# Energy Saving Trust
## Report

**Field Trial of the Fischer Future Heat**

**Dynamic Electric Storage Heating System**

**September 2017**

| Property | Temperature Monitoring Began | Daily Electricity Consumption Monitoring Began | Half-Hourly Electricity Consumption Monitoring Began | Fischer System Installed | All Monitoring Ended |
|---|---|---|---|---|---|
| **A** | 2016-10-01 | 2016-10-19 | 2017-01-06 | 2017-01-05 | 2017-04-30 |
| **B** | 2016-10-03 | 2016-10-23 | 2017-02-12 | 2017-01-05 | 2017-04-30 |
| **C** | 2016-10-02 | 2016-10-22 | 2017-01-05 | 2017-01-04 | 2017-04-30 |
| **D** | 2016-10-03 | 2016-11-18 | 2017-02-02 | 2016-12-22 | 2017-04-30 |
| **E** | 2016-10-01 | 2016-11-09 | 2016-11-08 | 2017-01-09 | 2017-04-30 |
| **F** | 2016-12-11 | 2016-12-09 | 2016-12-09 | *Pre-trial start* | 2017-04-30 |
| **G** | 2016-11-22 | 2016-12-07 | 2016-12-07 | *Pre-trial start* | 2017-04-30 |

*Table 2. Monitoring and installation milestones for each property.*

# 4 Methodology: Overview of Data Analysis Techniques

Using electricity consumption and air temperature data, a methodology was devised to quantify the performance of the heating systems. This methodology comprised several techniques to assess aspects such as operating times; responsiveness; internal comfort; energy consumption and associated $CO_2$ emissions; and running cost. These techniques, detailed below, subsequently allowed for comparison of the Fischer System against the Former System.

## 4.1 Heating Degree-Day Analysis

A heating degree-day (HDD) is a measure that can be used to quantify the heat demand of a building, relative to an external base temperature. Explicitly, it is calculated as the difference between the base temperature and the actual outside temperature multiplied by time. For example, if the base temperature is 13.5°C and the daily outside temperature is known to be 9.5°C during a three-day period, the HDD would be equal to $(13.5 - 9.5) \times 3 = 12$ degree days. The base temperature differs from one building to another, and depends on several factors such as the building's insulation, solar radiation, and the behaviour of the occupants. A base temperature was calculated for each property using HDD regression optimisation and this base temperature was used in subsequent analysis.

## 4.2 Indoor Temperature

An "indoor temperature" was defined as the weighted mean of all five indoor temperature readings:

$$T_{indoor} = \sum_{n=1}^{5} T_n w_n$$

where $T_n$ and $w_n$ are the temperature and its weighting at each location in the property. The weightings used were as follows:

| Value | Weighting |
|---|---|
| $T_B$ | $w_B = 1/3$ |
| $T_{L1}$ | $w_{L1} = 1/9$ |
| $T_{L2}$ | $w_{L2} = 1/9$ |
| $T_{L2}$ | $w_{L3} = 1/9$ |
| $T_H$ | $w_H = 1/3$ |
| $T_O$ | $w_O = 0$ |
| | $total = 1$ |

## 4.3 Daily Temperature

Furthermore, an average daily temperature was calculated for both outdoors:

$$T_{outdoor\ daily} = \frac{\sum_{n=1}^{N} T_O\,(t_n)}{N}$$

and indoors:

$$T_{indoor\ daily} = \frac{\sum_{n=1}^{N} T_{indoor}\,(t_n)}{N}$$

where $N$ is the number of temperature readings per day and is equal to 96.

## 4.4 Internal Comfort

For this trial, "internal comfort" was considered in the context of the *thermal comfort* experienced by householders (and delivered by the household's heating system). The term *thermal comfort* is widely used to express a person's level of satisfaction with their thermal environment. Thermal comfort is generally understood to depend on six fundamental factors, namely: humidity; air velocity; air temperature; radiant temperature; insulation from clothing; and human metabolic rate[3].

Air temperature – the most relatable and the simplest to measure – is the most commonly used of these factors when quantifying thermal comfort. For the purposes of this trial, air temperature readings were used to derive several indicators to quantify broadly the "air temperature profile" of the properties. These indicators were:

- consistency of indoor temperature over time; and
- vertical temperature range,

and are detailed in the sections below. These indicators might help to assess the internal comfort experienced by householders. **However, it is important to note that air temperature alone is not an accurate measure of thermal comfort. The remaining environmental and behavioural factors were outside of the scope of this trial.**

### 4.4.1 Consistency of Indoor Air Temperature over Time

For a domestic property, we might expect to see periodicity in the indoor air temperature that corresponds with the behaviour of the household. For example, a conventional working household predominantly using heat in the morning and evening may exhibit a bi-modal daily cycle. Similarly, behavioural differences between weekdays and weekends may give rise to weekly "five-two" cycles.

Despite these differences, we expect to see some consistency in indoor air temperature, such as on a daily and/or weekly period. In fact, consistency of indoor temperature over time may help to assess the responsiveness of a building and its components, as well as the internal comfort experienced by householders, and a more consistent indoor air temperature over time may be desirable. To compare the consistency of indoor air temperature over time of both heating systems, a simple measure of consistency was defined as the reciprocal of the standard deviation (SD)[4] of the daily indoor temperature over time such that:

$$consistency = \frac{1}{SD(T_{indoor\ daily})}.$$

A daily indoor temperature that varies very little from the mean over time will show a small SD, and may be said to be more consistent over time.

### 4.4.2 Living Room Temperature Profile and Vertical Temperature Range

The air temperature at any given point in a room or a property can depend strongly on several factors, including draughts from windows and doors and the position of heat sources such as radiators. The temperature profile of any given space can therefore be highly complex. One

[3] http://www.hse.gov.uk/temperature/thermal/factors.htm

[4] The standard deviation (SD) is a measure of the amount of variation or dispersion of a dataset. In a dataset with a low SD, the data points tend to be close to the mean of the dataset. On the other hand, in a set with a high SD, the points tend to be more spread out.

important consideration for internal comfort is the difference in air temperature as a function of height within a room. For example, a large difference in temperature between floor-level and ceiling-level may contribute to thermal stress.

BS EN ISO 7330:2005 uses the concept of "vertical air temperature difference" to mean the difference in air temperature between two points, located on the vertical at heights $h_0$ and $h_1$ above floor-level. $h_0$ and $h_1$ are taken to be 0.1 m and 1.1 m respectively when considering seated occupants, and 0.1 m and 1.7 m respectively when considering standing occupants. The standard sets acceptance thresholds of < 3°C for seated occupants, and < 4°C for standing occupants. A vertical air temperature difference falling below the relevant acceptance threshold is considered to contribute to thermal comfort.

This trial uses a similar measure, the "vertical temperature range", to quantify the vertical air temperature distribution within the living room. The main differences here are that three temperature readings were taken instead of two, with loggers positioned at floor-, mid- and ceiling-level instead of at fixed heights (refer to Figure 3 above). Using these readings, the vertical temperature range, $\Delta T_n$, was defined as:

$$\Delta T_n = T_n^{max} - T_n^{min}$$

where $T_n^{max}$ ($T_n^{min}$) is the maximum (minimum) temperature across all three loggers at some point in time, $t_n$.

## 4.5 Air-Temperature Responsiveness

Responsiveness[5] can be considered as the ability of a system to adjust quickly to external conditions. One aspect of responsiveness was considered above (see section "Consistency of Indoor Air Temperature over Time"). Responsiveness was also considered in terms of how quickly a heating system was able to warm up a room. 15-minute temperature readings were averaged across all dates to produce a typical 24-hour temperature profile of 96 mean values. The time taken for the air temperature to increase from a minimum to a maximum value was identified visually, this time gives an indication of air-temperature responsiveness.

## 4.6 Typical 24-Hour Charging Profile and Cost

Half-hourly electricity data was averaged across all dates to generate typical 24-hour charging profiles, each consisting of 48 mean readings. These profiles were used to qualitatively assess the charging patterns of the Fischer System compared to those of conventional night-storage heaters.

Half-hourly electricity consumption data was further used with EST's average electricity tariffs[6] to estimate the cost of running the heating systems. These tariffs are shown in Table 3 and are representative of average fuel prices in Great Britain from May 2016 to April 2017.

| Standard Rate [p/kWh] | Economy 7 Rate [p/kWh] |
|---|---|
| 14.37 | 7.60 |

*Table 3. Average 2016-17 electricity tariffs in Great Britain.*

[5] The term "responsiveness" in the context of this trial should not be confused with any understanding of "responsiveness" used within the UK Government's recommended *Standard Assessment Procedure*.
[6] http://www.energysavingtrust.org.uk/about-us/our-calculations

## 4.7 Householder Survey

A householder survey was conducted following the end of the field trial, in May 2017. As well as to collect key characteristics about the properties participating in the trial, the survey was designed to gauge householders' satisfaction with their heating systems. Questions were aimed at Fischer System installation process; internal comfort delivered by the heating system; controllability and responsiveness; distribution of heat; and cost.

# 5 Data Analysis

The following analysis follows the same broad structure as Section 4 More detailed information and sub-analyses can be found in the Appendices.

## 5.1 Participating Households

The householder survey was used to obtain several key characteristics of the households (labelled A-G), namely *location*; *property type*; *number of bedrooms*; *number of reception rooms*; *weekly occupancy*; and *off-peak electricity times*. These characteristics are summarised for each household in Table 4. Householders were asked to complete an "occupancy calendar" [7], which was used to calculate an average weekly occupancy. Location is given as the first half of the property's postcode.

| Property | Location | Property Type | No. Bedrooms | No. Reception Rooms | Weekly Occupancy | Off-Peak Electricity Times |
|---|---|---|---|---|---|---|
| **A** | CF5 | Apartment | 2 | 1 | 0.80 | 00:00 – 07:00 |
| **B** | PO30 | Bungalow | 3 | 2 | 0.94[8] | 02:00 – 07:00 |
| **C** | SS8 | Bungalow | 3 | 1 | 1.00 | 00:30 – 07:30 |
| **D** | IP28 | Terraced house | 2 | 1 | 0.68 | [9] |
| **E** | ME15 | Semi-detached house | 3 | 1 | 0.75 | 00:30 – 07:30 |
| **F** | IP28 | Bungalow | 3 | 1 | 0.50 | *NA standard tariff only* |
| **G** | DT1 | Apartment | 2 | 1 | 1.00 | - |

*Table 4. Summary of the key characteristics of the participating households.*

## 5.2 Internal Comfort

### 5.2.1 Consistency of Indoor Temperature over Time

A graph of daily indoor temperature over time is shown in Figure 4. Figure 4 illustrates that the daily indoor temperature fluctuates more during Phase One than during Phase Two; at the same time, the graph shows no obvious seasonal impact. Summary statistics for each property and heating system are shown in the graph (mean line and standard deviation ribbon) and detailed in Table 5. These statistics show that, amongst the five comparable properties (A to E):

- four (B, C, D and E) exhibit a lower mean temperature (average change of -0.7°C) in Phase Two than in Phase One;

[7] The "occupancy calendar" consisted of a grid split into seven rows (days Monday to Sunday) and eight columns (three-hour intervals from 00:00 – 03:00 through to 21:00 – 00:00). Householders were asked to consider an "average week" and complete each element of the calendar by stating whether their property was occupied (one) or not (zero). A weekly occupancy (between 0 and 1) was calculated as the mean occupancy.

[8] Two survey responses were received from householders at Property B. All numeric responses for Property B were averaged (arithmetic mean) across both respondents.

[9] Householders at Properties D and G declined to provide off-peak electricity times.

- the same four (B, C, D and E) exhibit a lower standard deviation in Phase Two than in Phase One.

Property A, which was occupied intermittently as a holiday home, shows a significantly different daily indoor temperature profile to that of properties B to E, with a mean temperature in Phase One equal to that in Phase Two (16.0 °C), and a higher standard deviation in Phase Two (± 2.8 °C) than in Phase One (± 1.8 °C).

While operating the Fischer System, householders were able to maintain a daily indoor temperature that was both more consistent and lower. A lower indoor temperature may suggest that less energy was used to run the system. The energy used to run the system is analysed in Section 5.6.

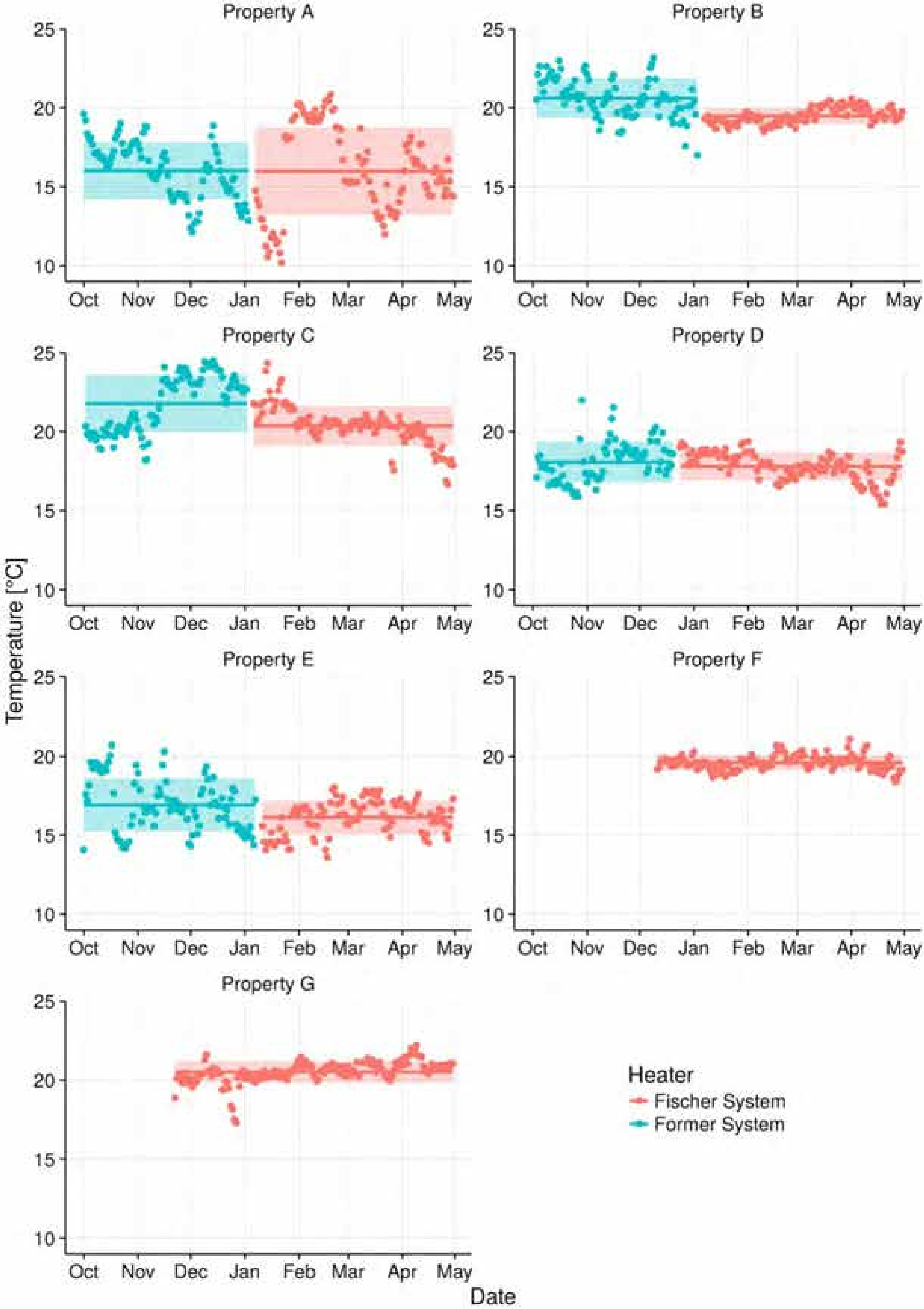


*Figure 4. Indoor daily temperature versus time, with mean line and standard deviation (SD) ribbon shown for each heating system.*

| | Former System | | Fischer System | | |
|---|---|---|---|---|---|
| **Property** | **Mean $T_{indoor\ daily}$ [degC]** | **$SD(T_{indoor\ daily})$ [degC]** | **Mean $T_{indoor\ daily}$ [degC]** | **$SD(T_{indoor\ daily})$ [degC]** | **Change in Mean $T_{indoor\ daily}$ [degC]** |
| **A** | 16.0 | 1.8 | 16.0 | 2.8 | 0.0 |
| **B** | 20.6 | 1.2 | 19.5 | 0.5 | -1.1 |
| **C** | 21.8 | 1.8 | 20.4 | 1.3 | -1.4 |
| **D** | 18.1 | 1.3 | 17.8 | 0.9 | -0.3 |
| **E** | 16.9 | 1.7 | 16.1 | 1.1 | -0.8 |
| **F** | *NA* | *NA* | 19.6 | 0.5 | *NA* |
| **G** | *NA* | *NA* | 20.5 | 0.7 | *NA* |
| | | | | | *Mean: -0.7* |

*Table 5. Mean indoor daily temperature and standard deviation for each property and heating system.*

### 5.2.2 Living Room Temperature Profile and Vertical Temperature Range

Temperature readings recorded at different heights in the living room were analysed over different time periods. Although the results of these analyses were inconclusive in quantifying a difference between the vertical temperature distribution between the Former System and the Fischer System, it was observed that the vertical temperature range was dependent on heating. Specifically, there was a larger vertical temperature range (a larger difference between floor and ceiling temperatures) when the heating system was in use. This relationship is clear at both 15-minute level, which shows the daily temperature profile of the properties; and on a daily level, which shows the seasonal temperature profile. Fuller details are provided in the Appendix (Section 8.1).

## 5.3 Prelude to Heating Degree-Day (HDD) Analysis

As a prelude to heating degree-day analysis, daily electricity consumption (see Figure 12 in Section 8.1) was plotted against daily outside temperature, as shown in the Appendix (see Figure 12 in Section 8.3). Visual inspection of these plots suggests that the relationship between electricity consumption and outdoor temperature differs significantly between Phase One (Former System) and Phase Two (Fischer System) and may require a more complex model than the linear HDD model. These aspects are described more fully in the Appendix (Section 8.3), and should be considered in conjunction with the heating degree-day analysis that follows.

## 5.4 Heating Degree-Day Analysis

In some properties, data collected from the outside air temperature logger showed sharp peaks during the day – an indication that readings had been comprised by radiant heat from the sun. As such, it was decided to conduct the analysis using weather station data. An online regression optimisation tool[10] with built-in weather station data was used to determine an appropriate base temperature for each property. A description of how this tool works can be found in the Appendix (Section 8.4.1). Null data points (electricity consumption) were discarded before analysis.

### 5.4.1 Heating Degree-Day Regression Optimisation

In the first instance, a regression optimisation was carried out for each property, using electricity consumption data from the full trial (i.e. both Phase One and Phase Two). The optimal regression for each property is summarised in Table 6, where *Base Temperature* is the optimal base temperature calculated to the nearest 0.5°C, *Total HDD* is the total number of heating degree-days used in the regression, and $m$ and $c$ are the gradient and intercept respectively. Base temperatures for the seven properties, with values between 13.5 °C and 18.0 °C, are broadly consistent with expectations[11] and were used in the rest of the analysis. Nonetheless, it is important to note that the $R^2$ values[12] for many of these regressions are small, with properties A and B showing $R^2$ values of only 0.17 and 0.16 respectively. Factors such as insulation, radiant temperature, householder preferences as well as heating from other appliances such as cookers will naturally lead to different base temperatures and may benefit from analysis with more complex models.

[10] degreedays.net

[11] 15.5 °C is commonly used in the UK as a standard base temperature.

[12] $R^2$ is the "coefficient of determination" of a statistical model, in this case the linear HDD model. It indicates the proportion of the variance in electricity consumption that is predictable from HDD, and gives some information about the "goodness of fit" of the model. In other words, it is a measure of how well the regression line approximates the real data points. It can take a value between 0 and 1, with a value of 1 indicating that the regression line perfectly fits the data.

# Energy Saving Trust – Product Performance Verification

| | |
|---|---|
| **Client:** | Fischer Future Heat UK Limited |
| **Address:** | The Waterfront, 19-20 North Mills, Leicester, LE3 5DH |
| **Product:** | Fischer Future Heat Electric Storage Heaters |
| **Report Date:** | September 2017 |

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### 5.4.2 Heating Degree-Day Regression Optimisation: A Sub-Analysis

As part of a sub-analysis, two further linear regression optimisations were carried out for each property: the first using electricity consumption data from Phase One only (Former System); the second using data from Phase Two only (Fischer System). The optimal regression for each phase and property is summarised in Table 7. These results are significant for two main reasons:

1. Of the five comparable properties, four (A, C, D and E) exhibit a base temperature in Phase Two (Fischer System) that **differs from** the base temperature in Phase One (Former System). In the case of Property D, this difference is as large as 6.5°C;
2. The same four properties exhibit an $R^2$ in Phase Two (Fischer System) that is **greater than** the $R^2$ in Phase One (Former System).

These outcomes are consistent with the observations made above that a single linear HDD model may not best describe both heating systems. However, the larger $R^2$ in Phase Two does indicate that the linear HDD model is a better fit to the Fischer System than to the Former System. In other words, electricity consumption of the Fischer System appears to be more predictable based on HDDs.

### 5.4.3 Heating Degree-Day Generation

The same online tool was further used to generate daily HDDs for each property, using the relevant base temperature detailed in Table 6. Daily HDDs for each property can be seen in in the Appendix (see Figure 13 in Section 8.4.2).

| Property | Base Temperature | Total HDD | *m* | *c* | $R^2$ |
|---|---|---|---|---|---|
| A | 15.0 | 1394 | 2.31 | 0.97 | 0.17 |
| B | 18.0 | 1543 | 2.38 | 9.50 | 0.16 |
| C | 16.5 | 1706 | 2.86 | 1.20 | 0.39 |
| D | 16.0 | 993 | 2.43 | 0.72 | 0.54 |
| E | 15.5 | 1007 | 4.33 | 1.16 | 0.42 |
| F | 16.0 | 1296 | 3.36 | 0.38 | 0.71 |
| G | 13.5 | 726 | 0.82 | 2.25 | 0.47 |

*Table 6. Summary of day-normalised HDD regression optimisation results for each property.*

| Property | Period | Base Temperature | Total HDD | *m* | *c* | $R^2$ |
|---|---|---|---|---|---|---|
| A | Fischer System | 11.0 | 399 | 4.50 | 1.28 | 0.27 |
| A | Former System | 10.5 | 251 | 0.50 | 17.30 | 0.21 |
| B | Fischer System | 18.0 | 741 | 0.86 | 9.86 | 0.09 |

| | | | | | | |
|---|---|---|---|---|---|---|
| B | Former System | 18.0 | 802 | 1.08 | 38.66 | 0.09 |
| C | Fischer System | 14.5 | 809 | 3.28 | 0.52 | 0.50 |
| C | Former System | 16.5 | 674 | 1.90 | 15.23 | 0.21 |
| D | Fischer System | 13.5 | 462 | 2.99 | 1.97 | 0.63 |
| D | Former System | 7.0 | 61 | 0.96 | 26.81 | 0.24 |
| E | Fischer System | 13.5 | 323 | 4.68 | 0.66 | 0.30 |
| E | Former System | 7.5 | 119 | 1.90 | 45.41 | 0.25 |

*Table 7. Summary of day-normalised HDD regression optimisation results for each property and each trial phase.*

## 5.5 Air-Temperature Responsiveness

Figure 5 shows the typical 24-hour temperature profiles for the living room for each property and heating system.

Some of these plots exhibit clear punctual heating modes in the form of smooth sharp peaks in temperature (e.g. see the peak for Property F at 09:15). In these cases, it was possible to estimate a value for Air-Temperature Responsiveness in line with the definition earlier in the report. Other plots did not exhibit sufficiently clear heating modes to allow for Air-Temperature Responsiveness to be calculated confidently. Property-specific observations and values for Air-Temperature Responsiveness (where appropriate) are detailed in Table 8.

| Property | Observations of the Fischer System | Air-Temperature Responsiveness |
|---|---|---|
| A | Following installation, the general profile changed dramatically, with lower temperatures and the appearance of two clear heating modes. | 3h (morning) and ≈ 2h15 (evening) |
| B | Following installation, the general profile remained similar, with slightly higher temperatures and a significantly reduced peak at around midday. The peak around midday suggests that the loggers may have been affected by convection currents or thermal stratification. | *no punctual heating mode* |
| C | Following installation, the general profile remained similar, with a clearer morning heating mode. | 3h (morning) |
| D | Following installation, the general profile remained similar, with consistently lower temperatures. | *no punctual heating mode* |
| E | Following installation, the general profile changed significantly, with consistently lower temperatures throughout the day. | ≈ 3h15 (evening) |
| F | One clear heating mode and one gradual heating mode are visible. | 2h (morning) |
| G | One punctual heating mode is visible in the morning, with temperature kept relatively constant throughout the afternoon and evening. | 3h45 (morning) |

*Table 8. Observations and values for Air-Temperature Responsiveness based on 24-hour profiles.*

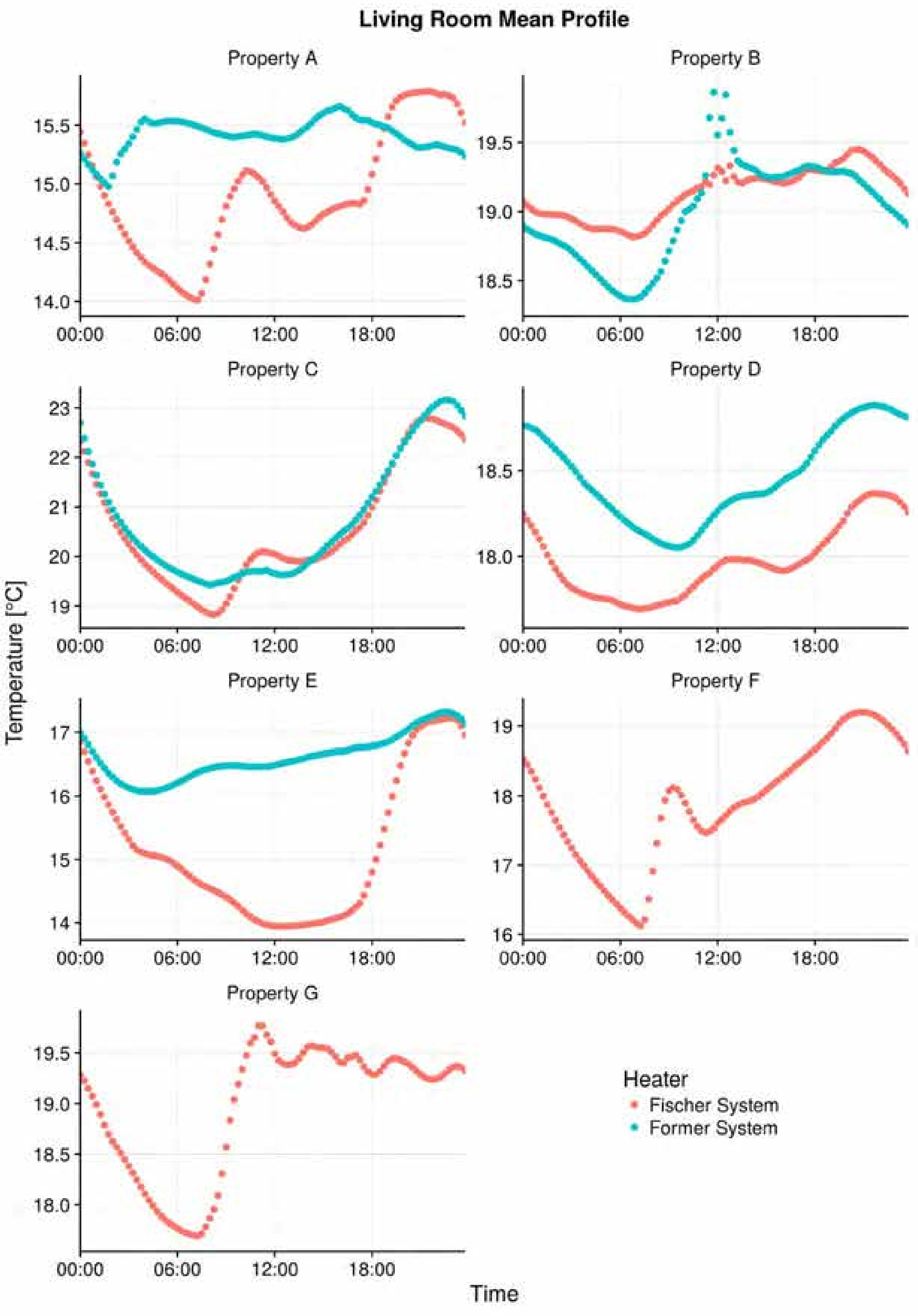


*Figure 5. Typical 24-hour temperature profile for the living room.*

## 5.6 Energy Consumption

The total energy consumption and total HDDs for each property and heating system are shown in Table 9. The amount of electricity consumed per HDD degree day is consistently lower in the Fischer System than in the Former System.

| | Former System | | | Fischer System | | | |
|---|---|---|---|---|---|---|---|
| Property | Total Electricity Consumption [kWh] | Total HDDs [°C·day] | Electricity Consumption per HDD [kWh·°C$^{-1}$·day$^{-1}$] | Total Electricity Consumption [kWh] | Total HDDs [°C·day] | Electricity Consumption per HDD [kWh·°C$^{-1}$·day$^{-1}$] | Change in Electricity Consumption per HDD (%) |
| **A** | 1458.8 | 570.1 | 2.56 | 1937.4 | 838.2 | 2.31 | 9.7 |
| **B** | 3691.1 | 801.9 | 4.60 | 1435.4 | 740.6 | 1.94 | 57.9 |
| **C** | 2389.0 | 673.9 | 3.55 | 2711.6 | 1032.4 | 2.63 | 25.9 |
| **D** | 943.5 | 323.2 | 2.92 | 1555.7 | 669.7 | 2.32 | 20.4 |
| **E** | 2951.6 | 543.8 | 5.43 | 1563.2 | 463.5 | 3.37 | 37.9 |

*Table 9. Electricity consumption per HDD, shown as absolute values and percentage change between Phase One (Former System) and Phase Two (Fischer System).*

| | Fischer System | | |
|---|---|---|---|
| Property | Total Electricity Consumption [kWh] | Total HDDs [°C·day] | Electricity Consumption per HDD [kWh·°C$^{-1}$·day$^{-1}$] |
| **F** | 4402.9 | 1295.9 | 3.40 |
| **G** | 920.2 | 725.8 | 1.27 |

*Table 10. Electricity consumption per HDD, shown as an absolute value.*

### 5.6.1 Typical 24-Hour Charging Profile

Typical 24-hour charging profiles for the Fischer System can be seen in Figure 6, each consisting of 48 mean half-hourly readings (in kWh) against time of day. It should be noted that:

- electricity consumption generally remains below 1 kWh per half-hour interval, and peak consumption generally remains below 2 kWh in any one half-hour interval. Property F is the only exception to this, where peak consumption reaches approximately 3.5 kWh in one half-hour interval;
- properties A, C, E and G exhibit multimodal charging profiles, with a clear charging mode in the early hours of the morning and a second in the evening;
- properties B, D and F show significant levels of charging throughout the day, indicating a more constant heat demand.

Figure 7 shows the typical 24-hour charging profile for both the Fischer System and the Former System for Property E, where half-hourly data was also available for Phase One. This clearly shows the move from a conventional night-storage charging profile to a bi-modal profile, with some trickle charging.

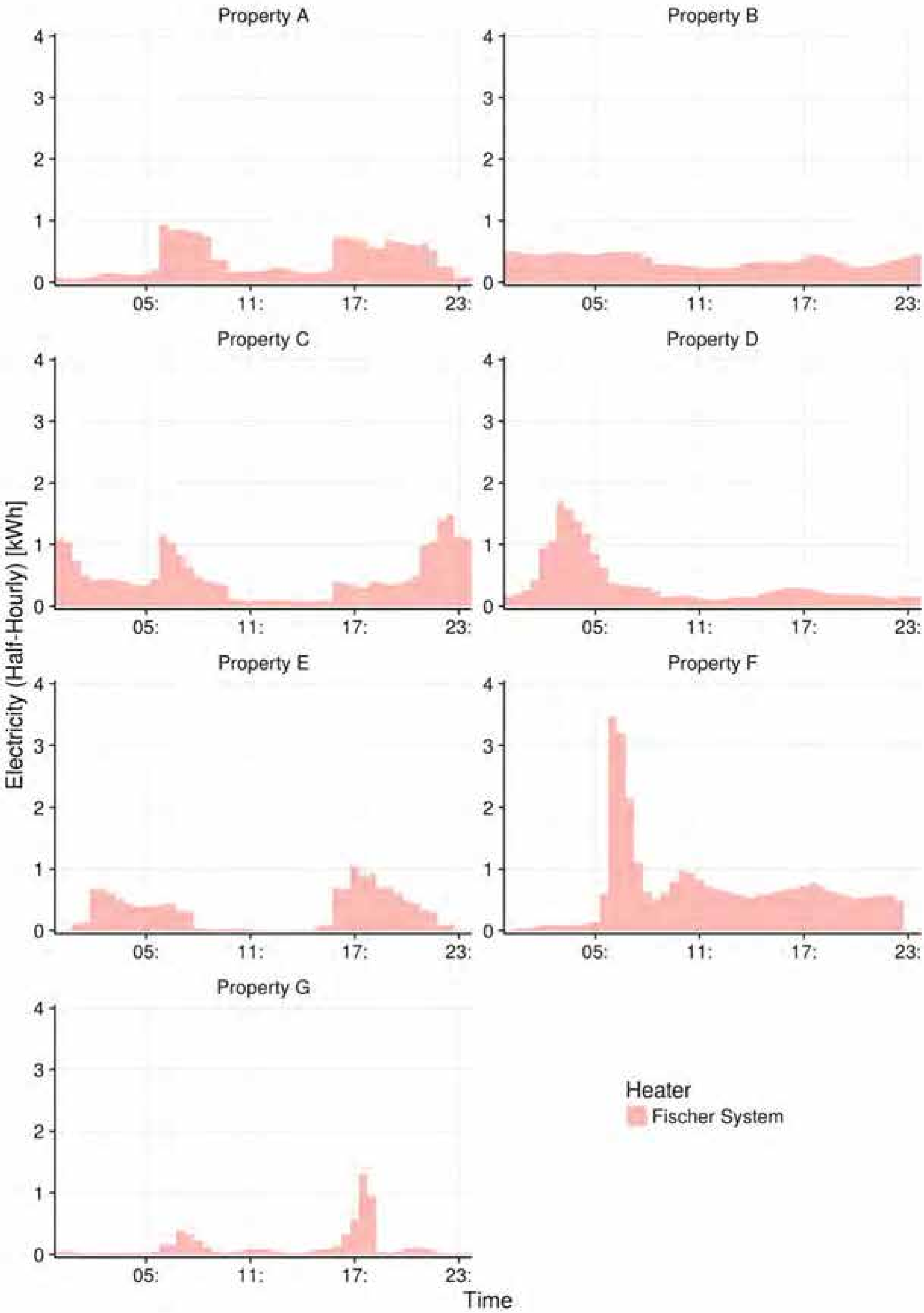


*Figure 6. 24-hour charging profiles for the Fischer System.*

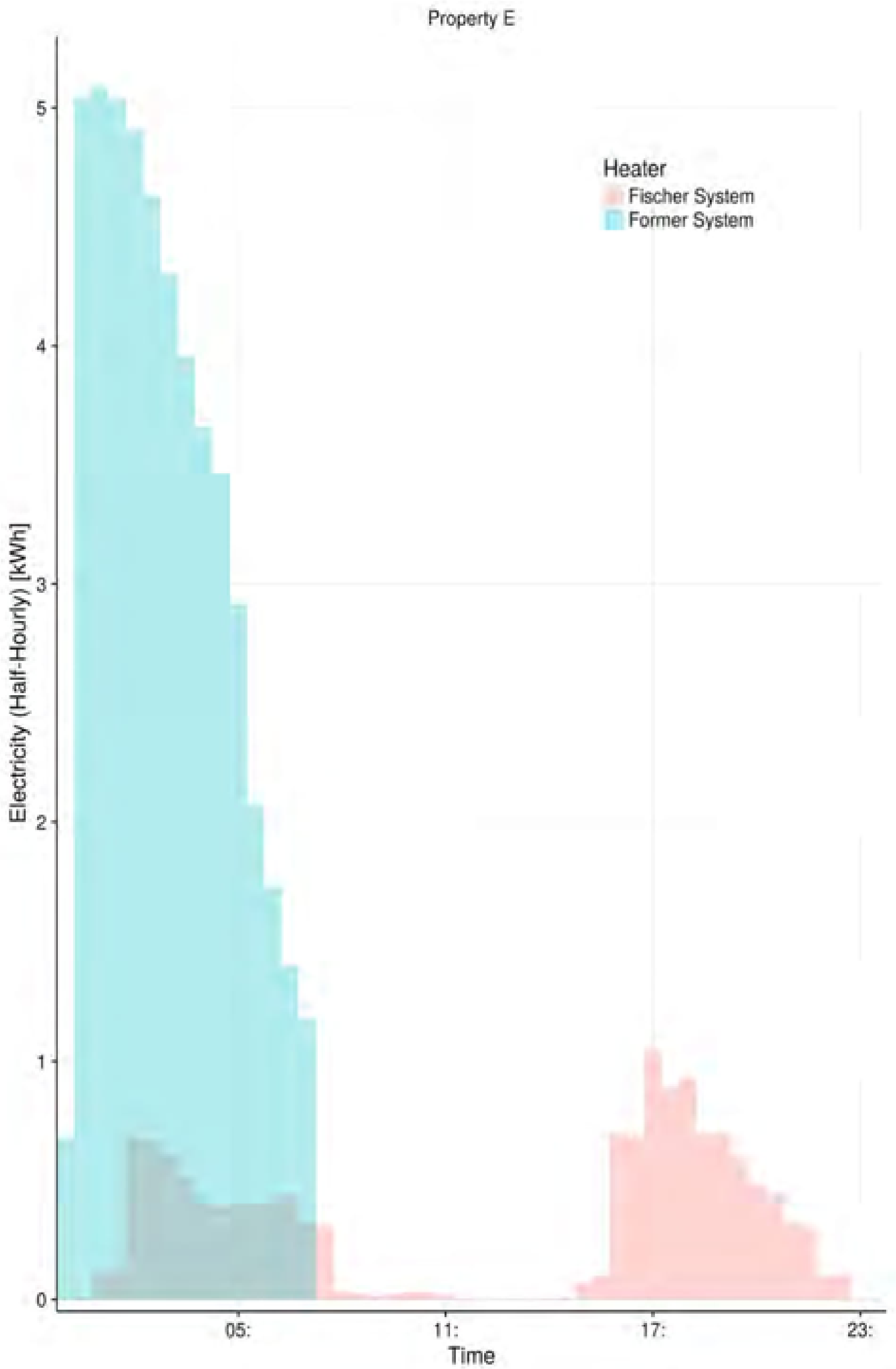

*Figure 7. 24-hour charging profiles for the Former System and the Fischer System at Property E.*

## 5.7 Running Cost

Running costs were estimated using off-peak electricity times provided in the householder survey. For properties D and G, where householders declined to provide information about their time-of-use tariff, off-peak times were assumed to be from 00:30 to 07:30. For property F, where the householder reported not having a time-of-use tariff, costs were calculated was on the standard tariff only. Half-hourly electricity consumption data was corrected for Daylight Saving Time to account for the time-of-use tariff's dependence on local time.

Table 11 shows the *Estimated Cost* and *Projected Annual Cost* of electricity consumption for the

Fischer System for each property, and Table 12 shows similar values for the Former System for Property E. NB *Total HDDs* and *Estimated Cost* correspond to days where full half-hourly consumption data was available and should not be compared with values in Table 9.

| | Fischer System | | | |
|---|---|---|---|---|
| **Property** | **Total HDDs [°C·day]** | **Estimated Cost [£]** | **Annual HDDs [°C·day]** | **Projected Annual Cost [£]** |
| **A** | 771 | 236 | 1638 | 502 |
| **B** | 642 | 149 | 2576 | 597 |
| **C** | 968 | 302 | 2193 | 685 |
| **D** | 610 | 142 | 1909 | 443 |
| **E** | 743 | 153 | 1781 | 366 |
| **F** | 1117 | 542 | 2054 | 997 |
| **G** | 587 | 98 | 979 | 163 |

*Table 11. Estimated cost and projected annual cost of electricity consumption for the Fischer System for each property.*

| | Former System | | | |
|---|---|---|---|---|
| **Property** | **Total HDDs [°C·day]** | **Estimated Cost [£]** | **Annual HDDs [°C·day]** | **Projected Annual Cost [£]** |
| **E** | 476 | 200 | 1781 | 748 |

*Table 12. Estimated cost and projected annual cost of electricity consumption for the Former System for Property E.*

# 6 Householder Survey Results

A total of eight survey responses were received. One survey response was received for six of the seven households and two survey responses were received for the seventh household (with two householders returning one survey each. The results were aggregated and are summarised below. For the seventh household, each respondent's responses were given a weighting of 0.5 to avoid skewing the aggregation.

## 6.1 Installation Process

When asked "*How time-consuming was the installation process?*" (on a scale of *1 Very time-consuming* to *7 Very quick*) [Q25], all seven households gave a score of 7/7. With installations completed within a day, respondents generally commented that the installation was "clean" and "efficient". When asked "*How convenient was the installation?*" (on a scale of *1 Very convenient* to *7 Very inconvenient*) [Q26], responses were slightly more mixed, although largely positive with a mean score of 2.3.

All households confirmed having received an induction or training from the installer/manufacturer on how to operate the Fischer System [Q27]. When asked which literature they received from the installer [Q28], all seven households confirmed having received at least a short-guide and five households confirmed having received a full instruction manual.

When asked to rate their overall satisfaction with the Fischer System (on a scale of *1 Very satisfied* to *7 Very unsatisfied*) [Q30], householders gave a mean score of 2.1, commenting:

- The installation was "*quick, went to plan and was clean*"
- *"Just sheer excellence all around, efficient, no nonsense, great explanations and so easy to communicate."*
- *"The installers were, polite, informative, helpful and efficient."*
- *"Just so straightforward and easy."*

One household gave a score of *3 Neutral*, commenting that there were issues with one of their heaters following installation, which resulted in it needing replacing. One household gave a low score of 7 but declined to make any comments.

## 6.2 Internal Comfort

When asked to think about indoor temperatures and thermal comfort when operating the Former System [Q33], six households said that the temperature in their home was either *Uncomfortable* or *Very uncomfortable*, compared to one that answered *Comfortable*. This compares to the Fischer System, where six said that the temperature in their home was either *Comfortable* or *Very comfortable* [Q35], compared to one that answered *Very uncomfortable*. This is an overall positive result, with households generally perceiving their level of comfort to have increased after installation of the Fischer System (this being despite indoor temperatures being lower with the Fischer system).

## 6.3 Controllability and Responsiveness

When asked to score the ease-of-use of the thermostat and programmer/time-switch when operating the Fischer System (on a scale of *1 Very difficult* to *7 Very easy*) [Q38], households gave a mean score of 6.3/7. Six households perceived the Fischer System to be easier to control than the Former System [Q42], while one perceived both systems to be similar in terms of their controllability. Respondents commented:

- *"We never really knew how the old heaters worked and therefore found them inefficient and difficult to control. The new ones are simple to use and quick to react."*
- *"The controls are a delight and so sensitive and effective. I can alter the individual rooms as I wish at the touch of a switch. This makes it so easy to have the temperature at the right time and in the right room. So easy and just removes all stress now in heating the room."*
- *"The use of the heaters is straightforward and even easier than I had thought."*
- *"It works well for us, because we stay at the flat intermittently and can control the heat easily. We can remotely control it so the heating comes on before we arrive."*

As mentioned above in Section 6.1, one household reported experiencing problems with one of the heaters in the Fischer System [Q43]; the problems were resolved when the heater was replaced.

Two households reported adjusting the thermostat settings of their Fischer System several times per day, three reported adjusting the thermostat once per day, and two reported never adjusting the thermostat [Q45]. When asked how long, on average, it took for their property to heat up to the required temperature [Q46], all households reported a delay of no more than 60 minutes: two households reported a delay of 0 to 15 minutes, two reported a delay of 15 to 30 minutes, and the remaining three reported a delay of 30 to 60 minutes. All households unanimously agreed that the Fischer System was faster at heating the room than the Former System [Q47].

## 6.4 Distribution of Heat

Five households reported positively that the Fischer System heated rooms more evenly (similar temperatures at different locations and heights in a room) than the Former System [Q48], and the remaining two households reported that the Fischer System and the Former System performed similarly in this respect.

## 6.5 Cost

Householders were asked how expensive they considered the up-front cost of the Fischer System to be ("*Expensive*", "*What you would expect for a domestic heating system*", "*Good value for money*", "*Cheaper than alternative heating systems you considered installing*", or "*More expensive than alternative heating systems you considered installing*") [Q51]. Three households answered "*Expensive*", one answered "*More expensive than alternative heating systems you considered installing*", two households answered "*Good value for money*", and one answered "*What you would expect for a domestic heating system*".

Five households reported having received a bill since installation of the Fischer System. Of these, three reported spending less money on electricity since installation [Q50], and two reported spending the same amount. One householder commented that the heaters had saved energy, but noted that the "*real savings will not be known for about a year*" following a change-over from Economy 7 to a new tariff. Another householder commented that they considered the

# Field Trial: Quantifying the Performance of the Fischer Future Heat Dynamic Electric Storage Heaters in 7 Domestic Properties

## 1 Executive Summary

### 1.1 Background

In 2016-17, Energy Saving Trust worked with Fischer Future Heat to evaluate the Fischer Future Heat Dynamic Electric Storage Heaters (referred to as the "Fischer System" in this report). The advanced features of this electric storage heating system are its independently and wirelessly controllable heaters; its use of trickle charge outside of peak hours; and its perforated clay core, positioned close to the front panel of the heater, which Fischer states is to optimise heat distribution.

EST independently evaluated the system's performance and provided factual, consumer-focussed information within the remit of its "Product Verification" service, with the aim of helping Fischer Future Heat to communicate with consumers about the energy-related benefits of their product.

A field trial was devised to quantify the performance of existing electric storage heating systems (referred to as "Former System" in this report); and subsequently the Fischer Dynamic Electric Storage Heater System, within seven domestic properties. Households were selected to participate in the trial after having decided to have the Fischer System installed in their property, and were offered a financial incentive to participate. Two of the seven households had installed the Fischer System before the trial began and were included to understand better how the Fischer System performed, in terms of its charging, heating profiles and running cost.

### 1.2 Methodology

A methodology was devised by EST to evaluate the following aspects of the heating systems:

- **Internal comfort** was assessed in terms of how indoor temperature varied throughout the trial, the evenness of heat distribution within a room, and the perception of the end-users.
- **Electricity consumption** was assessed following heating degree-day normalisation.
- **Running cost** was estimated using half-hour electricity consumption data and time-of-use tariff data.
- **Responsiveness** was assessed in terms of the time taken for indoor air temperature to reach a maximum, and more broadly in terms of how indoor temperatures varied throughout the trial.

The trial proper took place between October 2016 and April 2017. Electricity consumption and air temperature data were monitored. The trial was split into two phases:

- Phase One (October 2016 – January 2017) – Monitoring of Former System;
- Phase Two (October 2016 – April 2017) – Monitoring of Fischer System.

property to be "*warmer and the heating easier to control*" following installation of the Fischer System, although emphasised that the property was a holiday home, making it difficult to compare electricity costs as occupancy varied significantly.

Although householders may have found the up-front costs of the Fischer System to be high, these responses suggest that they may see a higher rate of return if running costs are lower than with the Former System.

## 6.6 Overall Satisfaction

Householders were asked how satisfied, overall, they were with the performance of the Fischer System (on a scale of *1 Extremely unsatisfied* to *7 Extremely satisfied*) [Q53]. Householders were generally satisfied, giving a mean score of 6.0/7.

When asked how likely they would be to recommend the Fischer System to friends, family or colleagues (on a scale of *1 Extremely unlikely* to *7 Extremely likely*) [Q54], households gave a mean score of 6.0/7.

## 6.7 Summary of Householder Survey Results

Householder survey results were largely positive. Householders were generally satisfied with the installation process, which they perceived as quick and clean. While using the Fischer System, they reported feeling more comfortable and perceived the distribution of heat in rooms to be more even. Commenting positively, householders were highly satisfied with the controllability of the Fischer System, and unanimously perceived it to be faster at heating rooms than the Former System. Householders reported less favourably on the up-front cost of the Fischer System, but generally perceived its running costs to be lower than the Former System. One household reported initial problems with one of their Fischer System heaters, but these were rectified with a replacement product. There were few poor scores; however, on these occasions households did not provide a reason for their poor score, unfortunately providing no insight. Overall satisfaction was high, with mean scores of 6.0/7. Furthermore, households were generally satisfied with the process of being involved in an Energy Saving Trust field trial [Q55], giving a mean score of 5.6/7.

# 7 Conclusion and Verified Product Performance Claims

## 7.1 Conclusions

Analysis found that indoor temperatures were lower on average during Phase Two, once the Fischer Systems had been installed. Significantly, indoor temperatures varied less from day to day, indicating a more consistent indoor environment. Householders appeared to require a lower average indoor temperature and to be able to maintain a more consistent temperature, suggesting increased levels of comfort and more efficient use of energy.

Householders' very high levels of satisfaction with system controllability seems to be reflected somewhat in these temperature profiles and the increased day-to-day consistency in temperature.

Analysis of the vertical distribution of air temperature within the living room showed that properties had significantly different profiles to one another and was inconclusive. Further analysis taking into account electricity consumption and mean living room temperatures may provide better insight.

Heating degree-day analysis indicated that the Fischer System was better described by a linear regression model. Regressions for Phase Two of the trial showed a higher coefficient of determination, with electricity consumption more closely linked to outdoor temperatures, indicating better responsiveness to the outdoor environment.

By far the most significant result was the comparison of energy consumption between the two systems. Across the five comparable properties, the amount of electricity consumed per HDD was consistently lower once the Fischer Systems had been installed.

## 7.1 Verified Performance Claims

The following statements have been designed, in line with EST's "Product Verification" service, to be factual and consumer-orientated, and are intended for use within Fischer Future Heat's promotional materials.

"*In an Energy Saving Trust field trial of five properties, where traditional electric storage heaters were replaced with Fischer Future Heat Dynamic Electric Storage Heaters,… "*

- *"… the indoor air temperature was more consistent on a day-to-day basis in four of the five properties, indicating a more stable indoor environment."*
- *"… householders reported feeling more comfortable and at the same time maintained an indoor air temperature that was an average of 0.7°C lower, suggesting that less energy may be required to maintain desired levels of comfort."*
- *"… electricity consumption was more closely linked to outdoor temperatures, indicating better responsiveness and/or controllability with the Fischer heating system."*
- *"… heating degree-day analysis showed that the electricity consumption was consistently lower when operating the Fischer heating system. "*

Several caveats need to be associated with these statements, as listed below:

**Caveats**

- The verified claim is based on the information reviewed by EST as summarised in this report.
- Information contained in this report correct as of September 2017
- Verified claims must be used in conjunction with the caveats agreed with EST
- Verification of the Fischer Future Heat Electric Storage Heating system claims valid for 12 months as of October 2017 2017
- If featured with the Energy Saving Trust Verified brandmark, the brandmark must be reproduced in accordance with the brand guidelines.
- Materials featuring EST Verified claims and the EST Verified brandmark should be submitted to EST for approval (allowing 3 working days)

# 8 Appendix – Further Insight & Discussion

## 8.1 Living Room Temperature Profile and Vertical Temperature Range

For illustrative purposes, an example temperature profile from the three[13] living room loggers is given in Figure 8. The vertical temperature range was calculated for each property and heating system, and the results are represented in Figure 9 and Figure 10.

The data in Figure 8 was taken from 18th February 2017, when the Fischer System was in operation in all seven properties (Phase Two). It should be noted that properties A, C, D and E show similar fundamental vertical temperature distributions, with the Living Room 1 logger (floor-level) showing the lowest temperature and the Living Room 3 logger (ceiling-level) showing the highest temperature at a given point in time. Properties B, F and G do not show this same fundamental vertical temperature distribution[14]. It was noted that:

- Property A exhibits a bimodal temperature profile, with a clear morning maximum at approximately 10:00 and an evening maximum at approximately 20:00;
- Property E exhibits a bimodal temperature profile, with a clear morning maximum at approximately 08:00 and an evening maximum at approximately 21:00;
- Property C exhibits a unimodal temperature profile, with a clear evening maximum at approximately 21:00;
- Property D exhibits a unimodal temperature profile, with a clear evening maximum at approximately 20:00;
- Properties B, F and G exhibit less well-defined modal characteristics, with multiple local minima and maxima throughout the day;
- Properties A, F and G exhibit a steady fall in temperature during the early hours of the morning;

[13] Property F's "Living Room 1" temperature logger was lost in the post and therefore no temperature range was available for this property. Property F is omitted from the relevant graphs.

[14] The possibility of human error in placing the temperature loggers is acknowledged. Other factors may have contributed to these varied living room profiles, including insolation, convection currents within the room, or the loggers' proximity to any source of heat or draught.

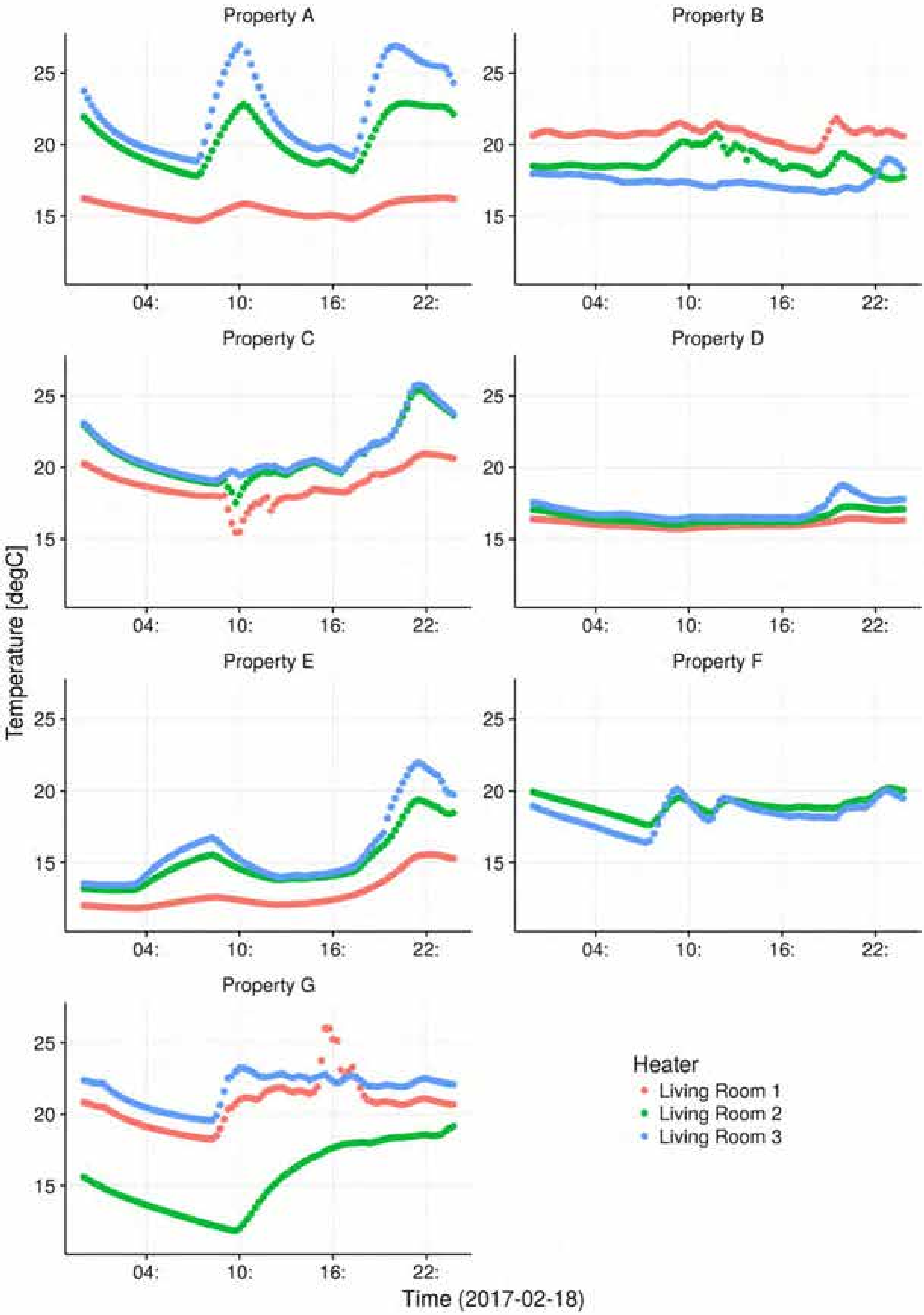


*Figure 8. Example living room temperature profile for 18th February 2017, when the Fischer System was operational.*

Figure 9 shows a typical 24-hour profile, and was generated by averaging the vertical temperature range by 15-minute interval across all dates, producing 96 mean values. The vertical temperature range is largest during the heating modes (maxima), and generally smallest immediately prior to these heating modes (to the left-hand edge of these maxima). This phenomenon is best illustrated in the graph for Property A in Figure 8:

- **Before 07:00** the air temperature and the vertical air temperature range are seen to be decreasing to their minimum values.
- **Between 07:00 and 10:00** the morning heating mode appears to occur, with the air temperature and the vertical air temperature range both increasing.
- **At 10:00** the morning mode appears to end, with both air temperature and vertical air temperature range reaching their maximum values, before decreasing again.

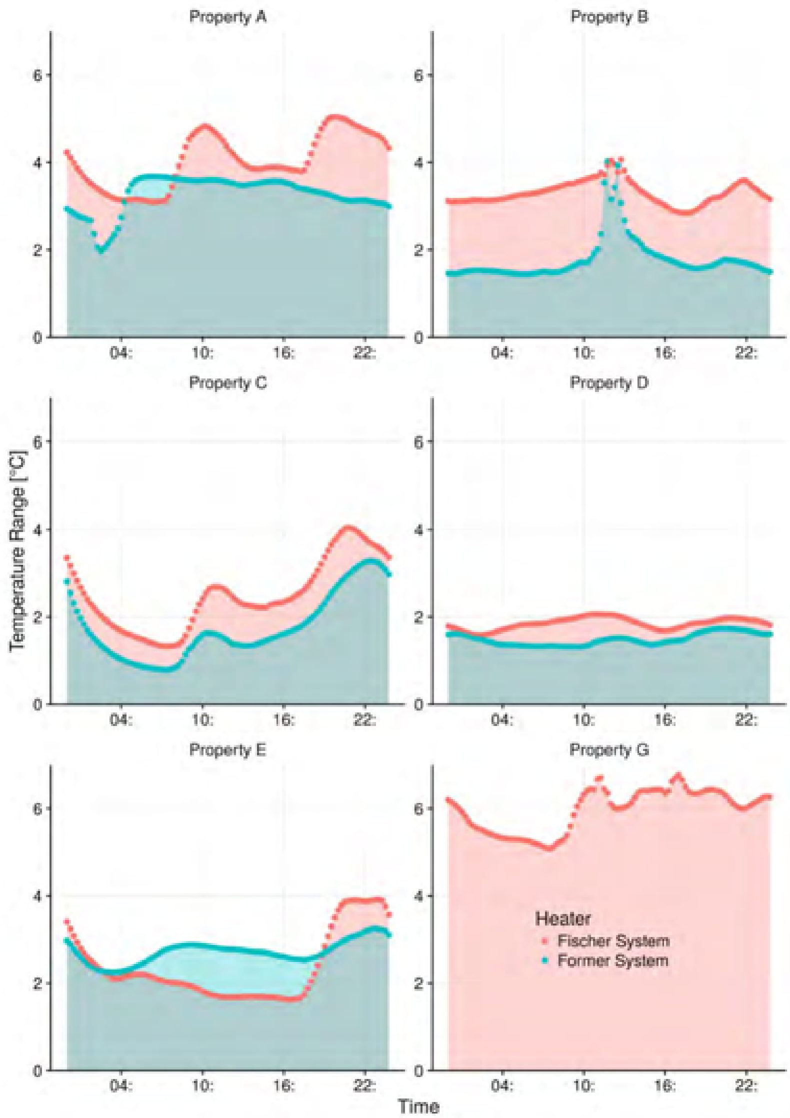


*Figure 9. Vertical temperature range versus time of day (date averaged).*

Figure 10 was generated by taking a daily average of the vertical temperature range, producing one mean temperature range for each day of the trial. What is clear from this figure is that there is a "seasonal" component to the vertical temperature range: with higher values generally found in the months of January and February, and lower values generally found at the beginning and end of the trial in the months of October and May. This is most obvious in the plots for properties A, C, D and E. For Property A, three extended troughs are visible during Phase Two, which may be explained by the fact that this property was occupied intermittently. For Property D, a plateau is visible during the month of October, which may be explained by an absence of heating prior to the heating season. This corroborates observations made about Figure 8 and Figure 9: that heating serves to increase the vertical temperature range.

For the reasons mentioned above, the vertical temperature range alone does not provide sufficient information to allow for comparison between the Fischer System and the Former System.

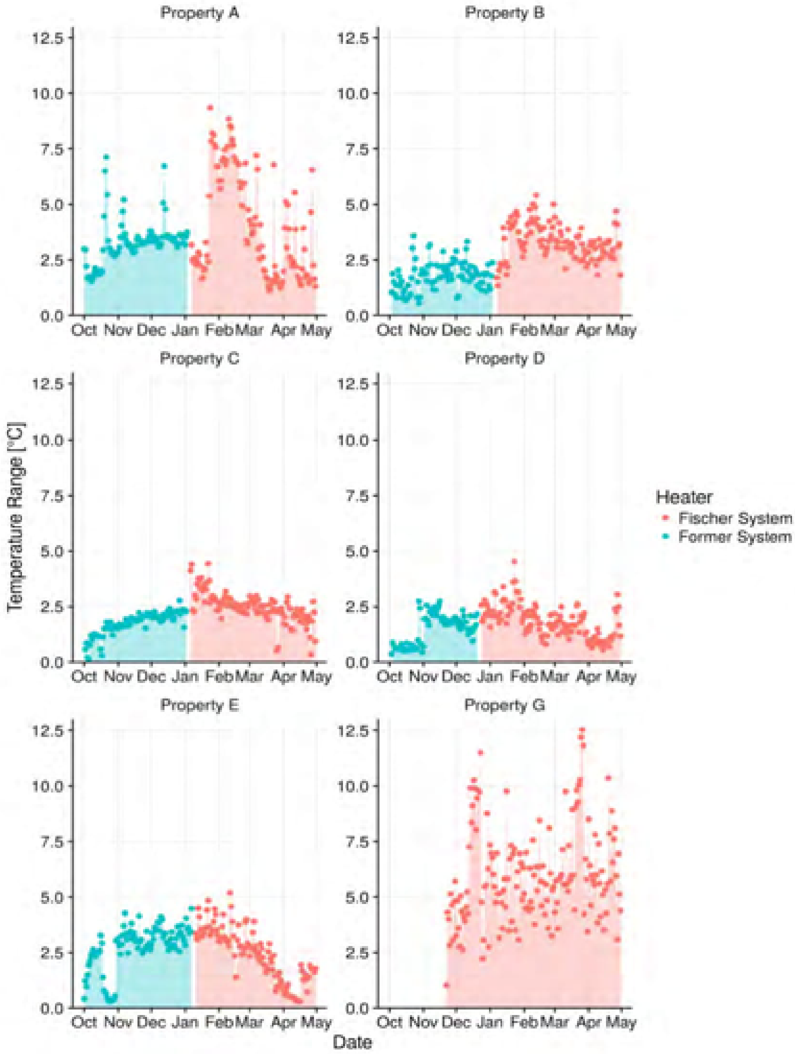


*Figure 10. vertical temperature range versus date (daily mean).*

## 8.2 Daily Electricity Consumption Data

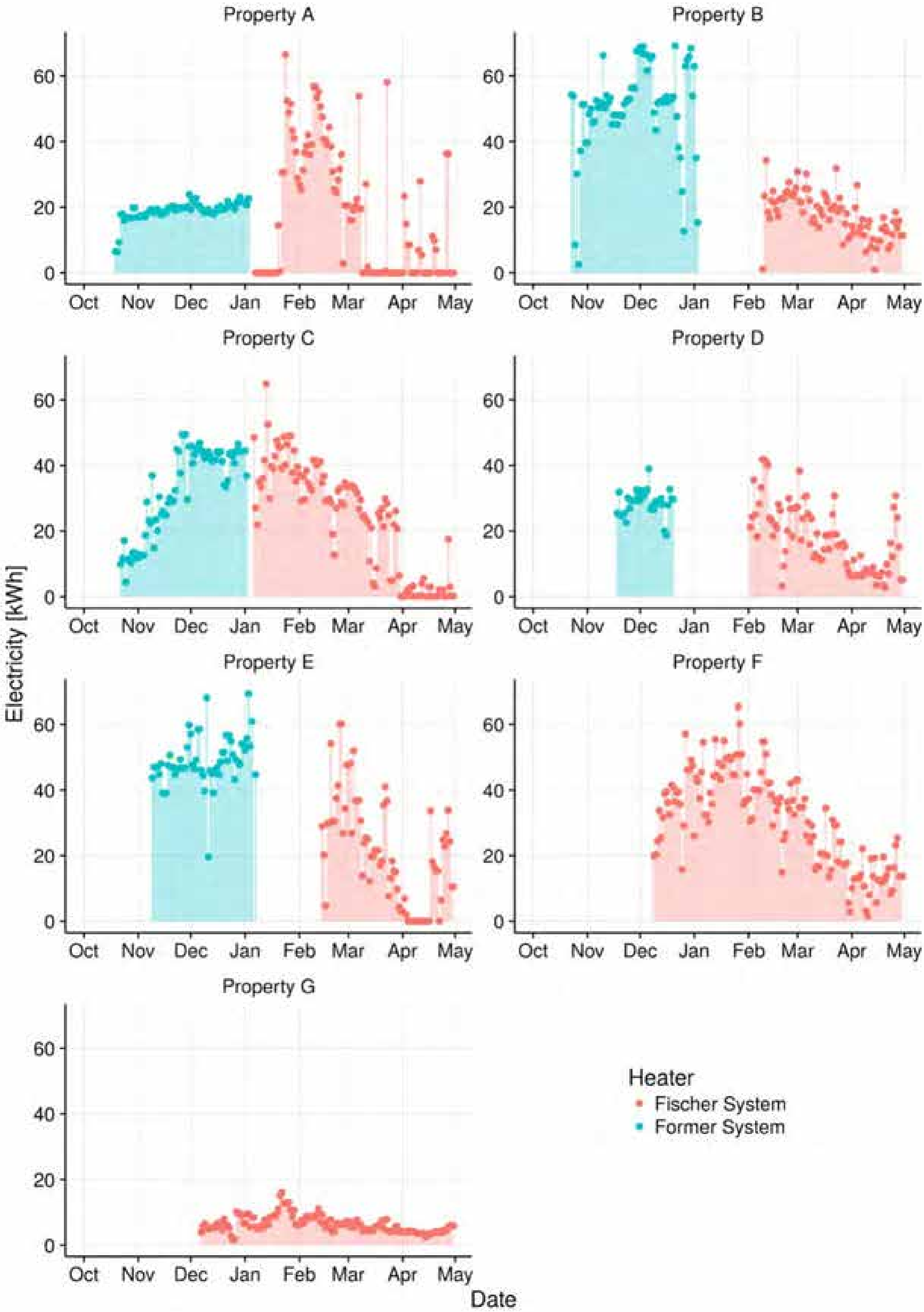


*Figure 11. Daily electricity consumption over time. An installation error at Properties B, C and D meant that some data was lost during January and February.*

## 8.3 Prelude to Heating Degree-Day (HDD) Analysis

A plot of daily electricity consumption versus daily outdoor temperature is shown in Figure 12. Brief visual inspection of this plot suggests that the energy consumption and heating patterns of the Former System and the Fischer System may be significantly different to one another. In particular, it was noted that:

- **for properties A, D and E**, the Former System regression lines show a shallow gradient. A change in daily outdoor temperature had only a small impact on the electrical consumption of the Former System in these properties. In contrast, for these same properties, the Fischer System regression lines show a steeper gradient.
- **for properties A, C and E**, the Fischer System data points show a cluster about $E_{daily\ consumption} = 0$ kWh. While some of this clustering may be explained by a smaller heat demand at higher daily outdoor temperatures (> 10°C), a property's occupancy may also play a significant role. These results are largely consistent with expectations for Property A, which was occupied only intermittently as a holiday home. The householder confirmed that the heating system was switched off when Property A was not occupied. The clusters seen for properties C and E may be explained by similar changes in occupancy and the resulting occupant behaviour. Interestingly, no similar cluster was observed during Phase One (Former System), whether because of different occupancy levels between Phase One and Phase Two, or because of differences in controllability between the two heating systems.

The plots indicate that any relationship between outdoor temperature and electricity consumption may have been significantly different between the Former System and Fischer System, and the above observations should be considered in conjunction with the following heating degree-day analysis.

The concentration of data points (clustering) that is visible at low electricity consumptions (≈ 0 kWh) may indicate periods of time during which a property was unoccupied, however, discarding these points would require the choice of suitable threshold values and may result in the loss of important information.

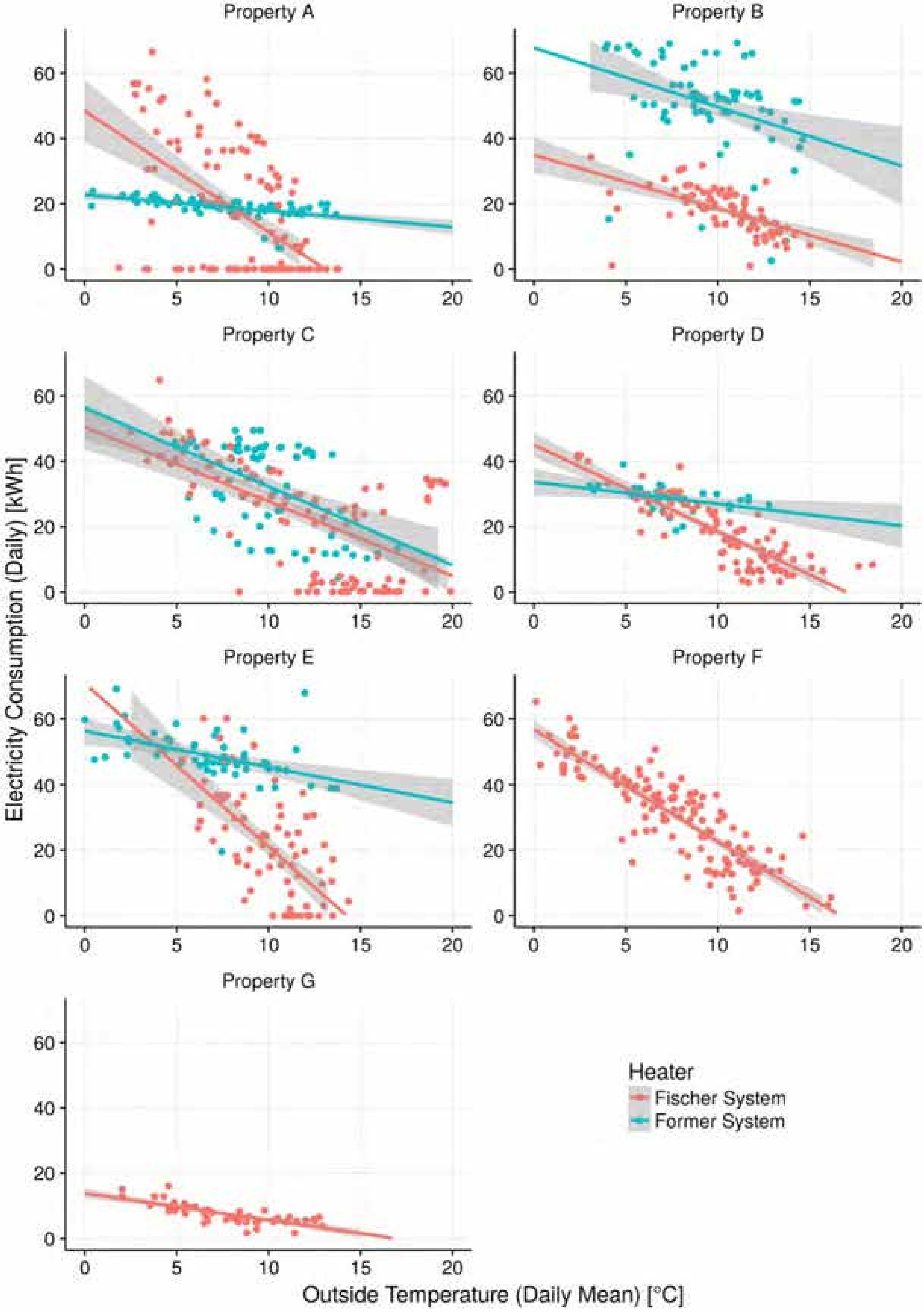


*Figure 12. Plot of daily electricity consumption against daily outdoor temperature.*

## 1.3 Results

*Householders maintained a lower and more consistent indoor temperature*

Analysis found that indoor temperatures were an average of 0.7°C lower with the Fischer System. Indoor temperatures varied less from day to day, indicating a more consistent indoor environment.

*Energy consumption decreased*

By far the most significant result was in the energy consumption of the two systems. The amount of electricity consumed was consistently lower with the Fischer System: across the five comparable properties, electricity consumption decreased.

*Householders reported high satisfaction*

Householders survey responses were received from all seven households. Respondents were highly satisfied with the Fischer Future Heat installation process. Generally, respondents perceived that their **levels of comfort increased** and believed that the **Fischer System heated rooms more evenly**. Respondents commented most favourably on the controllability and responsiveness of the new heating system, with the heaters being described as **"simple to use and quick to react"** and the controls as **"so sensitive and effective"**. Although respondents considered the up-front cost of the Fischer System to be expensive, this was at least partially counteracted by positive perceptions of energy savings.

*Fischer System shows a stronger link to outdoor temperatures*

Electricity consumption was more closely linked to outdoor temperatures following the installation of the Fischer System, indicating better responsiveness and/or controllability of the heating system.

*Charging profile moves away from the traditional night-storage profile*

Typical 24-hour charging profiles demonstrated the multi-modal charging profiles of the Fischer System, with two principle charging modes often visible during early morning and early evening. Charging data, from one of the properties, clearly demonstrated the move from the traditional unimodal charging profile of night-storage heaters following installation of the Fischer System.

## 8.4 Heating Degree-Day Analysis

### 8.4.1 Heating Degree-Day Regression Optimisation

The tool uses user-supplied electricity consumption data, along with built-in air temperature data (from a weather station chosen by the user) to calculate an optimal base temperature. Irregular time-periods within the electricity consumption data were handled by the tool with day normalisation. The tool returns multiple regressions, each ranked according to its "quality of fit", using a sophisticated algorithm including factors such as the regression's coefficient of determination ($R^2$). For each property, the closest weather station was chosen and is listed in Table 13.

| Property | Weather Station Identifier |
|---|---|
| A | EGFF |
| B | EGHH |
| C | EGUN |
| D | EGMC |
| E | EGMC |
| F | EGUN |
| G | 03857 |

*Table 13. Weather station identifier for each property. The weather station identifier is the unique key used by degreedays.net.*

| Property | Period | Total Readings | Start | End | Total Days | Gap Days |
|---|---|---|---|---|---|---|
| A | Fischer System | 70 | 2017-01-07 | 2017-04-27 | 111 | 0 |
| A | Former System | 71 | 2016-10-19 | 2017-01-03 | 77 | 0 |
| A | Full Period | 141 | 2016-10-19 | 2017-04-27 | 191 | 3 |
| B | Fischer System | 79 | 2017-02-09 | 2017-04-30 | 81 | 0 |
| B | Former System | 64 | 2016-10-23 | 2017-01-03 | 73 | 0 |
| B | Full Period | 143 | 2016-10-23 | 2017-04-30 | 190 | 36 |
| C | Fischer System | 107 | 2017-01-06 | 2017-04-30 | 115 | 0 |
| C | Former System | 66 | 2016-10-22 | 2017-01-02 | 73 | 0 |
| C | Full Period | 173 | 2016-10-22 | 2017-04-30 | 191 | 3 |
| D | Fischer System | 80 | 2017-02-02 | 2017-04-30 | 88 | 0 |
| D | Former System | 30 | 2016-11-18 | 2016-12-20 | 33 | 0 |
| D | Full Period | 110 | 2016-11-18 | 2017-04-30 | 164 | 43 |

| | | | | | | |
|---|---|---|---|---|---|---|
| E | Fischer System | 56 | 2017-02-14 | 2017-04-30 | 76 | 0 |
| E | Former System | 51 | 2016-11-09 | 2017-01-07 | 60 | 0 |
| E | Full Period | 107 | 2016-11-09 | 2017-04-30 | 173 | 37 |
| F | Full Period | 125 | 2016-12-09 | 2017-04-30 | 143 | 0 |
| G | Full Period | 118 | 2016-12-07 | 2017-04-30 | 145 | 0 |

*Table 14. Summary of the electricity consumption data used to perform day-normalised heating degree-day regression optimisation with the degreedays.net tool.*

### 8.4.2 Heating Degree-Day Generation

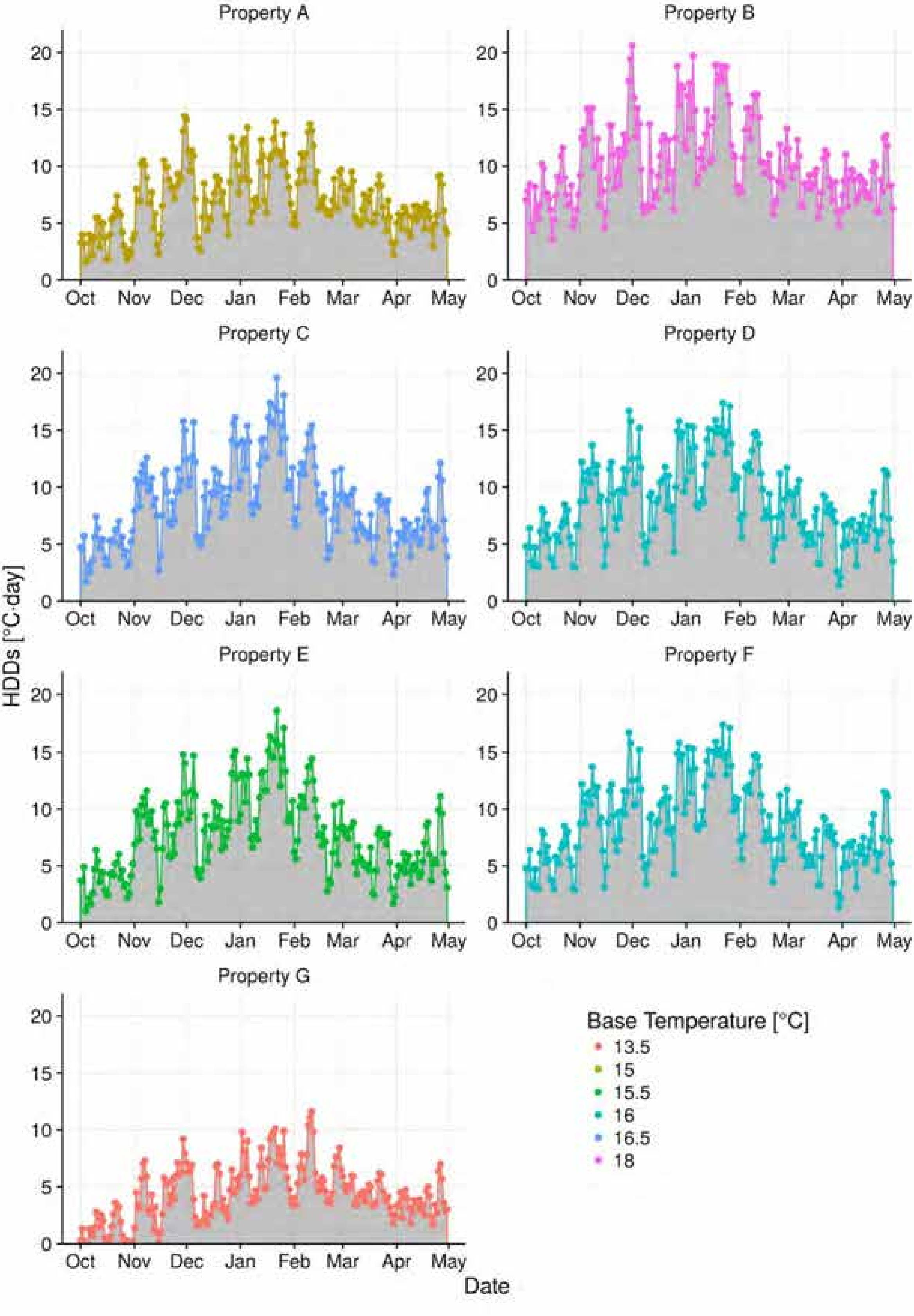


*Figure 13. Daily HDDs as generated by the online tool.*

## 8.5 Electricity Monitoring

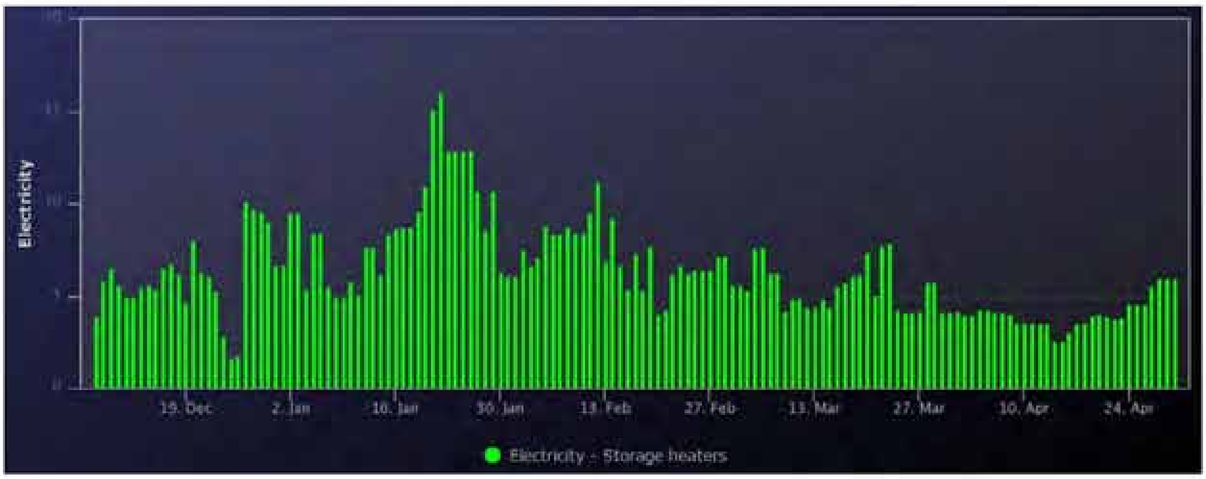


*Figure 14. Screen shot of daily electricity consumption [kWh] over time, as displayed on the Energy Platform. Sample taken from a single property.*

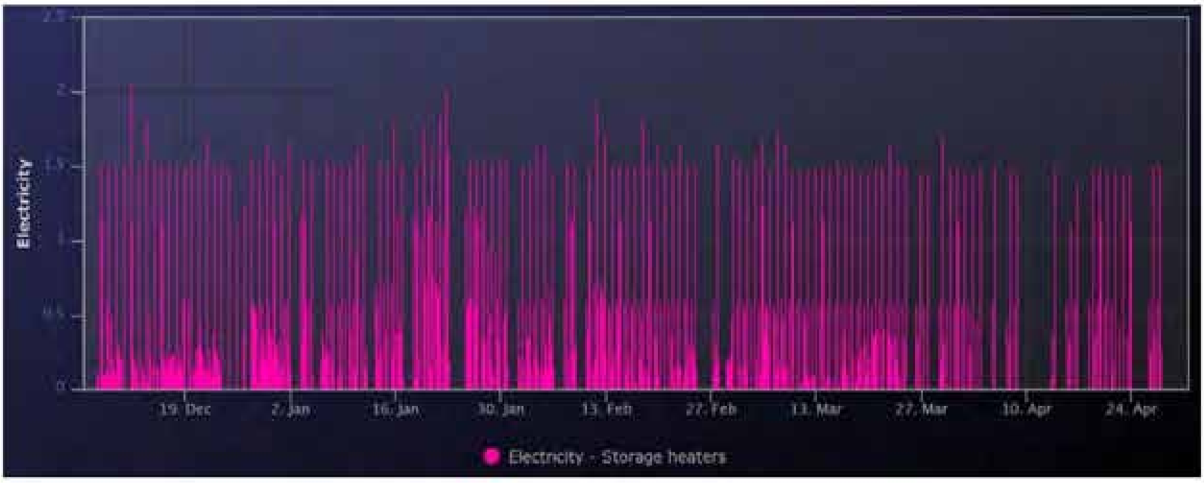


*Figure 15. Screen shot of half-hourly electricity consumption [kWh] over time, as displayed on the Energy Platform. Sample taken from a single property.*

# 2 Introduction

## 2.1 Background to EST

The Energy Saving Trust (EST) is the UK's leading independent and impartial organisation in the domestic energy sector. Our internationally renowned services are underpinned by the very best evidence, research and evaluation, and delivered by highly skilled and experienced specialists in the field. We have an outstanding track-record of delivery, whether leading programmes on behalf of UK-wide governments, the European Commission or working alongside businesses.

Our work includes delivery of large-scale household appliance testing and product standard-setting, verification and labelling schemes, water efficiency, low energy lighting and field trials with standard-setting for new and emerging renewable technologies. We administer multi-million pound grant schemes on behalf of governments for communities, businesses and households and undertake pioneering research that transforms how we can accelerate towards low-carbon living. We have built up a unique bank of insight, experience and best practice right across the domestic energy sector and continue in the evolution of our work.

EST offers a range of services relating to the evaluation and verification of the performance of energy efficiency and renewable technology. **EST Product Verification** is a bespoke service, designed to assist businesses in communicating the energy related and performance benefits of their products. The process involves the independent verification of a product's performance characteristics followed by the development of factual, informative, consumer-facing claims for use in promotional marketing materials.

## 2.2 Overview of the Field Trial

A field trial was designed to quantify the Fischer System within domestic properties, and to compare its performance against that of existing traditional storage heating systems. Air temperature and electricity consumption data were monitored to analyse the systems in terms of their operating times and responsiveness, their energy consumption and cost, and the levels of internal comfort that they generated. A householder survey exercise was also conducted, aimed at gauging householders' satisfaction with the heating systems.

A sample of seven households with electric storage heating systems was selected to participate in the field trial. Five of these households operated an old traditional storage heating system that the householders had decided to replace with a Fischer System. The remaining two households had been fitted with a Fischer System before the beginning of the trial. A smart electricity meter was installed in each property which measured the electricity consumption of the storage heater system circuit. Six temperature loggers were also fixed at different locations within the property. Monitoring of electricity consumption and air temperatures began in October 2016. The five households with old heating systems had a Fischer System installed in late December 2016 and early January 2017. Monitoring ran until the end of April 2017, after which the equipment was removed from the properties. In May 2017, householders were asked to complete a survey aimed at gauging their satisfaction with the Fischer System and their opinion on its performance, controllability, up-front and rolling cost, and capacity to generate internal comfort. Householders were offered a small financial incentive to participate in the trial.

## 2.3 The Fischer Future Heat Dynamic Storage Heating Technology

Fischer Future Heat manufactures, supplies and installs a range of electric heating solutions from water heaters and portable stoves to ceramic fireplaces and full-house storage heaters. The Fischer Future Heat Dynamic storage heating system, the subject of this field trial, consists of a series of individual free-standing, or wall- or caster-mounted heaters. The heaters consist of a 40 mm clay core, mixed with 45% aluminium oxide, enclosed in a powder-coated sheet-steel casing. The clay core is perforated and positioned close to the front panel of the heater, designed to maximise the quantity of heat directed towards the centre of the room.

The heaters store thermal energy when electricity is cheapest (i.e. during the off-peak hours of a time-of-use tariff such as Economy 7), and release the energy during the day as required. To maintain a comfortable temperature throughout a full 24-hour period, the system uses trickle charge to top up the storage outside of off-peak hours. A normal 13A socket is sufficient to handle the system's load.

The main advantage of the Fischer System is that each heater comes with a wireless room thermostat, which can be used in either automatic or manual modes. Allowing the user full control of timings and the target room temperature, the thermostat is designed to reduce energy consumption, and increase efficiency and comfort. Correct placement of the portable thermostat can avoid inaccuracies that result from integrated control panels, where the thermostat may too close to the heat source. Users can therefore position the thermostat according to their own comfort requirements, such as in the coldest spot within the room. A further smart Wi-Fi control affords users greater controllability via wireless devices such as a smartphone or tablet.

# 3 Monitoring Methodology

## 3.1 Electricity Monitoring

An ISKRAEMECO Mx382 GPRS smart electricity meter, as seen in Figure 1, was connected to the electric storage heating circuit in each property to monitor the electricity consumption of the heating system.


*Figure 1. ISKRAEMECO Mx38y type range[1].*

Electricity consumption data from the meter was bundled into two daily packets. The first packet contained the cumulative electricity consumption reading (available to the nearest 0.001 kWh). This data was provided as a daily value, calculated as:

$$E = \frac{E_n - E_{(n-1)}}{T}$$

where $E_n$ is the current day's reading and $E_{(n-1)}$ is the last available reading, and $T$ is the time in whole days between these two readings. The second packet contained 48 half-hourly readings (available to the nearest 0.01 kWh). Both packets were then sent by GPRS to the Energy Monitoring

[1] Image sourced from http://www.iskraemeco.com/en/portfolio/electricity-meters/residential-smart-meters/mx38y/

Platform, a platform created and managed by Energence Ltd. for storing and visualising energy data. Screenshots of the Energy Monitoring Platform are included for illustrative purposes in the Appendix (see Figure 14 and Figure 15 in Section 8.5).

## 3.2 Temperature Monitoring

Householders were sent an envelope containing six self-adhesive Tinytag temperature loggers (manufactured by Gemini Data Loggers UK) (see Figure 2), and were instructed to fix these to the wall at defined locations at their property, in the master bedroom, hall, main living room and outside the property. The locations are detailed in Table 1. The three living room loggers were positioned in a "vertical" orientation, at floor-, mid- and ceiling-level, as depicted in Figure 3. The loggers were already operational and required no activation by the householders. Readings (available to the nearest 0.001°C) were logged at 15-minute intervals over the trial period, and the loggers were returned at the end of the monitoring period.


*Figure 2. Tinytag temperature logger and associated software (Gemini Data Loggers UK)[2].*

[2] Image sourced from http://pressreleases.responsesource.com/news/50625/tinytag-data-loggers-join-the-energy-saving-trust-on-energy/

| Location | Value |
|---|---|
| Outside in a shaded position on the external surface of the property | $T_O$ |
| Hallway at mid-level | $T_H$ |
| Living room at floor level | $T_{L1}$ |
| Living room at mid-level | $T_{L2}$ |
| Living room at ceiling level | $T_{L3}$ |
| Master bedroom at mid-level | $T_B$ |

*Table 1. Locations of the six temperature loggers.*

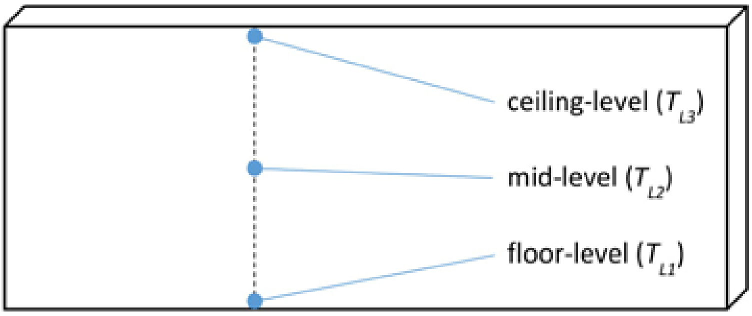


*Figure 3. Position of the three living room temperature sensors.*

## 3.3 Monitoring Milestones

Of the seven participating properties, five (labelled A-E) operated with an old storage heating system, and were monitored for both Phase One and Phase Two. The remaining two properties (labelled F and G) had already been installed with a Fischer System before the beginning of the trial, and were monitored for Phase Two only.

Temperature monitoring began in early October 2016 for properties A-E. Daily electricity consumption monitoring began in late October with the installation of the electricity meters. Half-hourly electricity consumption monitoring began mostly in Phase Two of the trial, except for Property E, where half-hourly data was available for some of Phase One also. Properties F and G joined the trial later, with monitoring beginning in November and December. A breakdown of the monitoring and installation milestones can be seen in Table 2.