, the 10am – 4pm period ("daytime period") represents the time of greatest PV generation. This section looks into the proportion of daily electricity consumption the TC5 and TC20 (IHD) households use during this period.

As shown in Figure 6, during weekdays TC5 and TC20 (IHD) households show a higher proportion of electricity consumption in the daytime period[5], indicating that their load profiles are slightly better matched to the availability of PV generation than in the case of the TC1a baseline. The difference between TC5 and TC20 (IHD) is not statistically significant for any month. Findings from the qualitative research[6] which demonstrated that people without an in-home display found other means to monitor and assess the amounts of electricity they imported and exported, offer some explanation of this effect. These methods included record keeping, collecting and interpreting monthly statistics and regularly checking meters. Participants with the in-home-display commonly became enthusiastic users of the illuminated green-red signalling system which prompted householders to change the timing of household practices, particularly those employing wet white-goods.

On weekends, all three test cells show a higher proportion of electricity consumed during the daytime period. In this case, the PV test cells only show a statistically significant difference to TC1a for up to 5 months of the year, with no particular seasonal link (for this test, see Table 8 in the Appendices). Again, the difference between TC5 and TC20 (IHD) is not statistically significant for any month.

[5] The only exception being April 2013, where there is no statistical difference between the TC1a and TC5 values.

[6] CLNR-L244: High Level Summary of Learning - Domestic Solar PV Customers (2014)

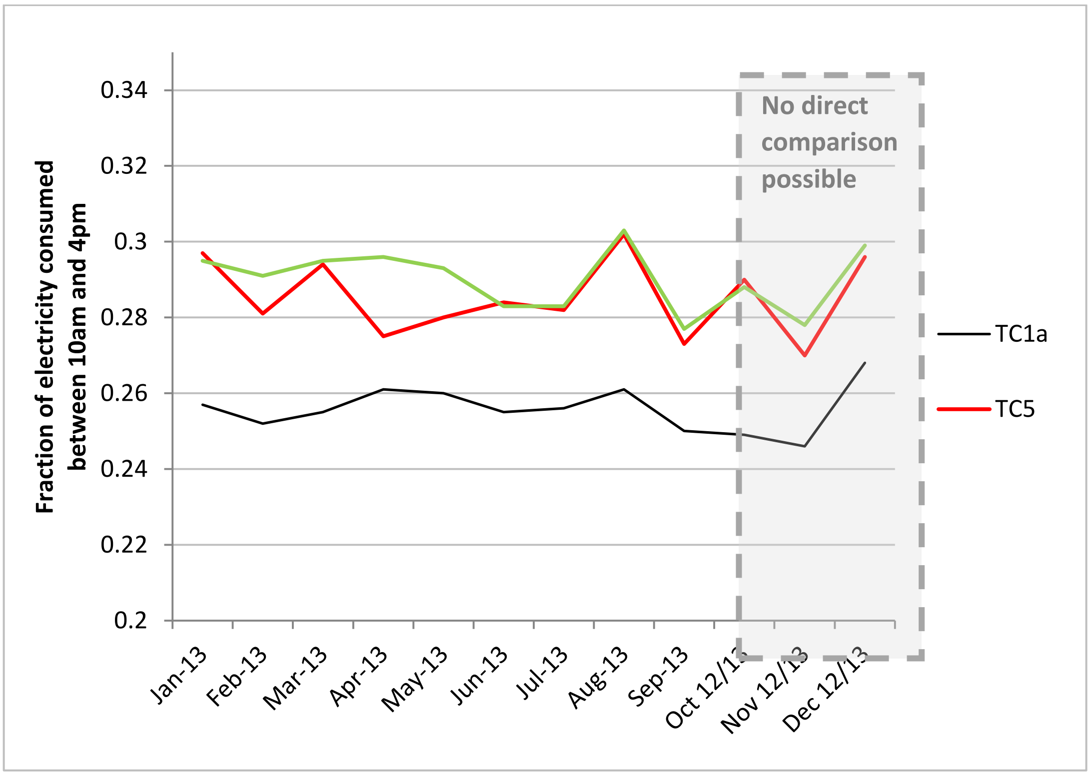

Figure 6: Proportion of electricity consumed in the 10am-4pm period during weekdays, averaged for each month, for all three test cells

The proportion of electricity used during the daytime period shows no discernible relationship to season or time of the year, despite higher levels of PV generation during the summer months. Therefore, there is no indication that households adjust their consumption patterns to match PV output (for example, to minimise export/import). Furthermore, the lack of difference between the values for TC5 and TC20 (IHD) reinforces the view that these customers' demand patterns seem relatively inflexible. Changes in consumption outside of the peak generation period were not studied.

4.4.2 Proportion of electricity used on site

Although limits have been identified to the scope for balancing generation with household electricity use, on average across the year the majority of electricity generated by the PV panels in TC5 and TC20 (IHD) is used on site (80% and 82% respectively), as shown in Figure 7.

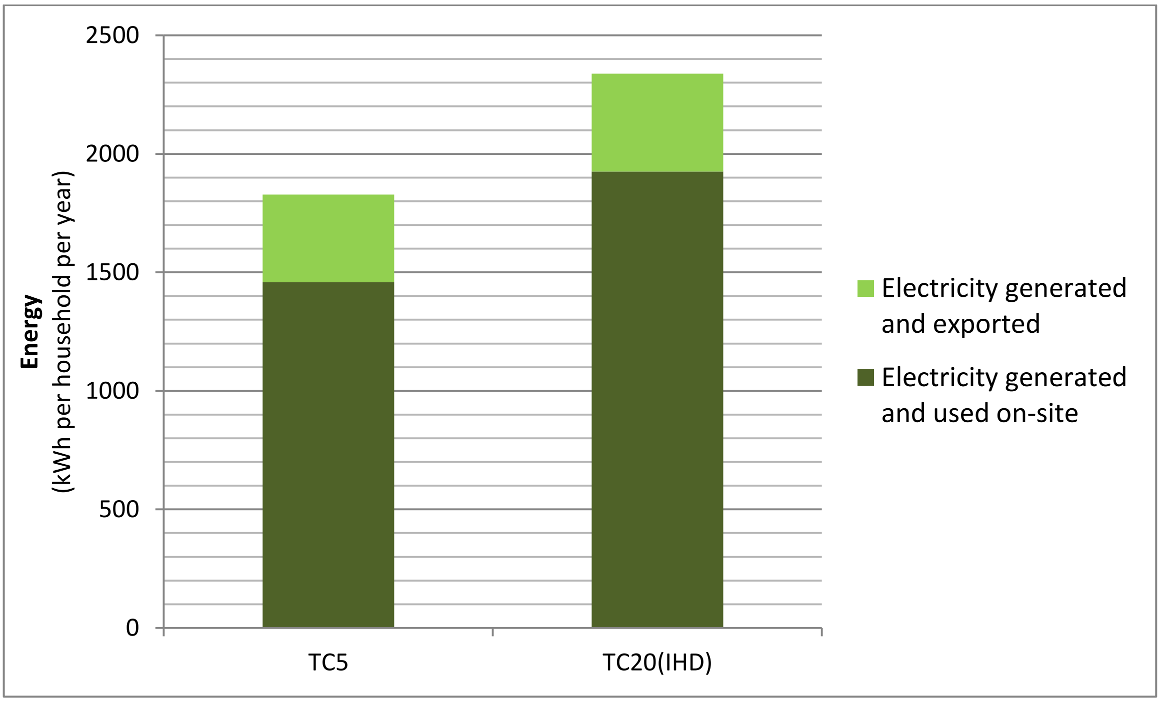

Figure 7: Proportion of generation used on site and exported. Average per household across the year.

The households with in-house displays (TC20 (IHD)) only show a marginally higher on-site use of their electricity generation, which suggests that IHDs are of limited value when attempting to adjust electricity use to match PV generation. This could be due to the fact that participants were not at home during peak generation periods to actually see the IHD.

4.4.3 A note on the Feed-In Tariff

The Feed-in Tariff to encourage the deployment of distributed forms of renewable generation is composed of a generation tariff (payable for every kWh of electricity generated) and an export tariff (payable for every kWh of electricity exported to the grid). The export tariff is typically lower than the price of electricity for the consumer, and therefore it is generally more financially beneficial to use PV generation on site, as this minimises the amount of electricity that needs to be purchased.

However, the amount payable can only be calculated accurately if there is an export meter present, which is not the case for all households with PV installations. Where this is not available, export is estimated at 50% of the electricity generated [5], which Figure 7 would suggest is an overestimate for customers in TC5 and TC20 (IHD).

Assuming these customers' electricity use patterns did not change on joining the trial, customers who only had an export meter installed upon joining may have lost out on their Feed-in Tariff income, as they will only be earning the export tariff for the actual ~20% export rather than the estimated 50%.

4.5 Power peaks

4.5.1 Peak export

One concern with the mass deployment of PV generation is the onset of a new "time of greatest network stress" due to high levels of distributed electricity exported to the grid when consumption is low – as could occur near midday in summer months. To understand the scale of this issue, the day of minimum demand in the daytime period was analysed. Using TC1a as a basis, this was found to be Tuesday 4th June 2013. Figure 8 shows the average TC1a load profile for this day alongside the net profiles for TC5 and TC20 (IHD).

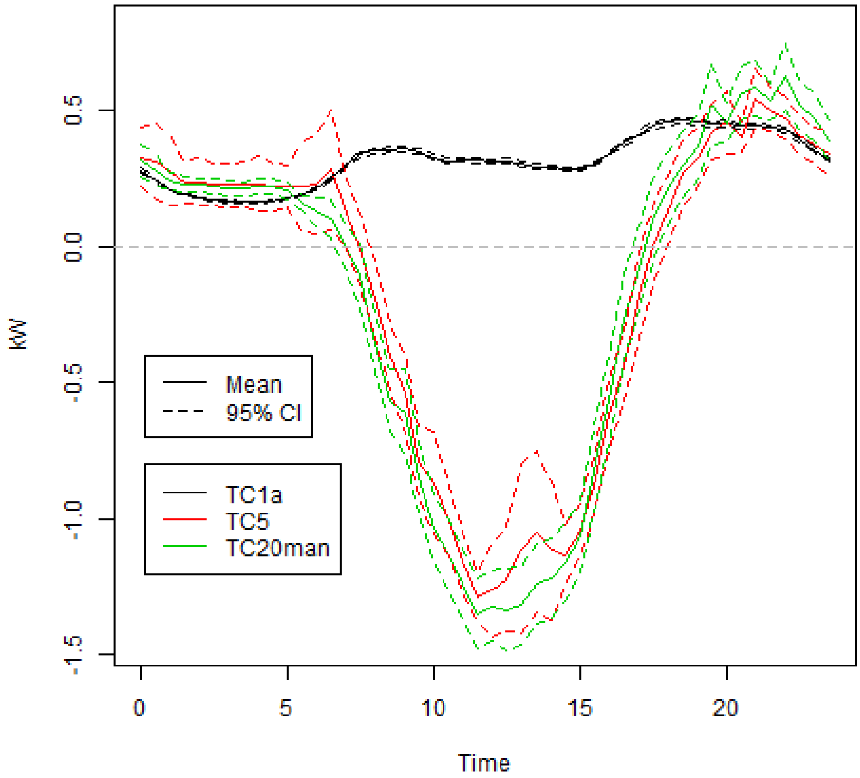

Figure 8: Load profile for Tuesday 4th June 2013, all test cells.
Positive values indicate net consumption, negative values indicate net export.

The overall profile shape is similar to that for other days, but with relatively high levels of electricity export in the case of the solar PV test cells. TC5 and TC20 (IHD) do not show significant differences in peak export, suggesting that the presence of an in-house display is not particularly useful in terms of mitigating this peak.

The peak electricity export is in the region of 1.3 kW, which is equivalent to the average electricity demand of 4 to 5 homes at that time of the day.

4.5.2 Peak demand

Whilst PV generation presents a clear risk for a new “time of greatest network stress” in summer, it is also useful to assess the impact upon demand around the evening peak.

Figure 9 shows the distributions of the mean daily peak[7] gross demand (i.e. excluding any PV generation) in the 4-8pm period for each of the three test cells. TC5 showed a mean annual mean peak between 14 and 33% greater than that of TC1a, whilst that of TC20 (IHD) was greater than TC1a by between 24% and 31%. The difference between TC5 and TC20 (IHD) mean peaks is not statistically significant.

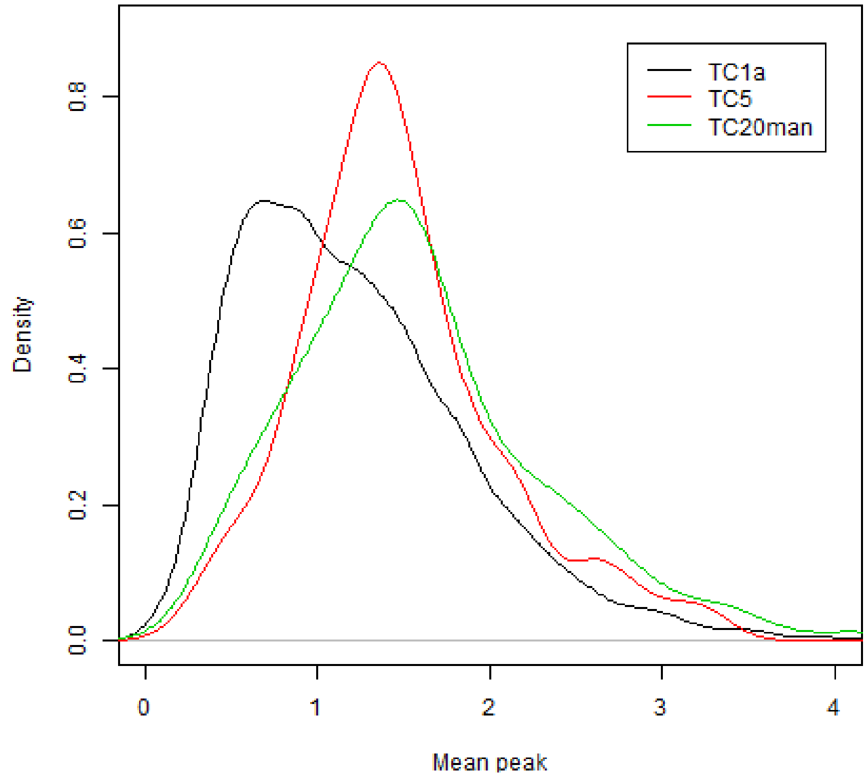

Figure 9: Mean peak gross demand in the 4-8pm period, averaged across the year

Looking at the effect of time of year (Table 11 and Table 12 in the appendices), the higher evening peak demand for TC5 and TC20 (IHD) is most visible around the summer months. There is no clear difference between weekdays and weekends.

However, the above only considers gross demand in the 4-8pm period whereas previously (Figure 2) it was shown that a significant proportion of PV generation also occurs after 4pm, especially in the summer. This means that it is possible that the higher 4-8pm (consumption) peaks identified above for TC5 and TC20 (IHD) coincide with times of electricity generation and therefore become less significant when net demand is considered. It is important to note, though, that no PV generation is expected at the time of greatest network stress (after 5:30pm on winter evenings).

[7] This is calculated by taking the peak half-hourly consumption in the 4-8pm period for every household for every day, and averaging across all customers and across the year.

The net monthly load profiles (Figure 11 in the appendices) can be used to check whether the evening peak demand for TC5 and TC20 (IHD) is indeed greater once PV generation is also taken into account. The profiles suggest higher evening consumption peaks in the solar PV test cells compared to TC1a, although in several months the 95% confidence intervals of the different test cells overlap, making it difficult to extract a solid conclusion. The data does not show whether these potentially higher evening peaks can be attributed to the existence of PV installations, and no further insight on this issue could be extracted from the social science research.

5 Conclusions

5.1 Learning Outcome 1

In order to support **Learning Outcome 1**, this report has analysed the electricity demand and generation characteristics of households with solar PV installations (test cells 5 and 20(IHD)). Although the focus has been on the current characteristics of this customer group, these provide an indication of the sort of patterns which may be expected to develop with the progressive roll-out of solar PV across the UK housing stock.

Averaged across the year, customers with PV panels were found to generate an amount of electricity equivalent to around 40% of their annual electricity consumption, although as expected this varied considerably between the winter and summer months due to differences in number of daily hours of sunshine, cloud cover and position of the sun relative to the array.

During the day, PV generation brought down net demand of these customers, often to negative values (i.e. net export), particularly outside the winter months. The peak in electricity export occurs at the height of summer, with the combination of low electricity demand and high generation. This will have to be managed by the network operators as the penetration of solar PV increases. At the opposite end of the scale, peak net demand still occurs in the evenings, especially in the winter months.

5.2 Learning Outcome 2

Comparisons between test cells are able to support **Learning Outcome 2**: Comparing the solar PV test cells against the baseline TC1a allows an investigation of whether customers adapt their electricity use to maximise savings by matching consumption to PV generation, and comparing TC5 to TC20 (IHD) allows to look into whether a real-time notification of excess PV generation further encourages customers to do this.

Customers in test cells 5 and 20 (IHD) consumed a higher proportion of their electricity use in the 10am-4pm period than those in TC1a, meaning their load profiles were slightly better suited to utilising PV generation. The high figures of on-site use of electricity generated (around 80%) suggest that these customers were relatively successful in achieving this. However it should be noted that no causation (i.e. PV installation leading to a change in consumption) can be established, and an alternative explanation could be that the underlying consumption profiles of PV adopters (from TC5 and TC20) is not representative of the population as a whole (TC1a).

The solar PV customers showed a higher gross annual electricity use than those in TC1a, although once the electricity generated is taken into account the net result is a reduction of around 22-32%. Again the higher annual gross consumption could be due to the demographic group that typically adopts PV systems. Alternatively this may indicate some form of “rebound” effect whereby customers who generate some of their own electricity feel able to consume more, which diminishes the net gain of installing any given amount of on-site generation.

Regarding the times of greatest network stress – peak winter demand and peak summer export – solar PV customers' behaviour did not mitigate these effects.

Comparing TC5 to TC20 (IHD) often resulted in no statistically significant difference, which suggests that in-home displays are of limited use in terms of encouraging customers to manually balance electrical consumption and generation. This could be due to the fact that participants were not at home during peak generation periods to actually see the IHD.

5.3 A note on demographics

As explained in section 3.1, there are reasons to believe the demographic make-up of Test Cells 5 and TC20 (IHD) is not representative of the UK population at large or of Test Cell 1a. Furthermore, there is no demographic information of the solar PV test cells which would allow a direct comparison of the TC5 and TC20 (IHD) test cells with sub-groups of TC1a.

Therefore, it is not possible to say categorically whether the differences identified when comparing to TC1a (higher annual electricity consumption, higher proportion of electricity use in the daytime, suggestion of higher evening peak demand) are related to the PV installation themselves or simply due to a different customer profile that predated the PV installations.

However, one point to note is that one of the outcomes from TC1a was that demographic groups with higher annual electricity use also tended to have the highest proportion of electricity use in the *evenings* [4]. Because TC5 and TC20 (IHD) customers display both higher annual electricity consumption and higher proportion of *daytime* electricity use than the TC1a means, they do not fit clearly into the demographic groups of TC1a.

6 References

[1] **CLNR-L244:** High Level Summary of Learning: Domestic Solar PV Customers, Harriet Bulkeley et al, December 2014

[2] **CLNR-L036:** "Project Lessons Learned from Trial Recruitment", Rebekah Phillips et al, July 2013

[3] **CLNR Residential Propositions,** British Gas, February 2013

[4] **CLNR-L216: Insight Report: Baseline Domestic Profile,** December 2014

[5] **DEI-CLNR-DC027** "Technical Note: Test Cell 20 Trial Design Note", Pádraig Lyons, September 2011

[6] **August 2014 SDRC Outputs – Test Cell 5 – TC5_Dataset**, August 2014

7 Appendix 1: Tests for statistical significance

Throughout this document, differences between test cells are tested for statistical significance by carrying out multiple t-tests. We correct the p-value using

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

This means that for annual tests, testing 3 test cells a significant p-value is below 0.0170. For monthly tests, testing 3 test cells (so 36 multiple tests) a significant p-value is below 0.0014. 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.

Throughout the document p-values are given to 4 decimal places, which means that at certain points a p-value of 0.0000 may be observed. The p-value is not truly zero, but only appears so as a consequence of only taking figures to 4 decimal places.

Two-tailed t-tests are used in this document to quantify if there has been any change in the means (μ) of any 2 distributions, they have null hypothesis

$$H_0: \mu_A = \mu_B$$

and alternative hypothesis

$H_1: \mu_A \neq \mu_B.$

This analysis is carried out using multiple t-tests applying the correction above, this is due to both time constraints not allowing us to fully explore a more complex model and to allow easy readership, as this approach matches that of other analyses carried out for the Customer-Led Network Revolution (CLNR). A more formal approach would be to possibly carry out this analysis using ANOVA and subsequent techniques.

8 Appendix 2: Data tables

Annual consumption

Table 2: Overall values for annual gross electricity consumption

Test Cell	Mean (kWh)	Standard Deviation (kWh)
TC1a	3507.122	1931.167
TC5	4216.132	2243.683
TC50 (IHD)	4674.720	2145.488

Table 3: Check for statistical significance: Two-tailed t-tests for gross annual consumption

Test cells used	TC1a vs TC5	TC1a vs TC20man	TC5 vs TC20man
p-value	**0.0001**	**0.0000**	0.0927
95% confidence interval	(-1053.727,-364.293)	(-1495.601,-839.595)	(-993.773,76.598)
Significant p-values are highlighted in bold			

Proportion of electricity used during the day

Table 4: Values for proportion of electricity use during the 10am-4pm period (average across the year)

Test Cell	Mean	Standard Deviation
TC1a	27%	5.5%
TC5	29.6%	5.8%
TC50 (IHD)	30.1%	5.5%

Table 5: Monthly values for proportion of electrical energy use during the 10am-4pm period (weekdays)

	Means (μ) and standard deviations (σ) for Monthly Weekday Ratios									
	TC1a			TC5				TC20 (IHD)		
Month	μ	σ		μ	σ	% change from TC1a		μ	σ	% change from TC1a
Jan-13	0.257	0.075		0.297	0.08	16%		0.295	0.071	15%
Feb-13	0.252	0.076		0.281	0.079	12%		0.291	0.072	15%
Mar-13	0.255	0.075		0.294	0.073	15%		0.295	0.074	16%
Apr-13	0.261	0.072		0.275	0.08	5%		0.296	0.071	13%
May-13	0.26	0.072		0.28	0.067	8%		0.293	0.073	13%
Jun-13	0.255	0.073		0.284	0.095	11%		0.283	0.069	11%
Jul-13	0.256	0.069		0.282	0.065	10%		0.283	0.067	11%
Aug-13	0.261	0.068		0.302	0.069	16%		0.303	0.078	16%
Sep-13	0.25	0.075		0.273	0.071	9%		0.277	0.07	11%
October 2012/2013	0.249	0.072		0.29	0.066	*16%**		0.288	0.063	*16%**
November 2012/2013	0.246	0.077		0.27	0.075	*10%**		0.278	0.069	*13%**
December 2012/2013	0.268	0.071		0.296	0.064	*10%**		0.299	0.056	*12%**

** note that for these months, the TC1a data is from 2012 and the TC5 and TC20 (IHD) data is from 2013, and therefore they are not directly comparable.*

Table 6: Monthly values for proportion of electrical energy use during the 10am-4pm period (weekends)

	Means (μ) and standard deviations (σ) for Monthly Weekend Ratios					
	TC1a		TC5a		TC20man	
Month	μ	σ	μ	σ	μ	σ
January 2013	0.307	0.081	0.333	0.085	0.329	0.087
February 2013	0.304	0.078	0.325	0.099	0.324	0.083
March 2013	0.305	0.076	0.311	0.085	0.324	0.081
April 2013	0.300	0.077	0.322	0.075	0.324	0.068
May 2013	0.303	0.078	0.295	0.079	0.318	0.069
June 2013	0.301	0.074	0.305	0.082	0.321	0.079
July 2013	0.289	0.071	0.314	0.073	0.307	0.072
August 2013	0.296	0.074	0.287	0.079	0.296	0.075
September 2013	0.297	0.077	0.326	0.081	0.335	0.083
October 2012/2013	0.295	0.078	0.298	0.083	0.313	0.067
November 2012/2013	0.295	0.082	0.311	0.077	0.312	0.070
December 2012/2013	0.297	0.080	0.321	0.083	0.317	0.078

Table 7: Check for statistical significance: Two-tailed t-tests for annual ratio of electrical energy consumed in the 10am-4pm period

Test cells used	TC1a vs TC5	TC1a vs TC20man	TC5 vs TC20man
p-value	**0.0000**	**0.0000**	0.5046
95% confidence interval	(-0.035,-0.017)	(-0.040,-0.022)	(-0.018,0.009)
Significant p-values are highlighted in bold			

Table 8: Test for statistical significance for difference in proportion of electrical energy used in 10am-4pm period, monthly values

	Month	p-value for the difference in the ratio for TC1a vs TC5 (4dp) [2 tailed test]	p-value for the difference in the ratio for TC1a vs TC20man (4dp) [2 tailed test]	p-value for the difference in the ratio for TC5 vs TC20man (4dp) [2 tailed test]
Weekday	January 2013	**0.0000**	**0.0000**	0.8260
	February 2013	**0.0000**	**0.0000**	0.2312
	March 2013	**0.0000**	**0.0000**	0.8187
	April 2013	0.0193	**0.0000**	0.0167
	May 2013	**0.0008**	**0.0000**	0.1422
	June 2013	**0.0000**	**0.0000**	0.9564
	July 2013	**0.0000**	**0.0000**	0.8964
	August 2013	**0.0000**	**0.0000**	0.8953
	September 2013	**0.0002**	**0.0000**	0.6451
	October 2012/2013	**0.0000**	**0.0000**	0.7651*
	November 2012/2013	**0.0003**	**0.0000**	0.3154*
	December 2012/2013	**0.0000**	**0.0000**	0.6197*
Weekend	January 2013	**0.0002**	0.0017	0.6323
	February 2013	0.0017	0.0026	0.9045
	March 2013	0.3848	0.0019	0.1564
	April 2013	**0.0012**	**0.0004**	0.8377
	May 2013	0.1999	0.0202	0.0070
	June 2013	0.4717	**0.0011**	0.1005
	July 2013	**0.0000**	0.0026	0.4375
	August 2013	0.1794	0.9507	0.3284
	September 2013	**0.0000**	**0.0000**	0.3566
	October 2012/2013	0.5995	0.0054	0.1021*
	November 2012/2013	0.0224	0.0161	0.9542*
	December 2012/2013	**0.0004**	0.0037	0.6385*
	All year	**0.0000**	**0.0000**	0.5046
	* A direct comparison for 2013 is available here			

Peak in gross electricity demand

Table 9: Gross peak demand: Means and standard deviations

Test Cell	Average of mean 4-8pm peak (kW)	Standard Deviation (kw)	Average of max 4-8pm peak (kW)	Standard Deviation (kW)
TC1a	**1.219**	**0.674**	**4.188**	**2.015**
TC5	**1.503**	**0.657**	**4.877**	**2.377**
TC50 (IHD)	**1.602**	**0.796**	**4.886**	**2.156**

Table 10: Check for statistical significance: difference in gross peak demand, annual values

Test cells used	TC1a vs TC5	TC1a vs TC20man	TC5 vs TC20man
p-value	**0.0000**	**0.0000**	0.2573
95% confidence interval	(-0.397,-0.171)	(-0.494,-0.271)	(-0.270,0.073)
Significant p-values are highlighted in bold			

Table 11: Check for statistical significance: Monthly mean/max peak by weekday or weekend, TC1a vs TC5

	Month	p-value for difference in mean 4-8pm peaks TC1a vs TC5 (4dp)	p-value for difference in max 4-8pm peaks TC1a vs TC5 (4dp)
Weekday	January 2013	0.1274	0.0043
	February 2013	**0.0006**	0.0085
	March 2013	0.0107	0.0391
	April 2013	**0.0000**	**0.0006**
	May 2013	**0.0000**	**0.0010**
	June 2013	**0.0000**	**0.0000**
	July 2013	**0.0000**	**0.0000**
	August 2013	**0.0000**	**0.0004**
	September 2013	**0.0000**	**0.0002**
	October 2012/2013	**0.0006**	0.0075
	November 2012/2013	0.0042	**0.0000**
	December 2012/2013	0.0460	**0.0000**
Weekend	January 2013	0.0111	0.0316
	February 2013	0.0444	0.0085
	March 2013	0.0086	0.2256
	April 2013	0.0117	0.0020
	May 2013	**0.0000**	**0.0000**
	June 2013	**0.0000**	**0.0000**
	July 2013	**0.0000**	**0.0000**
	August 2013	**0.0000**	0.0668
	September 2013	**0.0000**	0.1238
	October 2012/2013	***0.0003***	*0.0069*
	November 2012/2013	*0.1875*	***0.0006***
	December 2012/2013	*0.0265*	*0.0154*
	All year	**0.0000**	**0.0000**

Table 12: Check for statistical significance: Monthly mean/max peak by weekday or weekend, TC1a vs TC20 (IHD)

	Month	p-value for difference in mean 4-8pm peaks TC1a vs TC20 (IHD) (4dp)	p-value for difference in max 4-8pm peaks TC1a vs TC20(IHD) (4dp)
Weekday	January 2013	0.0018	0.0183
	February 2013	0.0027	0.0555
	March 2013	**0.0003**	0.8113
	April 2013	**0.0000**	0.0171
	May 2013	**0.0000**	0.4214
	June 2013	**0.0000**	**0.0000**
	July 2013	**0.0000**	**0.0000**
	August 2013	**0.0000**	**0.0000**
	September 2013	**0.0000**	**0.0000**
	October 2012/2013	***0.0000***	***0.0000***
	November 2012/2013	***0.0001***	*0.0013*
	December 2012/2013	***0.0007***	*0.0080*
Weekend	January 2013	**0.0003**	0.0518
	February 2013	0.0052	0.6998
	March 2013	**0.0000**	0.1982
	April 2013	**0.0000**	0.6322
	May 2013	**0.0000**	0.0067
	June 2013	**0.0000**	**0.0000**
	July 2013	**0.0000**	**0.0000**
	August 2013	**0.0000**	**0.0000**
	September 2013	**0.0000**	**0.0000**
	October 2012/2013	***0.0000***	***0.0000***
	November 2012/2013	***0.0003***	*0.0038*
	December 2012/2013	***0.0003***	***0.0007***
	All year	**0.0000**	**0.0000**

Net load profiles

Table 13: TC1a Means (µ) and Standard Deviations (σ) for the Minimum Day (3dp)

TC1a Means (µ) and Standard Deviations (σ) for the Minimum Day (3dp)								
	01/06/2013		02/06/2013		04/06/2013		June Average	
Time (end)	µ	σ	µ	σ	µ	σ	µ	σ
00:30	0.299	0.337	0.303	0.332	0.281	0.343	0.143	0.165
01:00	0.259	0.281	0.27	0.314	0.241	0.293	0.125	0.146
01:30	0.233	0.269	0.241	0.285	0.211	0.234	0.111	0.129
02:00	0.207	0.229	0.215	0.243	0.191	0.203	0.101	0.115
02:30	0.192	0.208	0.195	0.211	0.18	0.192	0.093	0.104
03:00	0.182	0.196	0.183	0.2	0.171	0.178	0.088	0.093
03:30	0.174	0.184	0.176	0.186	0.167	0.172	0.085	0.087
04:00	0.169	0.171	0.171	0.176	0.164	0.173	0.083	0.084
04:30	0.169	0.196	0.167	0.173	0.165	0.18	0.083	0.087
05:00	0.166	0.169	0.167	0.187	0.168	0.192	0.084	0.095
05:30	0.17	0.193	0.168	0.183	0.177	0.224	0.088	0.105
06:00	0.178	0.223	0.171	0.193	0.192	0.268	0.092	0.117
06:30	0.192	0.262	0.188	0.25	0.216	0.306	0.103	0.143
07:00	0.206	0.266	0.203	0.269	0.251	0.372	0.118	0.17
07:30	0.239	0.332	0.225	0.3	0.3	0.443	0.138	0.202
08:00	0.279	0.389	0.261	0.357	0.338	0.476	0.155	0.219
08:30	0.325	0.444	0.305	0.408	0.353	0.476	0.167	0.226
09:00	0.36	0.487	0.34	0.452	0.359	0.482	0.178	0.24
09:30	0.384	0.501	0.377	0.498	0.36	0.471	0.183	0.241
10:00	0.402	0.517	0.417	0.544	0.351	0.455	0.186	0.244
10:30	0.406	0.539	0.426	0.544	0.33	0.433	0.185	0.246
11:00	0.423	0.59	0.443	0.582	0.316	0.396	0.185	0.248
11:30	0.417	0.552	0.46	0.619	0.32	0.449	0.186	0.252
12:00	0.423	0.573	0.457	0.594	0.318	0.437	0.187	0.251
12:30	0.419	0.564	0.455	0.607	0.313	0.4	0.188	0.25
13:00	0.41	0.529	0.458	0.598	0.317	0.42	0.185	0.246
13:30	0.396	0.518	0.458	0.614	0.304	0.38	0.182	0.24
14:00	0.382	0.495	0.441	0.571	0.295	0.387	0.179	0.234
14:30	0.372	0.475	0.431	0.577	0.29	0.372	0.175	0.228
15:00	0.366	0.479	0.418	0.563	0.285	0.352	0.172	0.222
15:30	0.362	0.481	0.407	0.538	0.284	0.336	0.172	0.22
16:00	0.362	0.462	0.405	0.514	0.306	0.375	0.178	0.226
16:30	0.378	0.477	0.419	0.536	0.342	0.436	0.19	0.24
17:00	0.41	0.544	0.436	0.551	0.38	0.488	0.206	0.259
17:30	0.421	0.537	0.458	0.576	0.413	0.502	0.221	0.272
18:00	0.44	0.558	0.466	0.569	0.445	0.554	0.23	0.282
18:30	0.452	0.552	0.478	0.589	0.458	0.544	0.239	0.287
19:00	0.455	0.564	0.483	0.6	0.464	0.56	0.241	0.289
19:30	0.453	0.566	0.478	0.595	0.46	0.552	0.236	0.283
20:00	0.448	0.564	0.479	0.574	0.45	0.529	0.233	0.276
20:30	0.433	0.517	0.471	0.549	0.454	0.534	0.228	0.265
21:00	0.43	0.513	0.473	0.552	0.443	0.51	0.226	0.259
21:30	0.416	0.455	0.461	0.533	0.444	0.487	0.223	0.248
22:00	0.423	0.459	0.449	0.475	0.437	0.461	0.22	0.237
22:30	0.414	0.429	0.443	0.459	0.431	0.453	0.216	0.228
23:00	0.397	0.415	0.402	0.439	0.395	0.413	0.2	0.213
23:30	0.366	0.372	0.357	0.397	0.358	0.404	0.18	0.196
00:00	0.337	0.356	0.326	0.367	0.321	0.346	0.164	0.186

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Table 14: TC5a net load profiles for days of minimum demand

TC5Means (μ) and Standard Deviations (σ) for the Minimum Day (3dp)								
	01/06/2013		02/06/2013		04/06/2013		June Average	
Time (end)	μ	σ	μ	σ	μ	σ	μ	σ
00:30	0.301	0.305	0.336	0.315	0.331	0.599	0.325	0.39
01:00	0.291	0.403	0.306	0.4	0.312	0.758	0.291	0.425
01:30	0.257	0.382	0.271	0.39	0.28	0.701	0.259	0.411
02:00	0.221	0.186	0.229	0.211	0.235	0.417	0.233	0.29
02:30	0.21	0.18	0.218	0.188	0.24	0.47	0.221	0.258
03:00	0.202	0.16	0.2	0.153	0.229	0.408	0.213	0.264
03:30	0.204	0.229	0.203	0.191	0.226	0.426	0.205	0.232
04:00	0.193	0.183	0.183	0.142	0.23	0.463	0.202	0.243
04:30	0.183	0.142	0.197	0.197	0.232	0.548	0.201	0.236
05:00	0.201	0.312	0.213	0.262	0.22	0.471	0.207	0.263
05:30	0.201	0.283	0.161	0.136	0.222	0.424	0.201	0.339
06:00	0.192	0.198	0.169	0.408	0.219	0.883	0.19	0.382
06:30	0.208	0.277	0.113	0.347	0.23	0.98	0.178	0.427
07:00	0.19	0.22	0.061	0.312	0.283	1.196	0.172	0.518
07:30	0.156	0.321	0.037	0.308	0.127	0.687	0.146	0.551
08:00	0.184	0.462	-0.065	0.484	-0.009	0.728	0.102	0.603
08:30	0.207	0.62	-0.253	0.575	-0.193	0.759	0.038	0.661
09:00	0.243	0.879	-0.322	0.759	-0.403	0.66	-0.053	0.693
09:30	0.189	0.66	-0.39	0.838	-0.54	0.793	-0.146	0.718
10:00	0.18	0.723	-0.537	0.679	-0.79	0.699	-0.235	0.76
10:30	0.195	0.605	-0.478	0.646	-0.869	1.016	-0.272	0.772
11:00	0.072	0.745	-0.351	0.845	-1.01	0.692	-0.293	0.81
11:30	-0.08	0.671	-0.31	0.866	-1.155	0.602	-0.355	0.831
12:00	-0.12	0.889	-0.43	0.924	-1.286	0.5	-0.4	0.884
12:30	-0.285	0.679	-0.49	0.859	-1.261	0.939	-0.448	0.875
13:00	-0.691	0.83	-0.562	0.721	-1.223	1.024	-0.476	0.867
13:30	-0.762	0.822	-0.716	0.785	-1.111	1.706	-0.465	0.883
14:00	-0.464	0.872	-0.805	0.717	-1.048	1.626	-0.426	0.871
14:30	-0.549	0.616	-0.945	0.695	-1.116	1.379	-0.437	0.854
15:00	-0.796	0.641	-0.768	0.669	-1.133	0.62	-0.374	0.775
15:30	-0.534	0.609	-0.795	0.573	-1.043	0.536	-0.308	0.789
16:00	-0.665	0.685	-0.428	0.963	-0.856	0.602	-0.15	0.845
16:30	-0.497	0.782	-0.102	0.988	-0.618	0.71	-0.024	0.805
17:00	-0.055	0.759	0.022	0.837	-0.439	0.715	0.074	0.829
17:30	0.094	0.862	0.052	0.696	-0.177	0.82	0.181	0.903
18:00	0.153	0.71	0.26	0.689	0	0.809	0.262	0.826
18:30	0.183	0.647	0.241	0.657	0.13	0.685	0.305	0.729
19:00	0.258	0.614	0.306	0.632	0.268	0.675	0.366	0.661
19:30	0.448	0.71	0.357	0.505	0.33	0.602	0.424	0.638
20:00	0.421	0.483	0.476	0.628	0.421	0.539	0.467	0.586
20:30	0.462	0.659	0.522	0.545	0.459	0.63	0.497	0.568
21:00	0.389	0.352	0.548	0.566	0.404	0.317	0.528	0.553
21:30	0.469	0.437	0.557	0.439	0.543	0.609	0.534	0.531
22:00	0.48	0.515	0.582	0.554	0.506	0.442	0.524	0.524
22:30	0.439	0.405	0.493	0.423	0.474	0.405	0.504	0.509
23:00	0.425	0.367	0.489	0.502	0.411	0.365	0.464	0.482
23:30	0.454	0.635	0.404	0.447	0.373	0.367	0.413	0.439
00:00	0.389	0.461	0.383	0.45	0.34	0.439	0.371	0.426

Table 15: TC20(IHD) load profiles for days of minimum demand

TC20manMeans (μ) and Standard Deviations (σ) for the Minimum Day (3dp)								
	01/06/2013		02/06/2013		04/06/2013		June Average	
Time (end)	μ	σ	μ	σ	μ	σ	μ	σ
00:30	0.313	0.24	0.353	0.287	0.318	0.337	0.329	0.293
01:00	0.297	0.254	0.335	0.351	0.282	0.353	0.291	0.255
01:30	0.278	0.21	0.324	0.396	0.241	0.177	0.264	0.216
02:00	0.266	0.222	0.263	0.195	0.227	0.161	0.244	0.187
02:30	0.253	0.24	0.247	0.181	0.226	0.151	0.236	0.194
03:00	0.285	0.605	0.239	0.162	0.223	0.151	0.227	0.196
03:30	0.233	0.155	0.234	0.169	0.216	0.145	0.222	0.182
04:00	0.22	0.138	0.234	0.174	0.213	0.147	0.217	0.157
04:30	0.214	0.153	0.234	0.183	0.221	0.156	0.219	0.17
05:00	0.232	0.199	0.23	0.177	0.221	0.154	0.223	0.185
05:30	0.221	0.168	0.202	0.173	0.207	0.184	0.221	0.232
06:00	0.227	0.176	0.149	0.168	0.16	0.172	0.187	0.231
06:30	0.204	0.182	0.075	0.246	0.13	0.293	0.155	0.291
07:00	0.181	0.207	0.053	0.387	0.106	0.398	0.118	0.39
07:30	0.157	0.307	-0.01	0.433	-0.002	0.472	0.081	0.471
08:00	0.1	0.316	-0.13	0.564	-0.108	0.675	0.048	0.559
08:30	0.09	0.584	-0.271	0.794	-0.356	0.608	-0.034	0.61
09:00	0.076	0.646	-0.422	0.819	-0.567	0.661	-0.135	0.641
09:30	0.02	0.617	-0.525	0.804	-0.607	0.889	-0.211	0.701
10:00	-0.038	0.778	-0.511	0.949	-0.844	0.733	-0.293	0.773
10:30	0.016	0.736	-0.524	0.908	-1.036	0.695	-0.341	0.783
11:00	-0.007	0.881	-0.48	0.982	-1.131	0.728	-0.361	0.829
11:30	-0.131	0.81	-0.213	1.173	-1.238	0.727	-0.386	0.858
12:00	-0.366	0.743	-0.462	1.076	-1.35	0.739	-0.469	0.881
12:30	-0.309	0.833	-0.362	0.964	-1.32	0.748	-0.525	0.857
13:00	-0.682	0.925	-0.559	1.017	-1.333	0.835	-0.545	0.903
13:30	-0.714	0.798	-0.604	0.891	-1.317	0.808	-0.56	0.877
14:00	-0.55	0.83	-0.879	0.845	-1.241	0.833	-0.535	0.897
14:30	-0.49	1.096	-1.007	0.849	-1.217	0.84	-0.533	0.875
15:00	-0.703	0.91	-0.797	0.863	-1.162	0.813	-0.488	0.847
15:30	-0.533	0.761	-0.632	0.984	-1.067	0.727	-0.389	0.841
16:00	-0.558	0.749	-0.473	0.866	-0.79	0.927	-0.243	0.85
16:30	-0.427	0.735	-0.154	0.962	-0.563	0.925	-0.083	0.852
17:00	-0.141	0.818	0.028	0.905	-0.265	0.892	0.049	0.857
17:30	0.061	0.886	0.115	0.851	-0.078	0.874	0.129	0.828
18:00	0.232	0.889	0.266	0.831	0.095	0.864	0.206	0.776
18:30	0.147	0.537	0.349	0.844	0.216	0.762	0.289	0.735
19:00	0.278	0.624	0.354	0.689	0.303	0.691	0.335	0.664
19:30	0.363	0.547	0.453	0.808	0.371	0.683	0.452	0.793
20:00	0.483	0.536	0.631	0.902	0.522	0.839	0.489	0.707
20:30	0.593	0.766	0.647	0.735	0.454	0.419	0.523	0.61
21:00	0.571	0.604	0.722	0.832	0.565	0.551	0.553	0.567
21:30	0.606	0.637	0.596	0.471	0.584	0.579	0.561	0.537
22:00	0.591	0.67	0.622	0.48	0.534	0.386	0.546	0.483
22:30	0.529	0.368	0.629	0.611	0.625	0.695	0.548	0.469
23:00	0.521	0.439	0.561	0.475	0.524	0.507	0.499	0.463
23:30	0.489	0.495	0.481	0.45	0.478	0.515	0.434	0.409
00:00	0.402	0.354	0.405	0.38	0.39	0.452	0.381	0.355

9 Appendix 3: Additional graphs

Figure 10: Load profiles for Saturday 1st June 2013 and Sunday 2nd June 2013, all test cells

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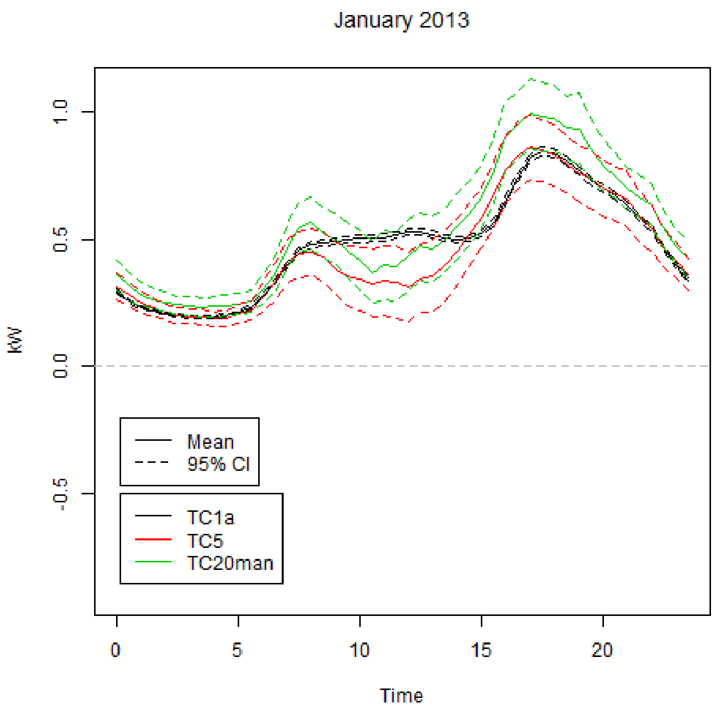
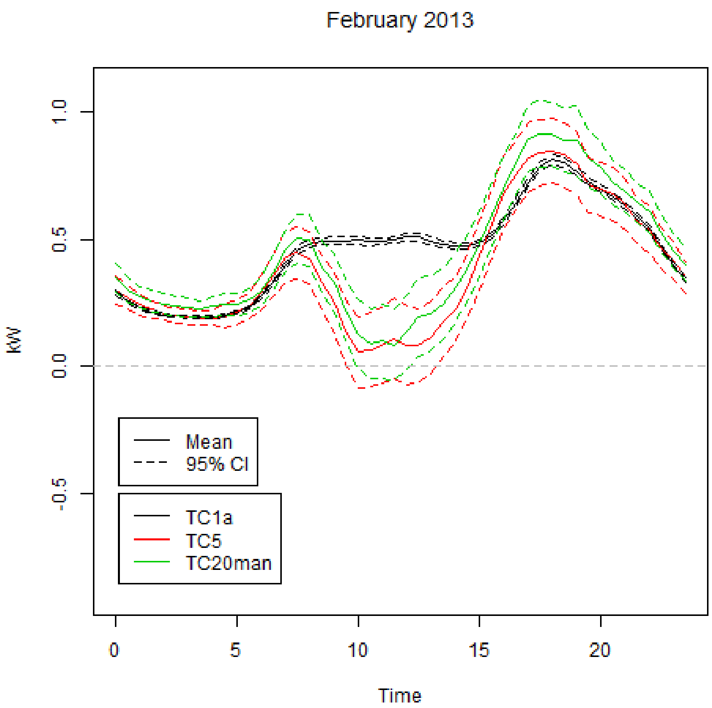
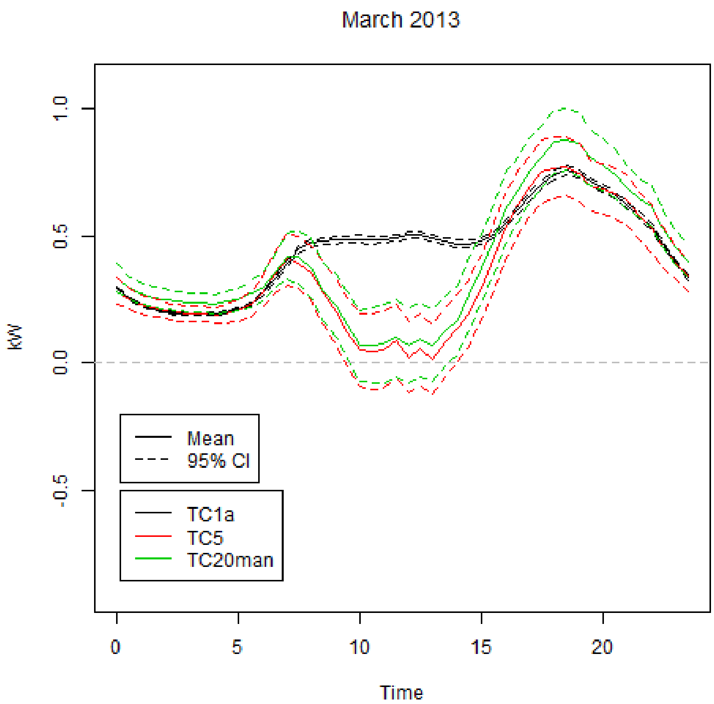
Figure 11: Average net load profiles for each month



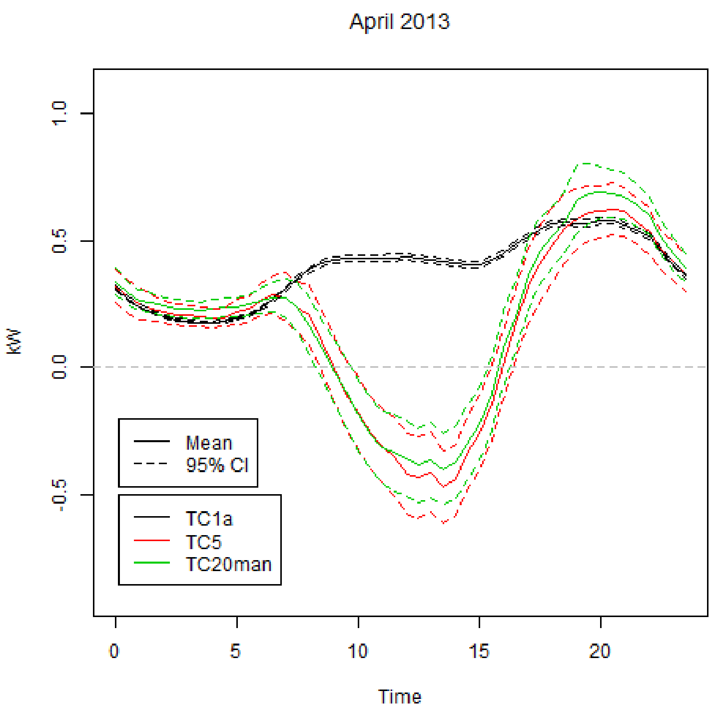
Average Load profile for January 2013, all test cells



Average Load profile for February 2013, all test cells

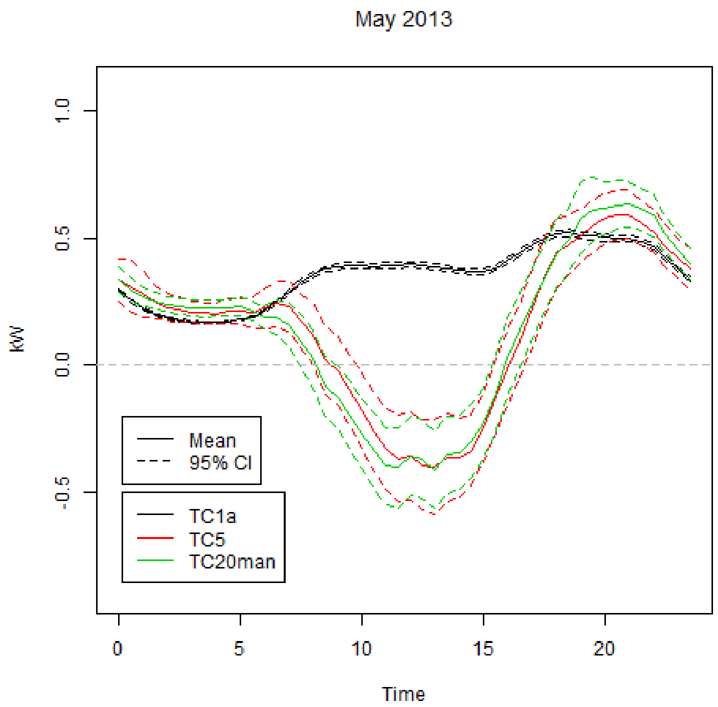


Average Load profile for March 2013, all test cells

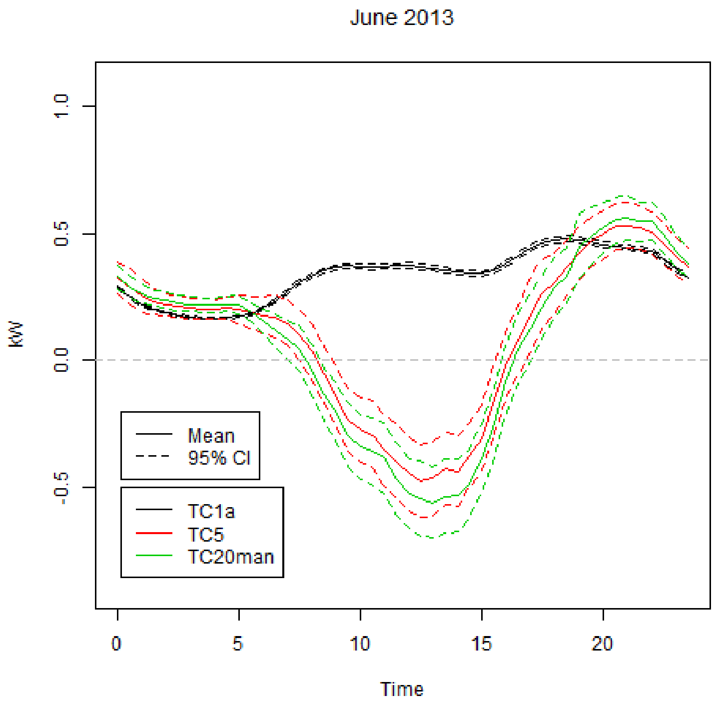


Average Load profile for April 2013, all test cells

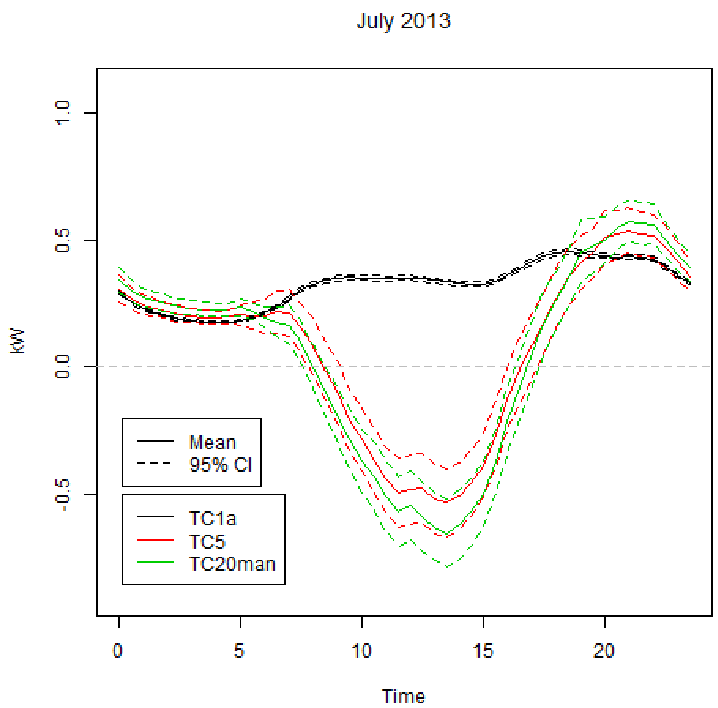
Figure 11: Average net load profiles for each month (Continued)



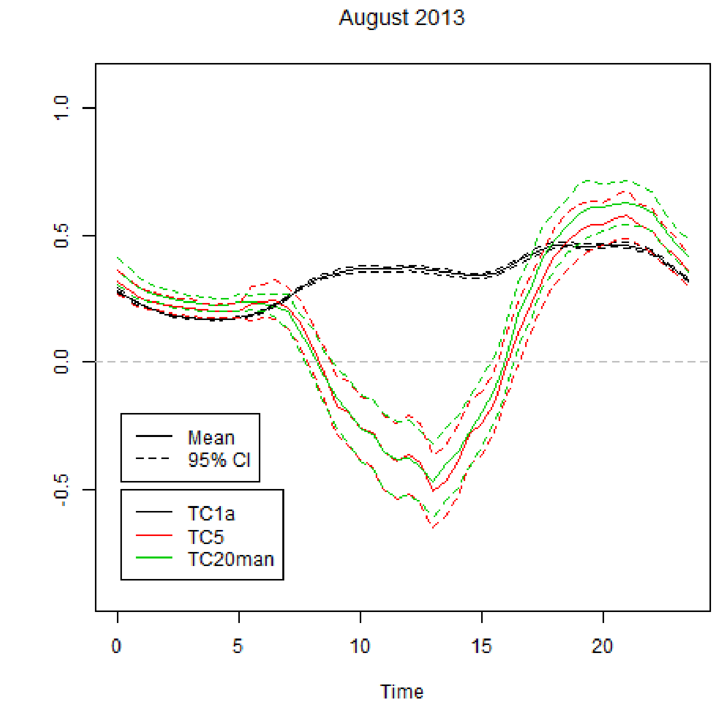
Average Load profile for May 2013, all test cells



Average Load profile for June 2013, all test cells

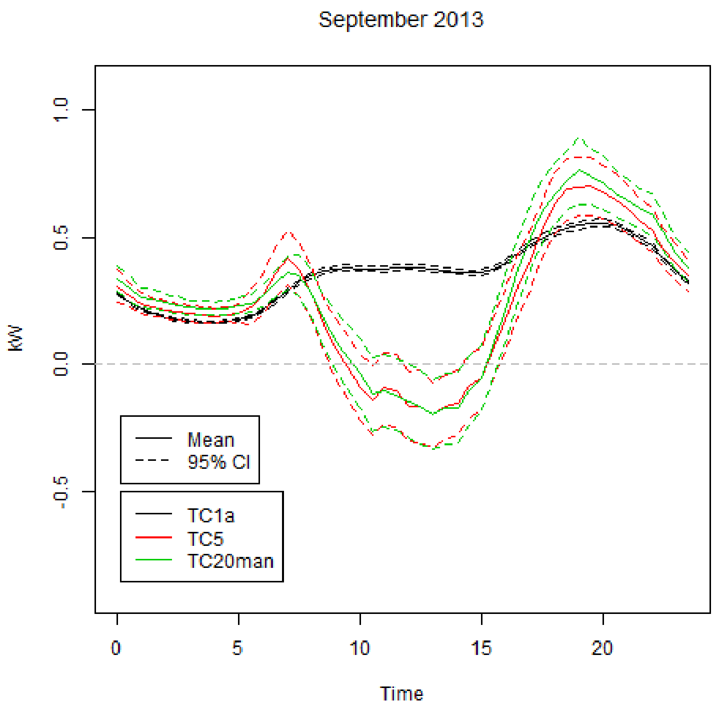


Average Load profile for July 2013, all test cells

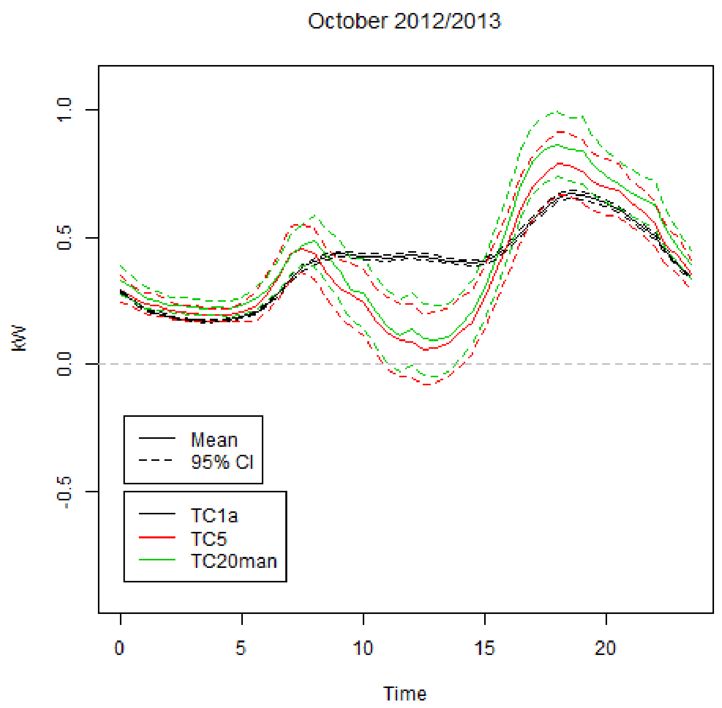


Average Load profile for August 2013, all test cells

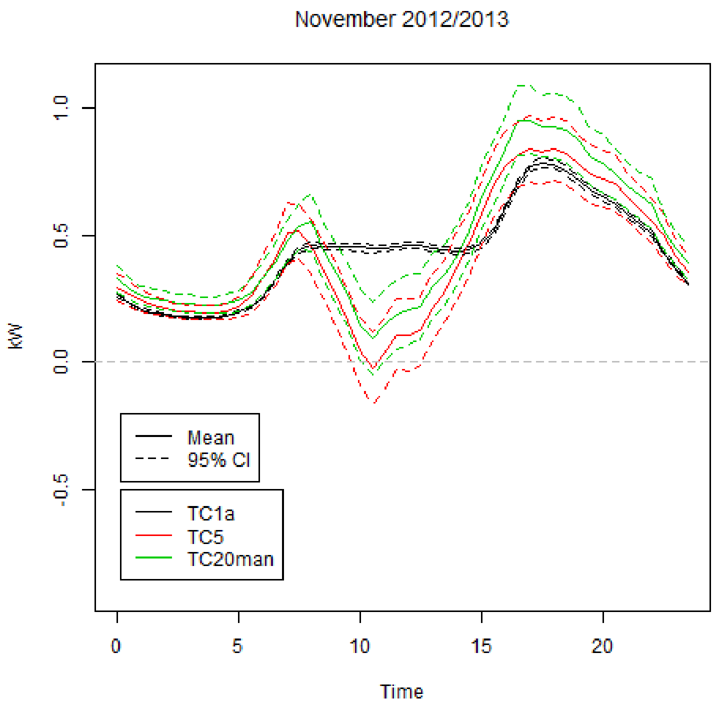
Figure 11: Average net load profiles for each month(Continued)



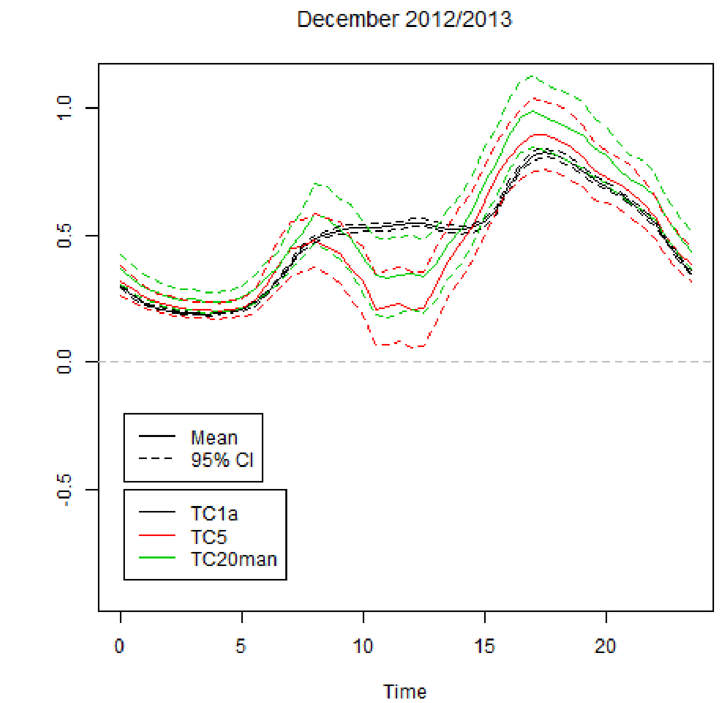
Average Load profile for September 2013, all test cells



Average Load profile for October 2012 (TC1a) and October 2013 (TC5/TC20man)



Average Load profile for November 2012 (TC1a) and November 2013 (TC5/TC20man)



Average Load profile for December 2012 (TC1a) and December 2013 (TC5/TC20man)

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