Customer-Led Network Revolution

Insight Report: Domestic Heat Pumps

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1 Executive Summary

Changing electricity demand, the electrification of the transport and heating sectors, and the increase in distributed renewable energy sources all present challenges to distribution networks. The Customer Led Network Revolution project aims to improve our understanding of current and future electricity use patterns of domestic and commercial customers. Data was collected from customers divided into different test cells (TCs) or samples, each with a particular combination of metering type, electricity tariff structure and/or low carbon technology.

Water & space heating make up a substantial proportion of domestic energy use, and therefore have a role to play in plans to increase energy security and reduce carbon emissions. Heat pumps could help achieve this due to the lower energy input required for the same amount of heating provided. Moreover by using electricity to provide heating, heat pumps provide an opportunity to facilitate the decarbonisation of heating. However the widespread electrification of heating via heat pumps would add significant pressure on electrical infrastructure, in particular an increase of peak demand at winter evening peak times when the network is usually under greatest stress.

To understand the potential impacts of heat pump deployment on grid operation, the Customer Led Network Revolution project carried out a trial in Test Cell 3 (TC3) and recruited 331 households with air source heat pumps, with monitoring of heat pump electricity consumption for the one year period from May 2013 to April 2014. The research also involved interviews with participants. This report summarises the analysis of this dataset, and uses the household consumption data from the "control" test cell TC1a as a baseline1.

Analysis of the trial outputs show that the heat pump consumption represents a significant additional electrical load compared to the rest of the house. The annual heat pump electricity consumption, averaged across all customers is 82% of the average annual household consumption in TC1a1 (2880 kWh/yr for the heat pump, 3498 kWh/yr for the TC1a average household). This corresponds to an average annual load factor on the heat pump of approximately 9%-11%.

In the winter season, when household electricity demands are high, the heat pump consumption is also the highest (both absolute and relative to the house consumption) due to the higher space heating demand. The trial results show that the average heat pump electricity consumption across customers in January was equivalent to 122% of the average household consumption in January in TC1a (13.96 kWh per day for heat pumps, 11.46 kWh per day for TC1a households).

Both household and heat pump demand are often highest in the winter evening peak period (4pm-8pm). For the evening peak period, averaged across customers for the month of January, the heat pump average electricity consumption is 102% of the average household electricity consumption in TC1a (3.17 kWh per day in the peak period for heat pumps compared to 3.11 kWh on average for TC1). Hence the overall effect of the heat pump is to roughly double electricity demand at times when the electricity network is already likely to be experiencing high levels of demand.

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[1] TC1a is presented as a baseline comparison, the data sets do not however overlap in time, TC3 data set spans May 2013 to April 2014, while TC1 data set spans May 2011 to April 2013

The heating season half-hourly heat pump consumption profiles, averaged across customers and across each month, show distinct morning (6am – 9am) and evening (4pm – 8pm) peak demands. These periods broadly coincide with the peak periods in house electricity consumption, as both are driven either by an increase in heating demand or appliance usage as people get up in the morning and arrive back home in the evening. For high or clustered uptake of heat pumps, this has implications especially for winter evening peak periods, when electricity demand is already highest. This impact could be reduced by using hybridised (gas and electricity fuelled) heat pumps or heat storage (which would have the effect of reducing the peaks).

In addition to the morning and evening peak period, the heat pumps in this trial show a distinct peak in consumption around 3am (Figure 5). This is due to default timer settings for hot water heating. This timing is not inherent to the heat pump operation and can be resolved by diversifying hot water charging times in the default settings of each heat pump. It is important to note from a network planning perspective, that during the winter months this early morning demand spike does not exceed the peak demand in the evening period (4-8pm).

The trial results show that the heat pump demand, averaged across customers, increases much more quickly in the morning peak period compared to the evening peak period. With large or clustered uptake of heat pumps, this impact network operation. It is often the case that load diversity is lower for appliances that are controlled by timers. Addressing this requires introducing other means of diversity (such as thermal storage, or automated randomisation).

The monitoring in TC3 also included household electricity consumption. Although the consumption patterns were relatively similar to typical house profiles, the overall consumption level was significantly lower than the average seen in Test Cell 1a. This difference is to date unexplained, and hence caution should be taken with interpreting results from this data set.

The social science research indicates that participants may not always have made the best possible use of the heat pumps, and the research identified three key drivers for this:

- Customers found it difficult to understand the technology and how to operate it, both from a technical and an energy efficiency perspective
- There were no clear incentives to operate the heat pump in a specific way
- Customers were reluctant to "interfere" with the heat pump operation.

Take up of these new technologies should be supported by user friendly interfaces and a single point of contact for issues with the appliance.

Despite recruitment incentives, free broadband and subsidy of the heat pump to make cost comparable to boilers, recruitment for TC3 was particularly challenging [1]. The changing regulatory framework (i.e. delays to residential Renewable Heat Incentive) meant that market uptake of heat pumps has been lower than anticipated. The social housing sector constituted a substantial proportion of households in TC3 due to additional funding for social housing providers. Based on the CLNR trial results, the following could be taken into consideration for the rollout of heat pumps:

- As a heat pump load represents a near doubling of total household consumption, widespread rollout of the technology could present significant challenges to electricity networks. Technology solutions such as hybrid heat pumps or heat storage could reduce the impact, but future research is needed to understand technical feasibility, environmental performance and consumer acceptance.
- In the case of widespread heat pump deployment, steps may need to be taken to introduce diversity into heat pump operation, in particular the morning pick-up in demand.

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2 Trial Overview

2.1 Description

This report details the analysis of the domestic heat pump test cell 3, which provides profiles of electricity consumption for 89 households with air source heat pumps. The Test Cell consisted of both British Gas and non-British Gas customers. The households were monitored for a one year period from May 2013 to April 2014.

Separate metered electricity consumption data is available for the heat pumps and for the household consumption. The heat pump consumption was recorded on a 1 minute interval. The household consumption was also monitored on a one minute basis, and for BG customers half hourly smart meter readings were available as well.

Where relevant, Test Cell 1a (basic profiling of domestic smart meter customers), is used in this report as the baseline household consumption alongside which the results of TC3 heat pump data are compared.[2]

2.2 Purpose

This trial was designed to support Learning Outcome 1. Specifically, it provides the data needed to understand the electricity use patterns of air source heat pump users, how the heat pump electricity demand compares to household demand and the possible impacts of widespread heat pump adoption.

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[2] TC1a is presented as a baseline comparison, the data sets do not however overlap in time, TC3 data set spans May 2013 to April 2014, while TC1a data set spans May 2011 to April 2013

3 Trial Design

3.1 Participation and recruitment

Test cell 3 comprised 381 domestic customers with air source heat pumps. Out of these, 89 customers had sufficient quality heat pump data readings available over the one year period to be included in the analysis. These include also non-British Gas customers, and customers outside the Northern Powergrid region.

Participants were offered a subsidy of £50-worth of vouchers on joining the trial, a further £50-worth of vouchers when they completed the trial and one year's free broadband valued at £277. In addition customers were provided with an incentive for the installation of heat pumps which made the remaining installation costs for the customer similar to that of a conventional new boiler.

There were a number of challenges recruiting customers for this test cell, meeting only 56% of the recruitment target, even with the incentives. Despite these challenges, with 381 customers participating, this test cell represents the largest UK trial with air source heat pumps to date. With 89 customers with sufficient quality recordings over a one year period this also represents the widest dataset on real world heat pump operation available in the UK.

The key aspects that were successful in the recruitment include [1]:

- **Extra funding from DECC secured household heat pump uptake**.
- **There have been few drop outs**, with only 8% in TC3

The key challenges identified in the recruitment process include [1]:

- The **market penetration of heat pumps was far lower than anticipated** during the design of the trial.
- Timing of funding from DECC for heat pumps resulted in **skewed demographic representation**, with social housing constituting a significant proportion of households in TC3.
- The **need to secure planning permission** from the local authority delayed heat pump installation in some cases[3].
- **Not all properties met the space and communications requirements** for the installation of the heat pumps and monitoring equipment.

The recruitment success factors and challenges are discussed in more detail in section 5.

[3] From 1st December 2011 domestic air source heat pumps are treated as permitted developments, however this is only if: there is no wind turbine at the property; the external unit is less than 0.6 m^3 in size; the unit is no more than one metre from the edge of the householder's property; it is not on a pitched roof, or near the edge of a flat roof and it meets additional criteria if in a conservation area, World Heritage Site or similar. For more information see: http://www.energysavingtrust.org.uk/Generating-energy/Choosing-a-renewable-technology/Air-source-heat-pumps#planning

3.2 Equipment and tariff

TC3 customers had air source heat pumps installed, in addition to the following equipment where not already present:

- **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 energy import, and an in-line meter to monitor the energy consumption of the heat pumps;
- **Communications:** a hub was installed to collect the metering data.

No change was made to customers' existing tariffs.

3.3 Data quality control

Inevitably, some customers' data needed to be removed from the study (for example through metering failure, withdrawal from the trial). The quality control process identified additional customers' data which needed to be removed because of discrepancies in the recorded data that could not be resolved. This left 89 customers with sufficient quality data over the one year period.

Monitoring in TC3 also includes household consumption. Although the patterns were relatively familiar, the overall level was significantly lower than the average seen in TC1a, which is to date, unexplained. Caution should therefore be taken in interpreting results from this household consumption data set.

4 Trial Results

4.1 Annual consumption results

Analysis of the trial outputs shows that the heat pump consumption represents a significant additional electrical load compared to the rest of the house. The annual heat pump electricity consumption, averaged across all customers is 82% of the average annual household consumption in TC1a (2880 kWh/yr for the heat pump, 3498 kWh/yr for the TC1a average household). This corresponds to an average annual load factor on the heat pump of approximately 9%-11%.

The heat pump consumption per day, averaged across customers and over the year is shown in Figure 1, alongside the house consumption from TC1a. From the network perspective, a house with a heat pump is like two houses which would have gas heating. The manufacturer specification rated Coefficient of Performance (COP) of the installed heat pumps is approximately 3 [4]. The daily heating provided by the heat pump, averaged across the year and customers, therefore corresponds to an equivalent gas consumption of ca. 26 kWh/day for a conventional boiler. This compares to an average UK household gas consumption (including other uses such as cooking) of ca. 38 kWh/day, or ca. 14,000 kWh/yr [3].

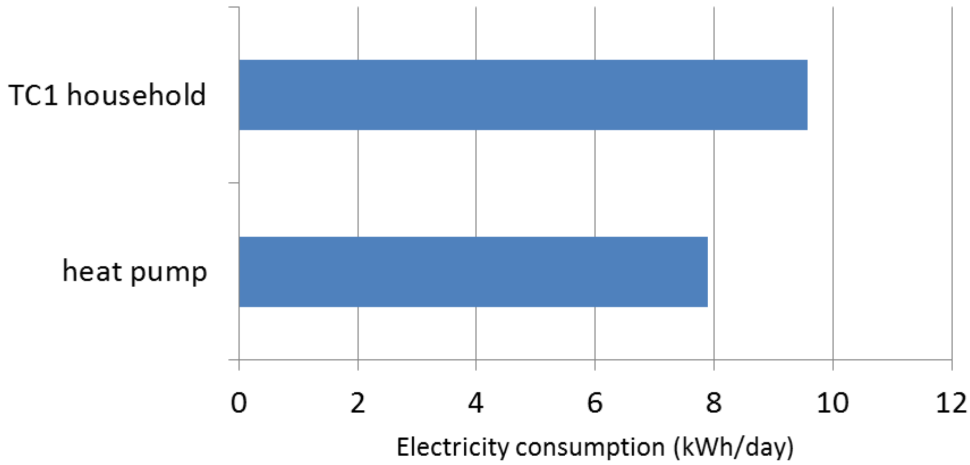


Figure 1: Daily consumption, averaged over the years and across all customers

4.2 Seasonal consumption results

As may be expected, heat pump electrical demand varies with time of the year, driven by the varying requirement for space heating. In the winter season, when household electricity demands are already high, the heat pump consumption is also the highest (both absolute and relative to the house consumption) due to the higher space heating demand.

Error! Reference source not found. shows the variation of the average daily heat pump electricity consumption, averaged across customers, throughout the year, alongside the TC1a household consumption[4]. The daily heat pump consumption in January was even higher than the average household consumption over the same time period in TC1a, at 122% (13.96 kWh per day for heat pumps, 11.46 kWh per day for TC1a households). Figure 3 shows the heat pump monthly average load factor, across all customers, which varies from 2% in the summer up to approximately 17% in January.

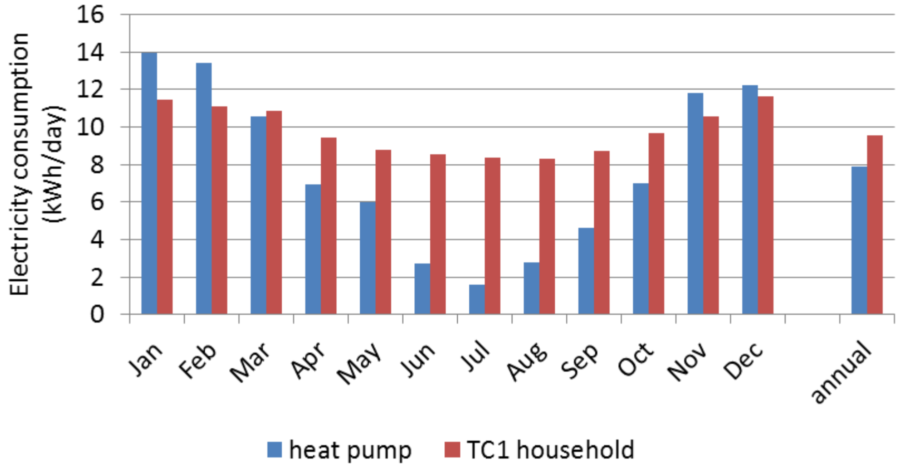


Figure 2: Daily heat pump and household consumption, averaged across customers per month and over the year. TC3: May 2013 - April 2014, TC1a: May 2011 – 2013 [5]

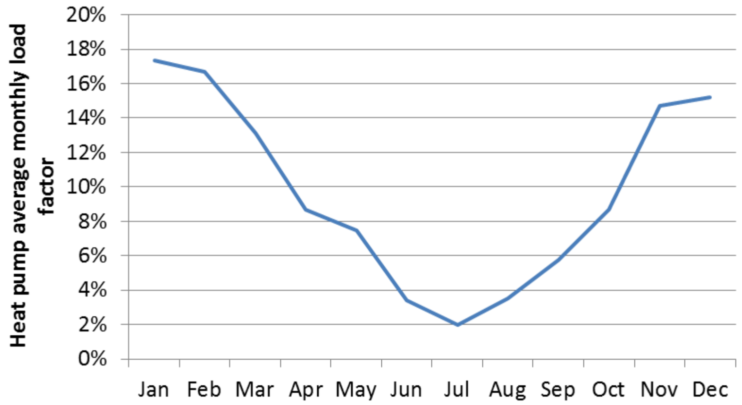


Figure 3 Heat pump average monthly load factor, across all customers

[4] TC1a is presented as a baseline comparison, the data sets do not however overlap in time, TC3 data set spans May 2013 to April 2014, while TC1a data set spans May 2011 to April 2013

4.2 Diurnal consumption profiles

The heat pump electricity daily demand profile, averaged across all TC3 households and across the year, is shown in Figure 4, alongside the TC3 average household demand profile. The heat pump demand profile shows distinct morning (6am – 9am) and evening (4pm - 8pm) peak periods, which broadly coincide with times of increasing heating demand as people get up in the morning or get back home in the evening.

The heat pump electricity daily demand profiles are also shown per month in Figure 5. Appendix 2 contains the separate graphs for each month, including the 95% confidence intervals. In the heating season all months show distinct peaks in heat pump electrical demand in the morning and evening, with little demand throughout the day for the summer period. The peaks become smaller as the months get warmer, with the evening peak dropping faster outside the winter period than the morning peak. This could be caused by thermal inertia of the house after being heated in the morning, requiring less heating in the evening.

As can be seen from Figure 5, the trial results also show that the heat pump demand, averaged across customers, increases much more quickly in the morning (6am) peak period compared to the evening peak period. With large or clustered uptake of heat pumps, this could impact network operation. It is often the case that load diversity is lower for appliances that are controlled by timers. Addressing this requires introducing other means of diversity (such as thermal storage, or automated randomisation).

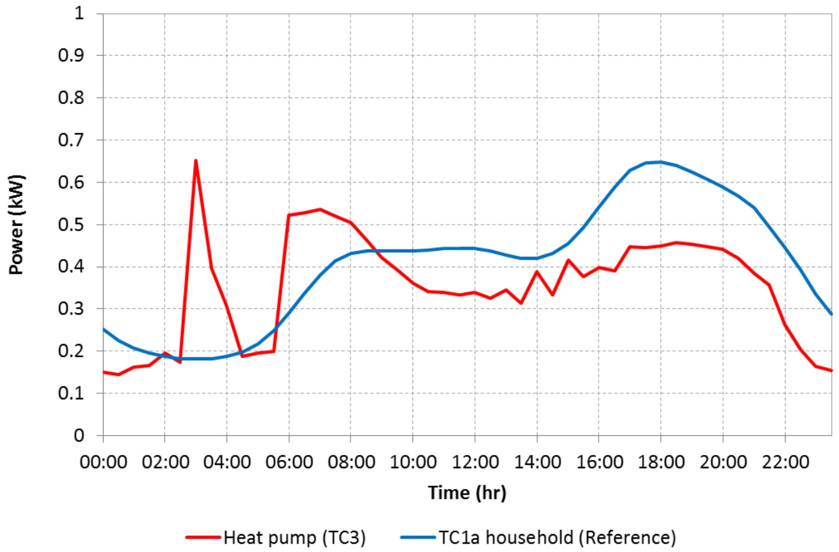


Figure 4: Annual daily load profile for the heat pump demand (red) and household demand (blue). Averaged across the year and across all customers for each test cell

In addition to the morning and evening peak period, Figure 5 also shows a distinct peak in heat pump consumption around 3am, which is fairly constant throughout the year. This peak is attributed to hot water heating. Across the heat pumps in the trial, customers had the same default timer settings for hot water heating, and this came on at 3am. While this may have been quite sensible, in that it essentially guarantees that occupants have hot water in the mornings, this setting is not an inherent requirement for the operation of heat pumps. A balance between hot water provision when required, and adding diversity could be achieved by, for example diversifying charging times in the default settings, with the hot water store retaining the heat for many hours afterwards.

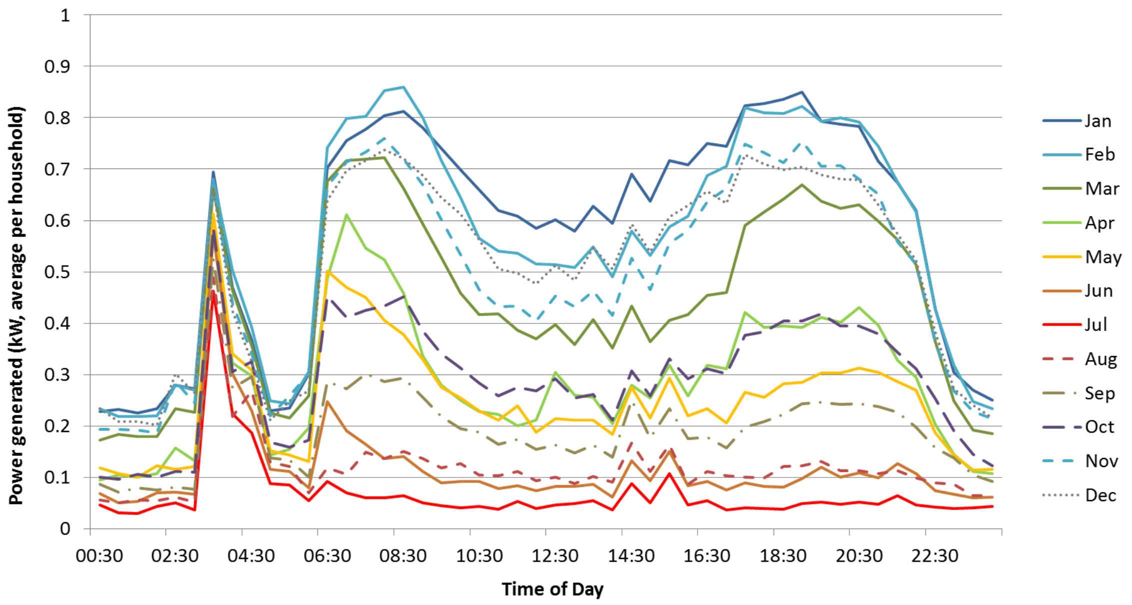


Figure 5: Daily profiles for heat pump demand, averaged for each month

The times of greatest network loading, usually occur in the evening peak (4-8pm) period, especially in the winter. Figure 4 shows the strong overlap between the heat pump and the household electricity consumption for this period. The average electrical consumption in TC1a for the evening peak period in January is 3.11 kWh per day, whereas for the TC3 heat pumps the electrical consumption in the same period is 3.17 kWh per day.

The same holds when looking at the half hourly period of greatest electricity demand, averaged across each half hourly period per month and across customers, which is depicted in Figure 6 [5]. The maximum average household demand across customers in TC1a for a half hourly period in January [6] is similar to that of the heat pump demand. Hence the overall effect of the heat pump is to roughly double electricity demand at the times when the electricity network is already likely to be experiencing high levels of demand.

[5] Analysis for the single day of highest network peak demand was not available for TC3

[6] The heat pump profile is based on the average over each half hourly period in January, while the household profile represents the maximum demand in any one half hourly in the month January

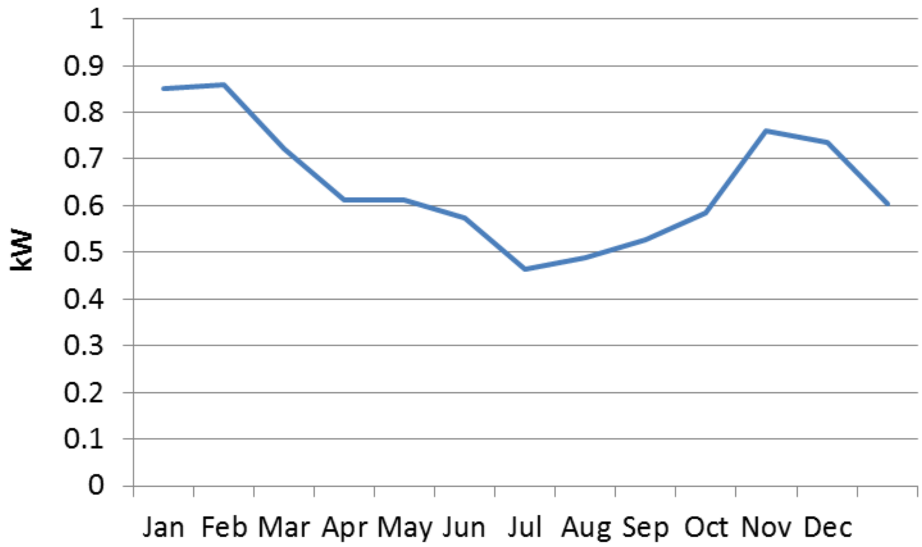


Figure 6 TC3 Heat pump maximum half hourly demand averaged across each half hourly period per month, across all customers

In the winter period, the heat pump evening and morning peak demand are similar, while for the rest of the year the morning peak demand is larger than the evening peak. The heat pump evening peak consumption period is more sustained than the morning peak period, i.e. the evening peak period is broader.

Although the peak consumption periods for heat pumps and house data generally overlap, the moments of absolute peak consumption within these periods seem to be different for heat pumps and houses in this dataset. With the heat pump absolute demand peak occurring earlier than the house peak in the morning, and later in the evening. This may slightly limit the impact of heat pumps on network peak demand. Without assessment of the confidence intervals it's however not clear if this effect is statistically significant.

When large scale or clustered uptake of heat pumps occurs as a switch from gas heating, this may add significant pressure on electrical infrastructure. Because of the higher average load factor and lack of any significant inherent electricity storage capability (compared with the gas network which does have significant storage capability), the electrical grid has less flexibility than the gas grid. Care must therefore be taken to avoid the shift causing additional pressure on electrical infrastructure, especially at winter evening peak times when it is usually under greatest stress. This impact could be reduced by using hybridised (gas and electricity fuelled) heat pumps or heat storage.

5 Social science learning

A major facet of the CLNR project is to examine in general how smart grid interventions might be designed and implemented, and to understand social responses to such interventions. In this section we report the CLNR social science learnings on how customers engaged and interacted with the Heat Pumps. Social science research methods consisted of a qualitative interview/tour. The survey interviews were designed to capture learnings and barriers in the recruitment, and current levels of engagement.

5.1 Trial recruitment

There were a number of challenges recruiting customers for this test cell, which ultimately recruited 56% of the initial target. Nevertheless with 331 customers participating, this test cell represents the largest UK monitored trial of air source heat pumps to date and is an extremely valuable source of data on heat pump operation. The social science research provided further insight into the key successes and challenges in the recruitment for this trial.

Key successful aspects in recruitment and use include [1]:

- **Extra funding from DECC secured household heat pump uptake**. DECC funding from the Building Innovation Programme supported heat pump installation so that the cost to the consumer was similar to a conventional new boiler installation. Social housing providers were moreover able to use this funding to leverage further EU match-funding to pay for the systems, which also meant an energy efficiency upgrade to their property stock.
- **There have been few drop outs**, with only 8% in TC3.

Key challenges in recruitment and use include [1]:

- The **market penetration of heat pumps was far lower than anticipated** during the design of the trial, partly due to the delay of the domestic Renewable Heat Incentive which aims to make the technology financially viable.
- Timing of funding from DECC for heat pumps resulted in **skewed demographic representation**. The limited timescale of the funding window and extra opportunity for social housing providers of levering EU match-funding, meant that social housing constitutes a significant proportion of households in TC3.
- The **need to secure planning permission** from the local authority delayed heat pump installation in some cases[7]. This was particularly an issue in areas where there were clusters of heat pumps.
- **Not all properties met the space and communications requirements** for the installation of the heat pumps and monitoring equipment.
- Installing monitoring equipment caused particular problems as it **required an isolation switch in the customer's home**, to allow equipment to be safely installed. Many houses

[7] From 1st December 2011 domestic air source heat pumps are treated as permitted developments, however this is only if: there is no wind turbine at the property; the external unit is less than 0.6 m3 in size; the unit is no more than one metre from the edge of the householder's property; it is not on a pitched roof, or near the edge of a flat roof and it meets additional criteria if in a conservation area, World Heritage Site or similar.

did not have such a switch, meaning only the supplier's appointed meter operator is authorised under industry guidelines to temporarily disconnect the power supply at the mains fuse instead (i.e. on the DNO side of the meter). Liaising with the relevant meter operator or supplier resulted in delays.

- **Data protection hampered identification of customers with heat pumps.** Although Northern Powergrid is aware of certain heat pump installations in their region and broadly where they are planned, this information could not be shared at a detailed MPAN level, due to data protection issues. Information on heat pump ownership was therefore gleaned from market intelligence and from discussion with housing authorities and councils, rather than via recorded data.

5.2 Use and interaction with heat pumps

The social science research provides further insight into the factors that affected successful heat pump installation and their ongoing effective use. The research shows both the positive potential of heat pumps to improve heating comfort while reducing bills, as well as concerns and risks for customers.

A key factor influencing the experience of the customers was found to be the customer's previous experience with heating systems, and how the transition was communicated and managed. Customers moving from individual night storage systems were much more positive about the new systems than those who had lived with district heating systems. When asked about their previous experiences, following respondents who used to have storage heaters described:

> *"You had no heat. They [storage heaters] were supposed to stay warm all day but they were cold by 11 o'clock so you were freezing. I had to use the electric fire all the time… but now I hardly ever use it" [EPJ004]*
>
> *"You had no control over them … when I come in in the evening, the place was cold" [EPJ011]*

The key benefits that some of the customers experienced, as identified in the interviews in the social science research, include the quality of the heat provided, the additional use for drying of clothes, reduced bills and quick hot water provision.

While some customers indicated they had the capacity to use and control the system, some customers also reported concerns about using the system and may not always have operated the heat pumps most efficiently.

The key concerns included whether running the system all day, which technically provides the most efficient service, would incur additional costs. Furthermore, some customers perceived the heat pumps as a complex technology and feared that interfering would cause the system to breakdown.

When asked about their experiences, the following respondents who had concerns about operating the heat pump described;

> *"I don't know whether its there's a fault on the system or what. Sometimes I'll switch it on the ON setting… it doesn't come on. So if I go and switch it on the All Day setting it'll come on sometimes. Or if I put it on All Day first and it doesn't come and I put it on the On, it'll come on. But sometimes it'll only come on All Day or On for a couple of*

hours and it'll switch itself off and the radiators cool down again. The only time I can get it to work properly is when I put it on Auto. [EPJ011]"

"I don't let anybody touch anything. I don't want to know. As long as it's working, I don't want to know. [EPJ009]"

The interviews show that many customers initially found the operating and control instructions confusing. After a time most customers were able to operate the system in a basic way. Most customers however left the system on the programme set initially on installation and controlled the heat pump through the thermostat. When asked about their experiences, following respondents described;

"They just put it in and I've left it as it was… I wouldn't know what to do. That's the only trouble. They didn't really tell you much about anything. [EPJ004]"

"That's the control which I do not touch. I operate it from the thermostat. [EPJ005]"

"I wasn't happy with the times they had set. So I tried to set the timer myself. So eventually I got there. Eventually. Reading the book over and over and over again. [EPJ008]"

This seems to correspond with the findings from the heat pump monitoring discussed in section 4.2. This showed that the heat pump demand, averaged across customers, increases much more quickly in the morning (6am) peak period compared to the evening peak period. This is consistent with most of the heat pumps coming on in the morning on the timed programme, while the evening peak period is influenced more strongly by how customers control the thermostat.

With large or clustered uptake of heat pumps, the quick increase in the morning peak could impact network operation. Addressing this requires introducing other means of diversity, for instance through automated or default randomisation of the programme or with thermal storage.

The interviews also showed a risk that customers may make adjustments that increase their electricity consumption, especially for households shifting from electric storage heaters. One responded said;

"The booster is brilliant. … if we've let the water get too cold. It takes less than an hour. [EPJ010]"

6 Conclusions

In order to support Learning Outcome 1, this report has analysed the electricity demand characteristics of air source heat pump customers in test cell 3.

There were a number of challenges recruiting customers for this test cell, meeting only 56% of the recruitment target. Despite these challenges, with 331 customers participating, this test cell represents the largest UK trial of air source heat pumps to date. With 89 customers with sufficient quality recordings over a one year period this also represents the widest dataset on real world heat pump operation available in the UK.

The delay in the Renewable Heat Incentive reduced the incentive for customers to take up heat pumps. Additional DECC funding from the Building Innovation Program and opportunities for EU-match funding, supported take-up specifically for social housing providers. Social housing therefore constitutes a significant proportion of households in TC3. This is however believed to reflect the current heat pump market.

The annual heat pump electricity consumption, averaged across all customers is 82% of the average household consumption in TC1a.

As can be expected for heating systems, demand was highest in the winter. During winter evening peak periods, the average overall effect of heat pumps is to roughly double electricity demand at the times when the electricity network is already likely to be experiencing the highest levels of demand. For high or clustered uptake of heat pumps, this could have implications both for network capacity and operation. This impact could be reduced by using hybridised (gas and electricity fuelled) heat pumps or heat storage.

The social science research findings provide further insights into the factors that affected successful heat pump recruitment, installation and their ongoing effective use. The research also shows both the positive potential of heat pumps to improve heating comfort while reducing bills, as well as the concerns and risks for customers.

While some customers indicated they had the capacity to use and control the system, some customers also reported concerns about using the system and may not always have operated the heat pumps in the most efficient manner. The research identified three key drivers for this:

- Customers found it difficult to understand the technology and how to operate it, both from a technical and an energy efficiency perspective
- There were no clear incentives to operate the heat pump in a specific way
- Customers were reluctant to “interfere” with the heat pump operation.

From these findings it is clear, that for take up of these new technologies to be successful in the future, then there needs to be: considered engagement through the installation phase, with single points of contact for appliance issues and for the interfaces and associated documentation to be simple and user friendly.

7 References

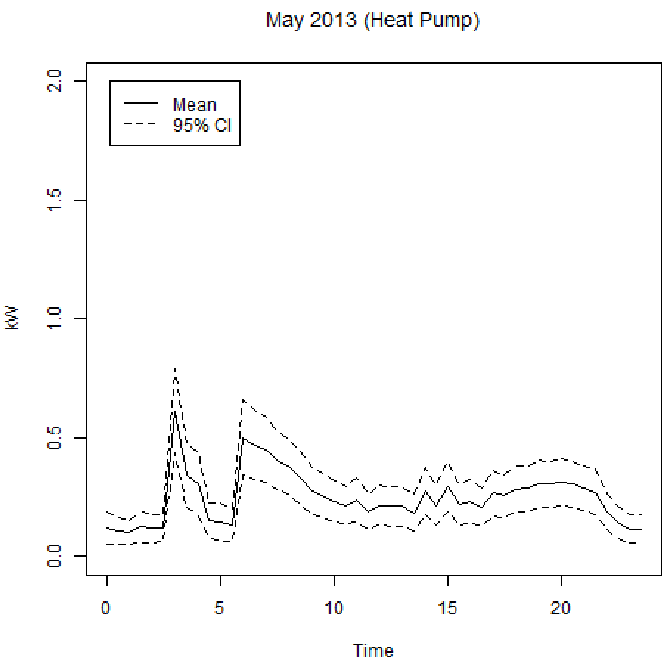
[1] **CLNR-L036:** “Project Lessons Learned from Trial Recruitment”, Rebekah Phillips et al, July 2013

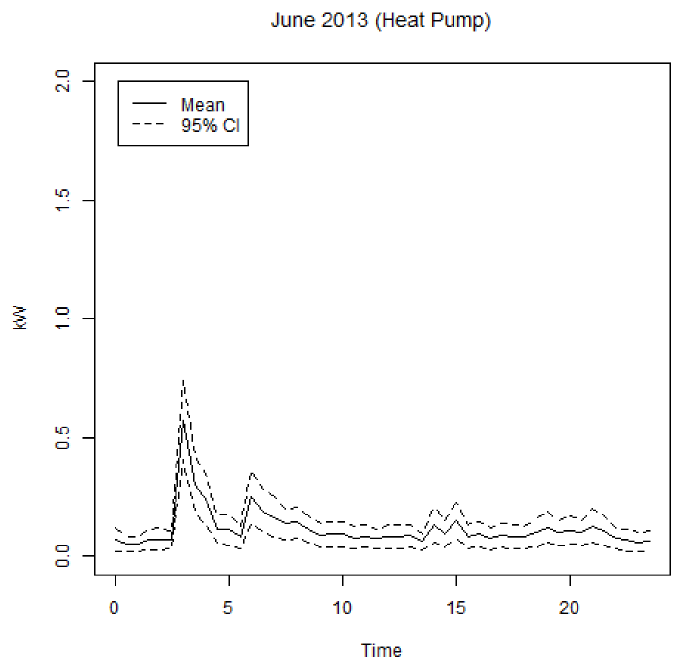
[2] **CLNR-L216**: **Insight Report: Baseline Domestic Profile; Test Cell 1a Customer Subgroup Analysis,** December 2014

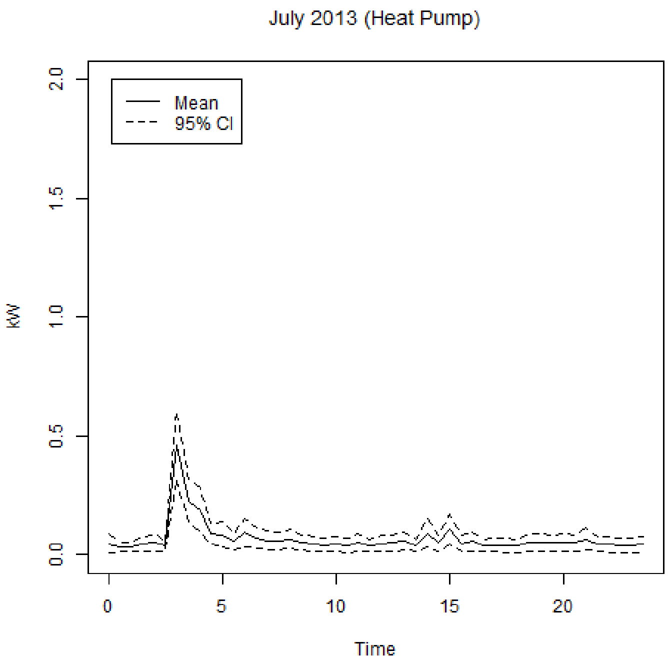
[3] **BRE report 286734 “**Energy Follow-Up Survey 2011, Report 3: Metered fuel consumption”, BRE for DECC, December 2013

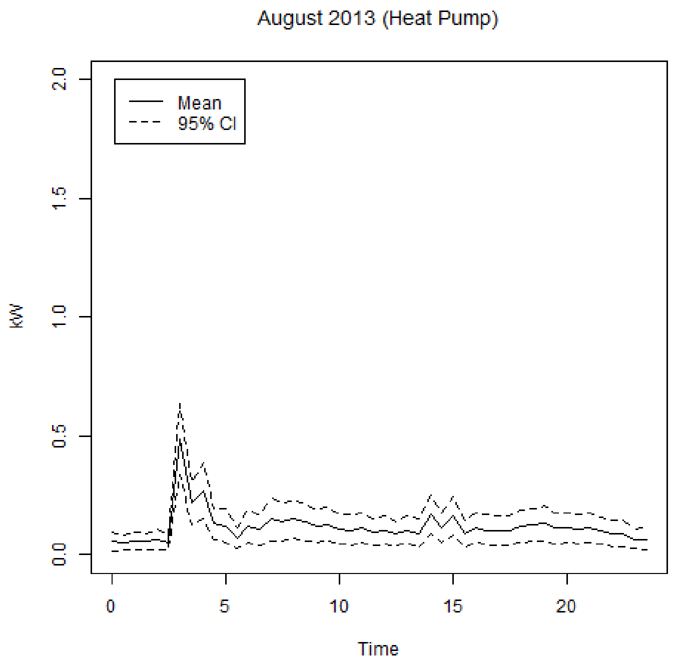
[4] **Ecodan,** heat pump technical specification

Appendix 1: TC3 Heat pump monthly plots



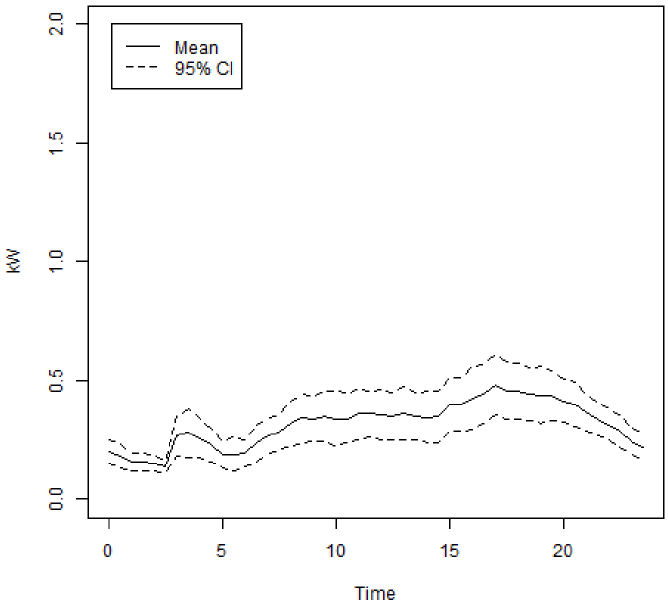




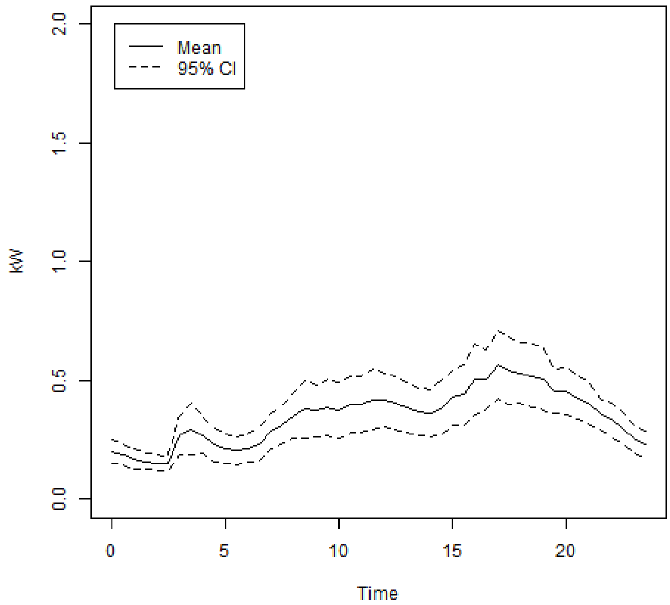


TC3 heat pump monthly plots (continued)

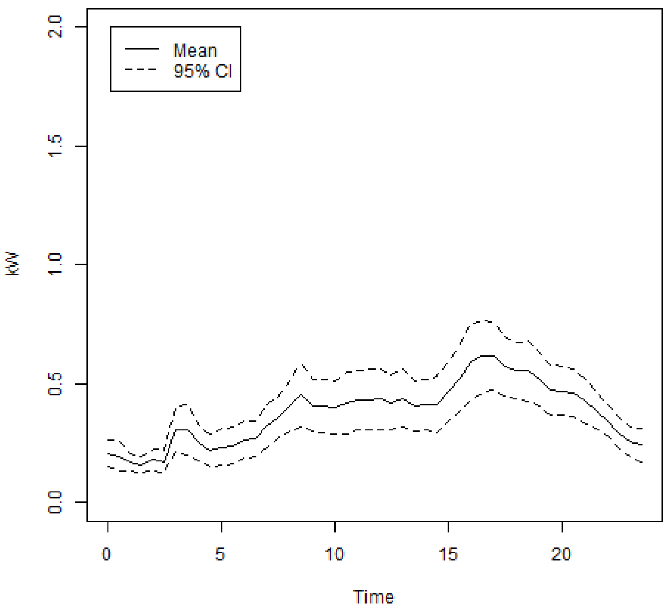
September 2013 (House Only)



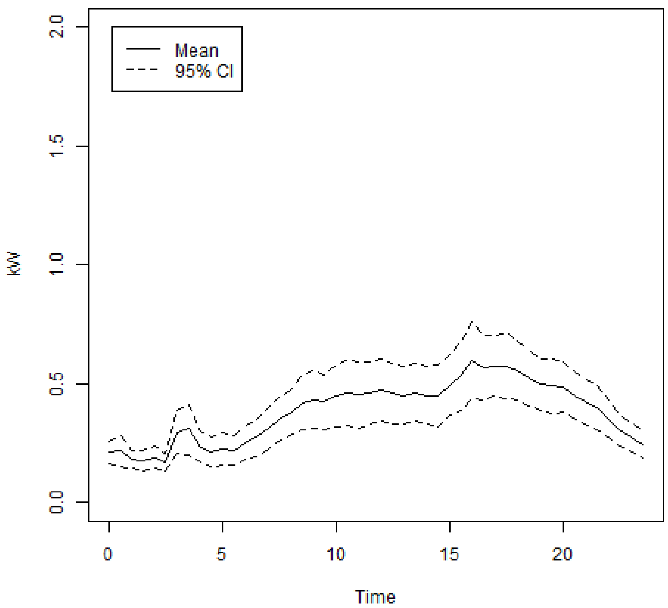
October 2013 (House Only)



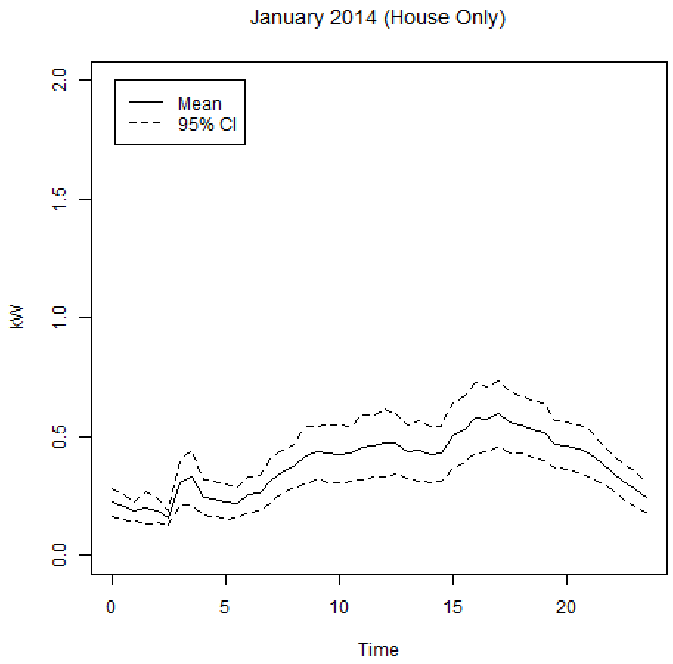
November 2013 (House Only)

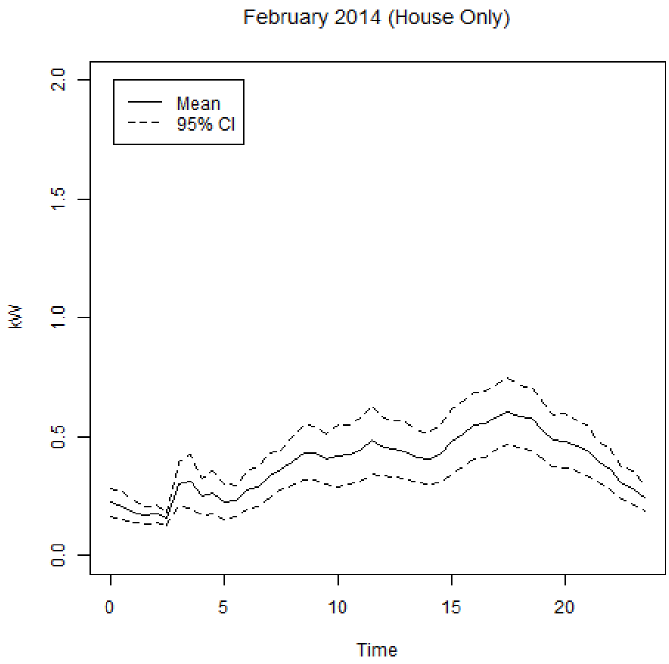


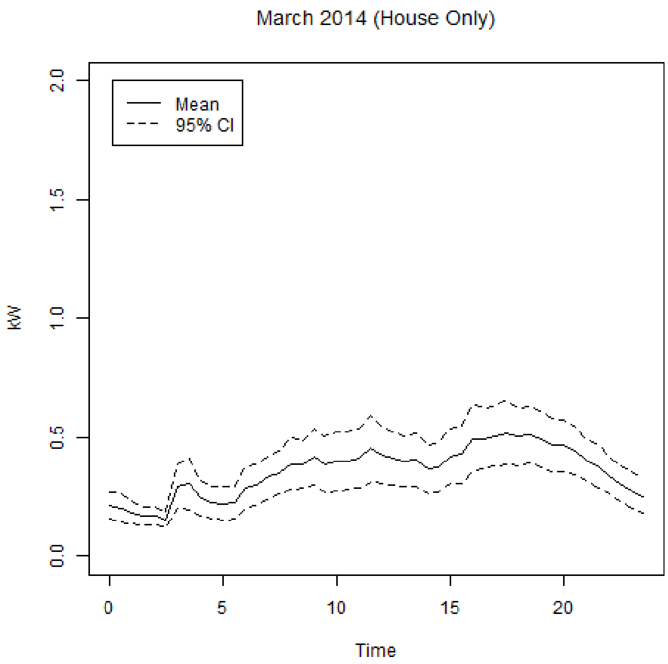
December 2013 (House Only)

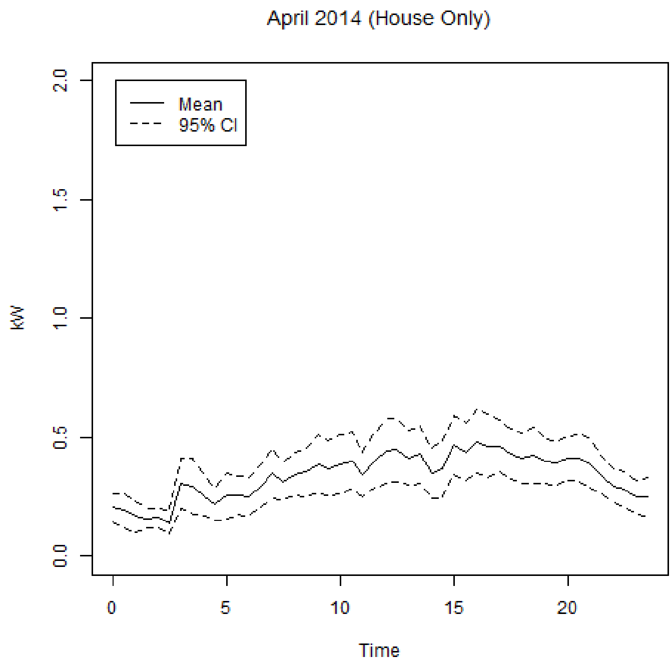


TC3 heat pump monthly plots (continued)

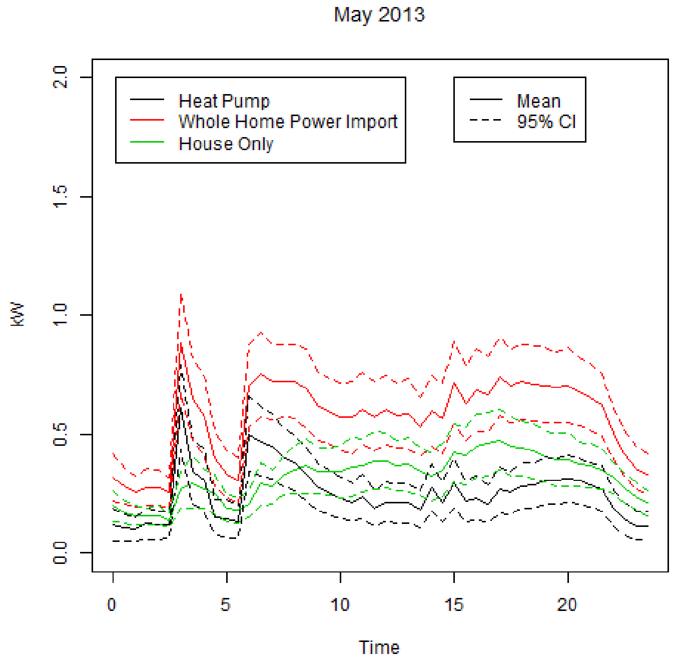


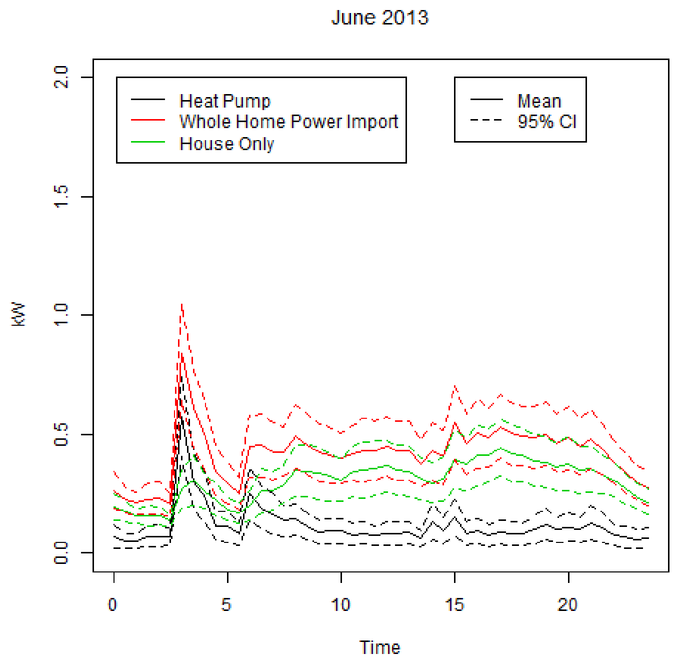


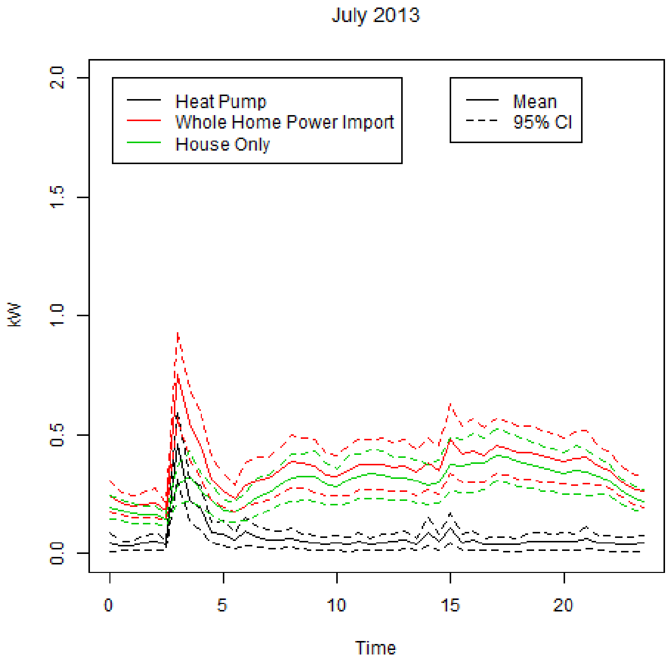


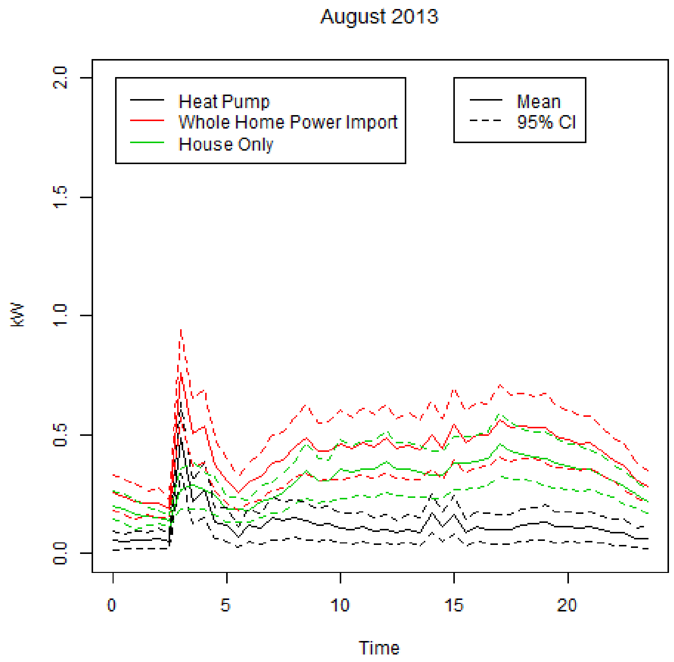


Appendix 2: TC3 Heat pump and household monthly plots

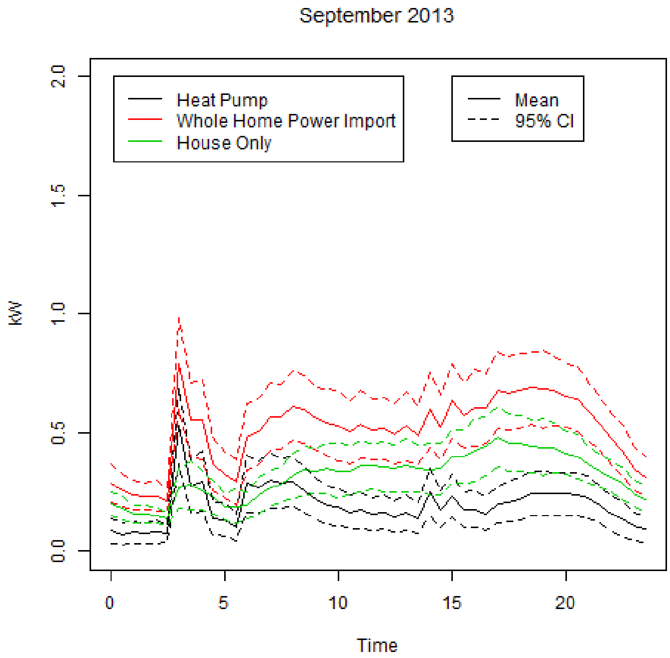


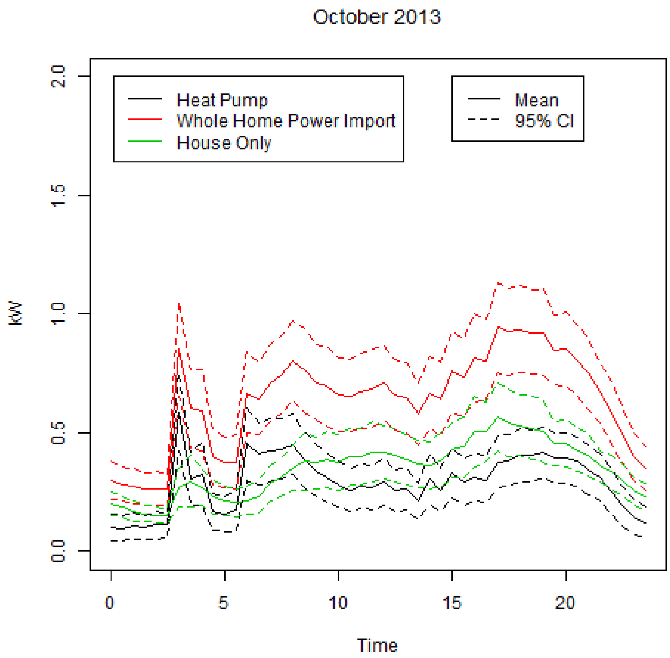


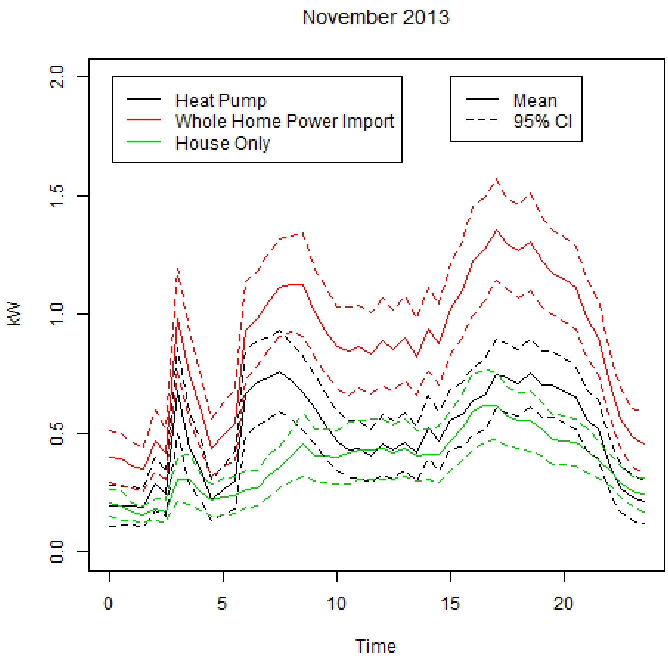


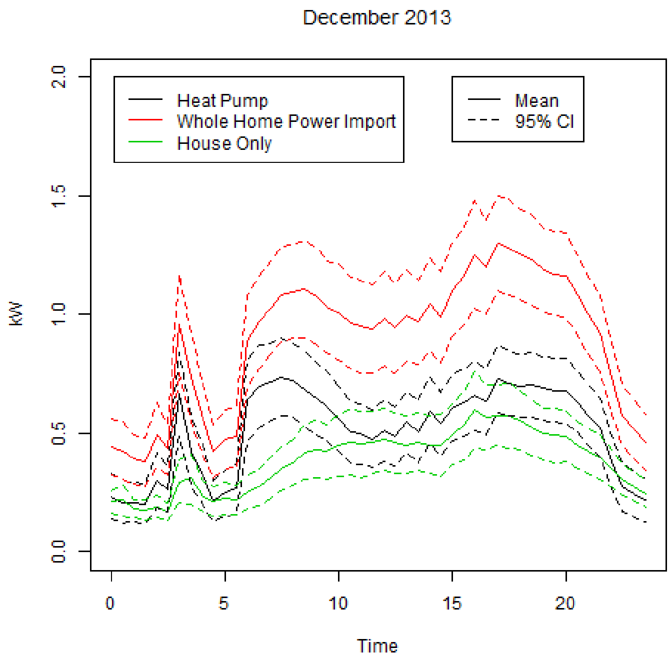


TC3 heat pump and household monthly plots (continued)

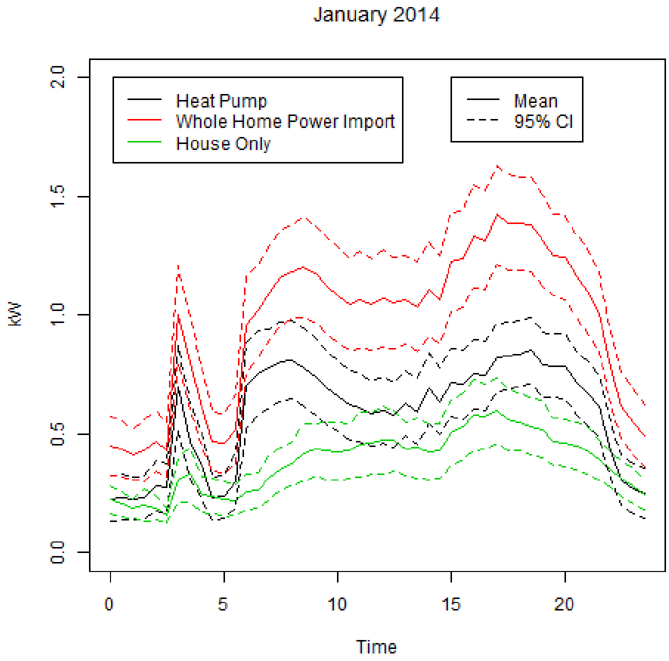


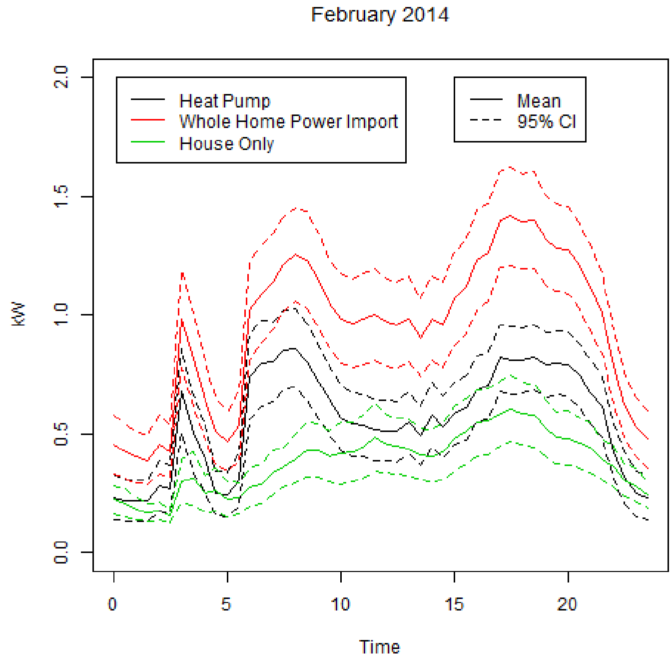


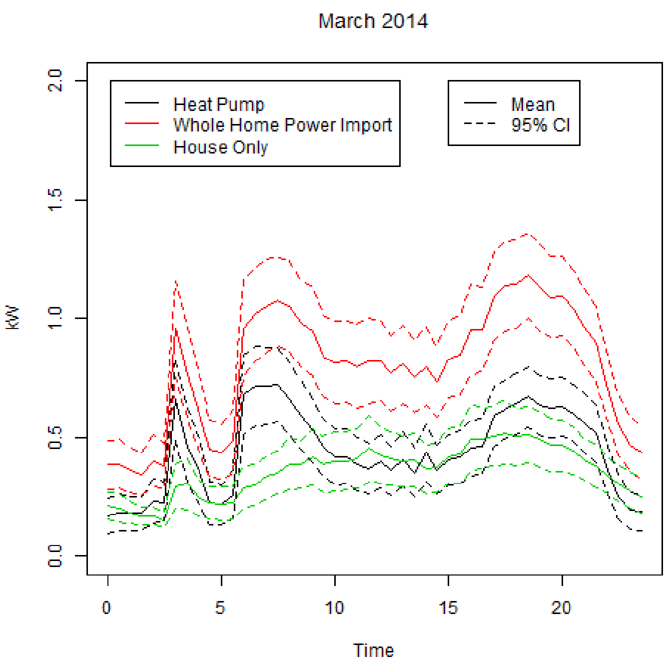


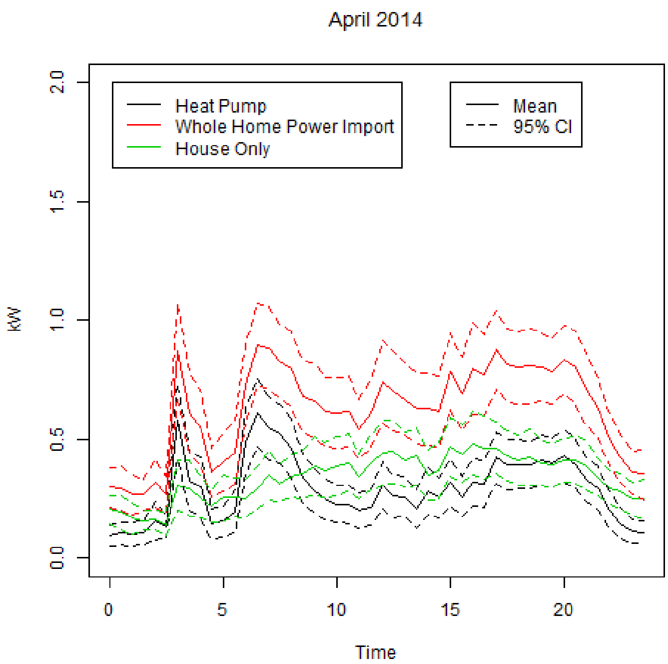


TC3 heat pump and house monthly plots (continued)









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Appendix 3: TC3 Heat Pump Mean Demand Data Table

				TC3 Heat Pump Mean Demand (kW)									
Time (end)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
00:30	0.228	0.234	0.172	0.095	0.119	0.069	0.047	0.056	0.087	0.1	0.194	0.234	0.139
01:00	0.232	0.219	0.184	0.105	0.108	0.05	0.031	0.051	0.072	0.097	0.194	0.209	0.131
01:30	0.226	0.218	0.179	0.101	0.1	0.053	0.03	0.056	0.08	0.106	0.192	0.209	0.131
02:00	0.233	0.22	0.18	0.108	0.123	0.07	0.044	0.055	0.075	0.1	0.187	0.202	0.136
02:30	0.279	0.279	0.233	0.157	0.116	0.072	0.051	0.062	0.081	0.111	0.287	0.302	0.171
03:00	0.272	0.27	0.227	0.132	0.121	0.067	0.037	0.052	0.077	0.11	0.245	0.264	0.159
03:30	0.695	0.681	0.663	0.578	0.613	0.573	0.463	0.489	0.527	0.586	0.677	0.663	0.604
04:00	0.469	0.503	0.464	0.322	0.341	0.302	0.224	0.218	0.274	0.306	0.439	0.424	0.362
04:30	0.367	0.392	0.356	0.297	0.308	0.23	0.187	0.268	0.296	0.325	0.34	0.325	0.307
05:00	0.23	0.249	0.225	0.144	0.152	0.116	0.088	0.129	0.138	0.168	0.22	0.212	0.173
05:30	0.235	0.243	0.216	0.154	0.144	0.111	0.085	0.121	0.134	0.159	0.259	0.249	0.176
06:00	0.301	0.306	0.259	0.196	0.131	0.08	0.055	0.07	0.1	0.172	0.302	0.268	0.186
06:30	0.703	0.741	0.677	0.488	0.501	0.248	0.092	0.119	0.286	0.453	0.667	0.639	0.472
07:00	0.756	0.799	0.717	0.611	0.469	0.191	0.07	0.106	0.272	0.411	0.714	0.697	0.482
07:30	0.777	0.802	0.719	0.546	0.45	0.164	0.06	0.149	0.301	0.425	0.733	0.716	0.485
08:00	0.804	0.853	0.722	0.524	0.406	0.137	0.06	0.137	0.286	0.433	0.76	0.737	0.487
08:30	0.812	0.86	0.663	0.459	0.378	0.141	0.065	0.151	0.294	0.451	0.719	0.721	0.478
09:00	0.78	0.8	0.593	0.336	0.33	0.112	0.051	0.136	0.256	0.385	0.669	0.687	0.434
09:30	0.74	0.716	0.528	0.28	0.276	0.089	0.045	0.119	0.219	0.34	0.602	0.645	0.389
10:00	0.699	0.645	0.458	0.251	0.255	0.092	0.041	0.127	0.195	0.313	0.533	0.612	0.358
10:30	0.66	0.566	0.417	0.228	0.229	0.092	0.044	0.105	0.188	0.284	0.465	0.562	0.327
11:00	0.62	0.54	0.418	0.223	0.211	0.078	0.038	0.103	0.165	0.259	0.432	0.506	0.305
11:30	0.608	0.536	0.387	0.201	0.239	0.084	0.053	0.111	0.174	0.275	0.434	0.498	0.307
12:00	0.585	0.515	0.369	0.212	0.188	0.074	0.04	0.093	0.154	0.269	0.404	0.476	0.287
12:30	0.601	0.514	0.398	0.304	0.214	0.083	0.047	0.101	0.163	0.292	0.453	0.512	0.308
13:00	0.579	0.508	0.359	0.26	0.211	0.082	0.049	0.088	0.147	0.255	0.432	0.484	0.291
13:30	0.628	0.548	0.407	0.256	0.211	0.086	0.055	0.102	0.163	0.262	0.462	0.547	0.315
14:00	0.594	0.49	0.352	0.204	0.184	0.061	0.037	0.091	0.139	0.211	0.416	0.506	0.279
14:30	0.69	0.579	0.433	0.28	0.276	0.132	0.088	0.167	0.251	0.307	0.526	0.593	0.366
15:00	0.637	0.532	0.364	0.254	0.215	0.093	0.05	0.111	0.177	0.258	0.466	0.539	0.313
15:30	0.717	0.587	0.406	0.319	0.293	0.151	0.108	0.163	0.234	0.331	0.556	0.607	0.378
16:00	0.708	0.609	0.417	0.258	0.22	0.084	0.047	0.086	0.175	0.292	0.58	0.629	0.348
16:30	0.75	0.687	0.455	0.318	0.233	0.092	0.055	0.112	0.178	0.312	0.636	0.657	0.378
17:00	0.744	0.706	0.46	0.311	0.206	0.075	0.037	0.103	0.158	0.301	0.662	0.634	0.37
17:30	0.824	0.819	0.59	0.421	0.266	0.089	0.041	0.1	0.198	0.377	0.748	0.728	0.435
18:00	0.828	0.81	0.617	0.392	0.256	0.082	0.04	0.099	0.209	0.383	0.732	0.709	0.433
18:30	0.836	0.808	0.642	0.395	0.282	0.081	0.038	0.121	0.222	0.405	0.712	0.699	0.439
19:00	0.85	0.822	0.67	0.392	0.285	0.098	0.049	0.123	0.244	0.404	0.754	0.704	0.453
19:30	0.793	0.793	0.638	0.411	0.303	0.12	0.052	0.131	0.246	0.418	0.706	0.689	0.444
20:00	0.787	0.8	0.624	0.401	0.303	0.1	0.048	0.113	0.242	0.395	0.707	0.681	0.436
20:30	0.783	0.791	0.63	0.431	0.313	0.109	0.052	0.113	0.243	0.394	0.68	0.679	0.437
21:00	0.715	0.745	0.599	0.396	0.304	0.099	0.048	0.107	0.238	0.379	0.652	0.631	0.411
21:30	0.673	0.675	0.562	0.328	0.286	0.127	0.064	0.113	0.227	0.343	0.559	0.574	0.382
22:00	0.619	0.617	0.514	0.295	0.27	0.107	0.047	0.099	0.197	0.311	0.516	0.523	0.347
22:30	0.428	0.427	0.364	0.203	0.187	0.074	0.042	0.09	0.158	0.253	0.363	0.382	0.25
23:00	0.305	0.318	0.249	0.145	0.143	0.067	0.04	0.087	0.138	0.191	0.269	0.272	0.187
23:30	0.27	0.248	0.192	0.111	0.115	0.06	0.041	0.064	0.105	0.145	0.228	0.241	0.154
00:00	0.251	0.234	0.185	0.107	0.116	0.062	0.043	0.065	0.092	0.122	0.214	0.216	0.145

Customer-Led Network Revolution

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