Fact HP

Final Data Analysis Report

Lead Organisation: Limerick Institute of Technology (LIT)
Prepared By: Padraic O'Reilly, Michael O'Shea, Stephen Murphy, and Christopher Costello

15th December 2020

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Abbreviations

ASHP	Air source heat pump
BER	Building Energy Rating
COP	Coefficient of Performance
DEAP	Dwelling Energy Assessment Procedure
DHW	Domestic hot water
GSHP	Ground source heat pump
IQR	Inter Quartile Range
PV	Photovoltaic (Solar Panel Array)
Q1	Quartile 1
Q3	Quartile 3
SEPEMO	Seasonal PEformance factor and Monitoring for heat pump systems in Building sector
SH	Superhomes
SH20	Superhome 2.0
SPF	Seasonal performance factor
WP	Work Package

Executive Summary

D4.1 of the FactHP Project presents analysis of datasets created from the monitoring of 36 heat pump systems and 5 PV systems in dwellings in Ireland. This analysis seeks to answer the question if it is necessary or appropriate to apply an "in-use" factor to the use of Heat Pumps in relevant Compliance Tools in Ireland e.g. the Dwelling Energy Assessment Procedure (DEAP).

1.0 Introduction

This document provides an overview on how data on the predicted and monitored performance of heat pumps in dwellings was collected and managed.

Analysis starts with a combined approach, where space heating and DHW are considered together. From the metering perspective, this approach allows for inclusion of the greatest number of test sites and analyses thermal energy produced and annual SPF, the two factors that are predicted by DEAP. The predicted electrical energy consumed by heat pumps is calculated within DEAP based on its predictions for the first two factors. This report compares predicted heat energy and calculated electrical energy to measurements of overall heat energy produced and electrical energy consumed using heat and electrical meters, and also compares the overall SPF calculated from DEAP's predictions to SPF calculated from site measurements.

A subset of the monitoring and data collection systems employed in FactHP allowed for separate analysis of space heating and DHW modes of heat pump operation. Considering that DEAP makes the core predictions addressed in this study at this operating mode level, availability of this data allows for specific comparison of predicted and measured performance of:

- Thermal energy produced for space heating – a check on the calculations for annual space heating required by the building and on heat pump performance;
- Space heating annual SPF;
- Thermal energy produced for DWH – a check on predicted energy for hot water use and the performance of the heat pump;
- DHW annual SPF;

Finally, for a smaller subset of houses, data was available from PV systems, allowing for comparison between predicted and actual performance.

Previous reports from FactHP which would provide useful background information are D1.1- Building identification report, D2.1-Meter installation report and D3.1-quality Analysis Procedures report.

2.0 Key Project Goals

Arising from the RD&D Topic 6 in 2018 which set out to determine if an "In-Use" factor should be applied to the use of Heat Pumps in DEAP, 3 key goals were identified at the start of the project. These informed the strategy for gathering and subsequent analysis of data. The goals were:

1. Assemble a group of participants willing to have the performance of their heating and PV systems monitored and compared to the predictions of DEAP. Where metering was not already in place, procure and install suitable monitoring systems and develop data reporting systems. For all monitored systems, collect and carry out robust quality checks on predicted ad monitored data and create a repository and management system for this data.
2. Complete analysis of the data to identify and describe any performance gaps between predicted and monitored energy performance arising from DEAP predictions of thermal requirements for space and hot water heating, heat pump SPF and PV electrical output.
3. Determine if an "In-Use" factor should be applied to the use of Heat Pumps in relevant Compliance Tools in Ireland e.g. the Dwelling Energy Assessment Procedure (DEAP).

3.0 Outline of Data Collection process

The DEAP process provides a prediction of *annual* space heating and DHW performance and so 12-months of operational data was sought for each of the observed systems in this study. Buildings were located in the Southern half of Ireland spread across counties Tipperary, Cork, Kerry, Waterford, Kilkenny, Wexford and Dublin. Monitoring took place over the period April 2019 – October 2020.

Electrical and heat meters were installed to capture the energy within the SPF_{H4} boundary (SEPEMO). Thus energy used by electric immersions for DHW was captured. Heat meters fell within accuracy Class 3 or better as defined in Annex MI-004 of the UK MID & Electrical meters fell within accuracy Class A or better as defined in Annex MI-003 of the MID. Details of the building identification work can be found in report D1.1 while D2.1 is a report on the meter installation process.

At the end of the building identification and meter installation phases, 42 buildings were included for observation. Over the course of the data collection phase, QC checks on data from sites revealed a variety of issues, some of which could not be overcome within the scope and timeframe of this project. Thus the initial number of 42 sites was reduced to 36. The study group consisted of 9 makes of heat pumps, 6 GSHP and 30 AHSP. 28 buildings had undergone deep retrofit, 1 shallow retrofit while 6 had heat pumps fitted as new builds. Appendix A presents the HP system information, Appendix B contains the 12-month predicted and Appendix C contains the monitored energy performance dataset for each of these houses.

In addition to heat and electrical meters, most of the observed houses had an associated data logging and reporting system. Some of these systems were in place prior to this project, had been extensively used and tested in previous projects and, while requiring considerable input from the FactHP team to ensure that they remained operational, were quite reliable. For this group of systems it was possible to identify separately the data associated with space heating and DHW operating modes. All of these systems were houses that had gone through a deep retrofit including ASHPs.

FactHP undertook to identify a new group of houses for monitoring purposes and to source and implement independent monitoring systems for these systems. Within the scope of the project, it was not possible to produce monitoring systems that could separate space heating from DHW mode data. Instead, available budget was used to install combined monitoring systems to as many houses as possible. The implementation of the associated reporting systems on these LIT monitored sites met with varied success. A variety of issues from internet security to meter configuration meant that remote reporting and data logging was partially successful. Nevertheless, all of these systems provided periodic and final data from meter readings from site. This group of systems included ASHPs & GSHPs and included new builds and retrofits. This was compounded with challenges caused by COVID where visits to homes had to be restricted/eliminated.

PV data was obtained from 5 houses by logging into the monitoring web platforms of the inverter manufacturers.
DEAP dwelling reports and heat pump tools were provided by the homeowners and/or their BER assessors. The relevant pieces of information were collated for further quality checks prior to analysis.

4.0 Outline of Data Analysis process

For each house, the predicted data for thermal energy required for space heating and DHW, along with the associated SPFs was acquired from DEAP documentation. This data was checked to ensure consistency between the dwelling report and the heat pump tool. Where discrepancies were found, they were corrected with a detailed note created on the nature of the required amendment.

DEAP calculates the theoretical thermal energy required for space heating and DHW as two separate modes using different calculation methods. In the heat pump tool, manufacturer's data for the specific heat pump to be used at the house is inputted to arrive at separate predicted SPFs for space heating and DHW. In order to allow for comparison with monitored systems that could not separate space heating and DHW modes, comparison of thermal energy produced was possible by adding the predicted annual totals together and comparing this amount to the heat meter reading for 12 months. For comparison of SPF in these cases, a value for predicted combined SPF was arrived at using the following formula:

Equation 1 Predicted Combined SPF

$$SPF_{Combined} = \left(\frac{sum\ of\ DEAP\ Space\ heat\ and\ DHW\ produced\ energy}{sum\ of\ DEAP\ Space\ heat\ and\ DHW\ Consumed\ energy}\right)$$

Section 5 of this report is focused on the largest group of houses, providing the high-level overall data for space heating and DHW modes and includes both air and ground source heat pumps, new build and retrofit dwellings. In sections 6 & 7 of this report the overall group is reduced to the systems that could provide separated monitored data for space heating and DHW. This group provides a further narrowing of focus in that all heat pumps are ASHP and all houses underwent deep retrofit. Having separate data for space heating and DHW also allowed for the data to be normalised, per square meter in the case of space heating and per occupant in the case of DHW. Section 8 presents and discussed a comparison of predicted and monitored data for 5 PV systems.

5.0 Combined Space heating and DHW

This section describes the comparison of predicted and actual performance for space heating and DHW combined and for the entire study group including AHSPs and GSHPs.

5.1 Thermal output

Figure 1 shows the spread of results for the comparison of predicted and actual combined heat energy produced. The distribution is slightly biased toward under prediction in that 21 of the buildings are above the line with 13 below meaning 21 systems produced more thermal energy than DEAP predicted. However, there is a significant cluster in the centre of the graph which is further demonstrated in figure 2 where the Interquartile Ranges (IQRs, also called the mid-spread, middle 50%) of the predicted and actual data overlap, with a slightly larger range for the predicted data.

The variation in mean combined thermal output was -8% showing that on average, overall consumption was 8% higher than the combined values thermal output for space heating and DHW predicted by DEAP.

Thermal energy prediction calculations are based on the expected heat loss from the building due to fabric and infiltration losses plus, in this instance, the thermal requirements for DHW based on number of occupants.

There is a significant range from Min to Max which is reflective of a wide range of building sizes in the study from 80m^2 to >300m^2. The variation at the lower end was significant at 47% underestimation of energy required while the dwelling with the highest predicted value of 26,983kWh had actual consumption of 19,856, an overestimation of 27%.

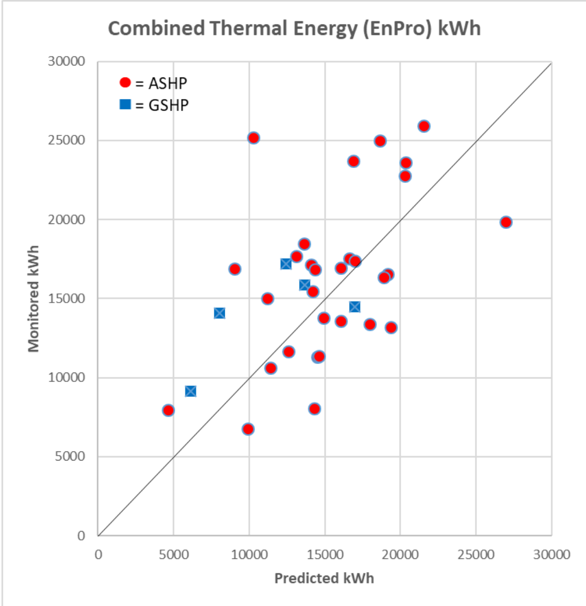

Figure 1 Combined Thermal: Energy Scatter Plot

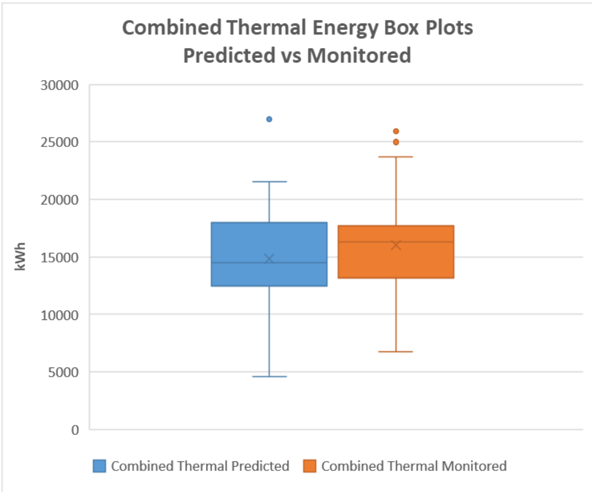

Figure 2 Combined Thermal: Energy Box Plot

Table 1 Combined Thermal: Thermal Output Comparison

	Combined Thermal Predicted	Combined Thermal Monitored	% Diff. between Predicted and Monitored
Min	4,605	6,775	-47%
Q1	12,530	13,303	-6%
Median	14,506	16,345	-13%
Q3	17,484	17,610	-1%
Max	26,983	25,930	4%
Mean	14,858	16,018	-8%
Range	22,378	19,155	14%
IQR	4,954	4,308	13%

5.2 SPF

The vast majority of systems had overall annual SPF within the range 250 – 400%. Furthermore, the values for Q1 & Q3 for predicted and actual SPF were in very close agreement with only +1% and -5% variations, respectively.

The mean combined measured SPF was 322% compared to a predicted 314% and this generally positive trend in relation to actual SPF is seen in the higher Min and Max figures and the wider IQR and higher value for Q3 at 473% compared to 379%.

Of the 5 GSHPs presented, 3 had better than predicted SPFs, one dramatically so as shown in figure 3. The other 2 GSHP SPFs were slightly lower than predicted. For the outlier with SPF in excess of 450%, DHW constituted the majority of the predicted thermal load at 5,177kWh vs 995kWh for space heating with predicted SPFs of 215 at 504, respectively. It was not possible to separate the space heating and DHW data for this system. In reality, the total thermal output from this system was 9,117 (see Figure 1) so it appears that a greater quantity of space heating was required and so more time was spent operating at the higher space heating SPF.

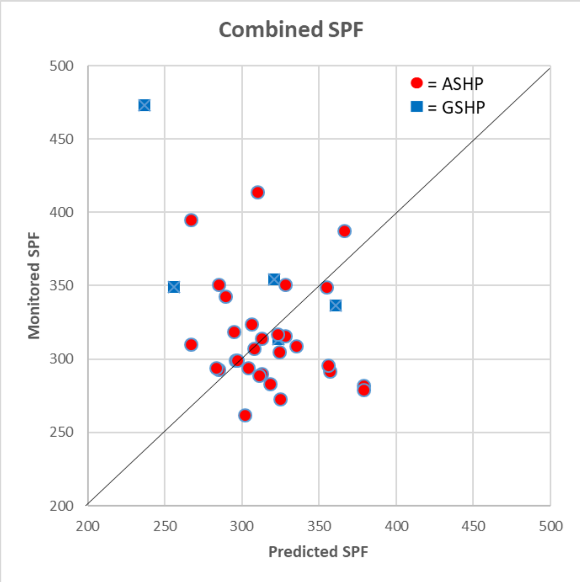

Figure 3 Combined Thermal: SPF Scatter Plot

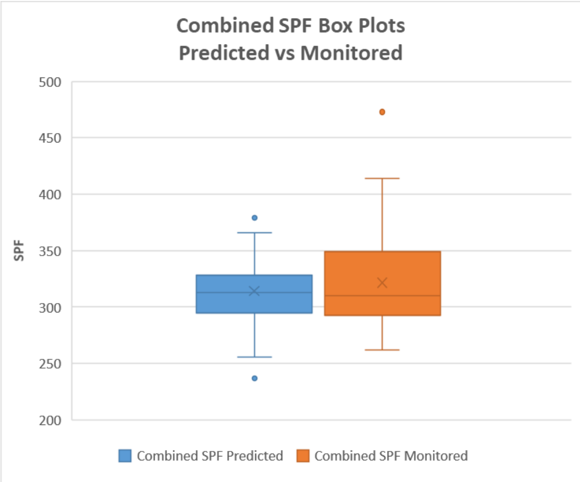

Figure 4 Combined Thermal: SPF Box Plot

Table 2 Combined Thermal: SPF Comparison

	Combined SPF Predicted	Combined SPF Monitored	% Diff. between Predicted and Monitored
Min	237	262	-11%
Q1	295.5	294	1%
Median	313	310	1%
Q3	328	346	-5%
Max	379	473	-25%
Mean	314	322	-2%
Range	142	211	-49%
IQR	32.5	53	-62%

5.3 Energy consumed

In DEAP, energy consumed prediction is derived from earlier estimates of thermal load and SPF. This section presents the metered data for comparison.

Figure 5 shows a significant range of values for kWh energy consumed and that there is a close match between predicted and measured values.

The IQR for both sets of data is similar with only a 5% variation.

The majority of systems in Figure 5 cluster in the region between 4,000 and 6,000kWh where the mean value for electrical consumption was 4,982kWh compared to a predicted value of 4,726, a difference of only 5%.

The methods for predicting annual thermal energy requirements for space heating and DHW are very different. So too are the methods used in the heat pump tool for determining the SPF for each mode. This first section of analysis presents overall data due to the fact that 11 out of the 36 systems monitored provided combined data only.

The next sections of analysis will focus on systems that had the capability to separate this data by operating mode.

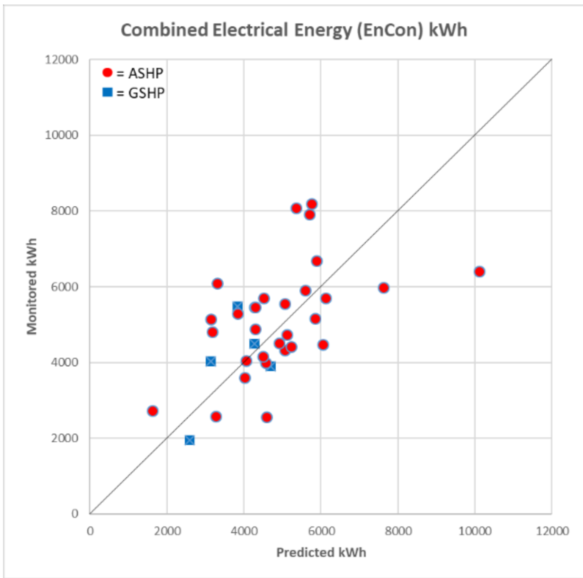

Figure 5 Combined Thermal: Electricity Energy Scatter Plot

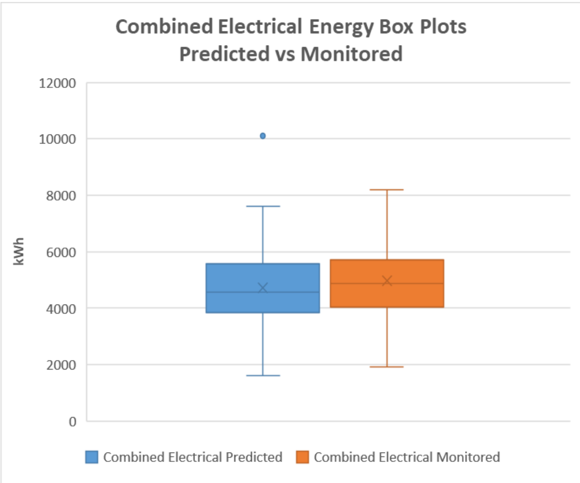

Figure 6 Combined Thermal: Electricity Energy Box Plot

Table 3 Combined Thermal: Electricity Comparison

	Combined Electrical Predicted	Combined Electrical Monitored	% Diff. between Predicted and Monitored
Min	1,617	1,928	-19%
Q1	3,936	4,105	-4%
Median	4,568	4,885	-7%
Q3	5,467	5,707	-4%
Max	10,108	8,197	19%
Mean	4,726	4,982	-5%
Range	8,491	6,269	26%
IQR	1,531.5	1,602	-5%

6.0 Space Heating Only

6.1 Thermal Output

Figure 7 shows the comparison of predicted and actual thermal output required for space heating for 26 systems. This comparison is essentially a check on the accuracy of the DEAP system for estimating space heating for the main heating system of the dwelling. In most cases, a secondary heating system was noted as being present in DEAP, but no data was available regarding the use of these systems.

The plot shows that the dots are generally close to the diagonal line where predicted = monitored but there is a trend toward the upper region of the graph indicating that actual thermal energy was generally higher than what was predicted. This is borne out by the fact that the mean value for predicted thermal energy for space heating was 11,624kWh while the mean measured value was 13,000kWh.

The scatter plot shows a concentration in the region of 10,000 – 15,000kWh which is again evidenced in the Q1 & Q3 values of the box plot.

The estimation of thermal energy used in a dwelling considers building fabric and air infiltration losses, but it also makes assumptions on how systems are controlled and how building users operate these controls. Instances were encountered during this project where houses were maintained at 21 and 22°C internal temperatures on a 24-hour basis which might explain some of the increased use with respect to predicted.

Of these 26 systems, 24 had a secondary heating system noted in DEAP. It is possible that these secondary systems were not used as much as was allowed for and that some of the underestimation of thermal energy for space heating could be accounted for in this way.

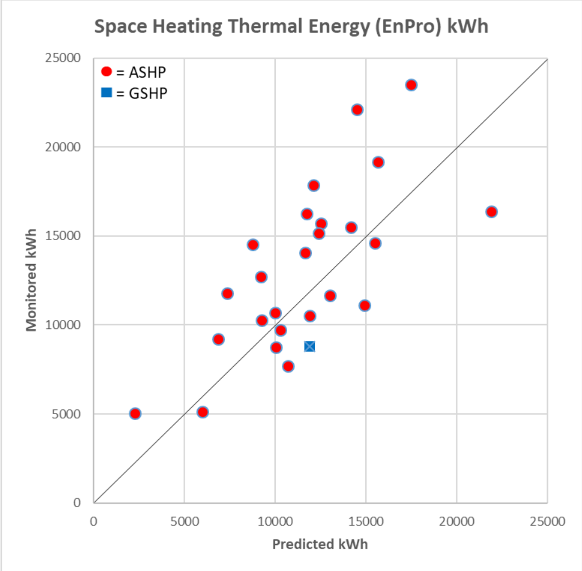

Figure 7 Space Heating: Energy Scatter Plot

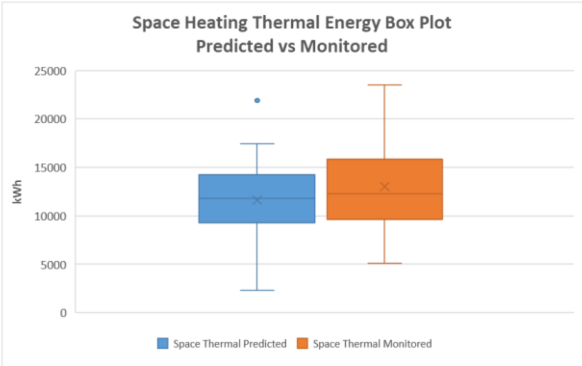

Figure 8 Space Heating: Energy Box Plot

Table 4 Space Heating: Thermal Output Comparison

	Space Thermal Predicted	Space Thermal Monitored	% Diff. between Predicted and Monitored
Min	2,302	5,059	-120%
Q1	9,462	9,857	-4%
Median	11,826	12,250	-4%
Q3	13,875	15,661	-13%
Max	21,900	23,524	-7%
Mean	11,624	13,000	-12%
Range	19,598	18,465	6%
IQR	4,413	5,804	-32%

6.2 SPF

Figure 9 clearly shows that space heating SPF was over-predicted for this group of houses. In only 3/26 cases did SPF equal or exceed the predicted value.

The bulk of the predictions were in the band between 350 and 400% while the bulk of the actual values existed between 300 and 350%.

The mean predicted value was 401 % while the mean actual value was 331% and the box plot clearly shows the shift downwards from predicted to the observed situation.

Some of the predicted values were in the range 450 – 520% which were significantly higher than the median value of 387% and which indicate a significant divergence between what was entered in the heat pump tool and what was ultimately commissioned.

This data suggests two areas for further investigation:

1. The main bulk of systems where the median predicted-observed SPF gap was 17%. It is possible that this gap could be reduced by improved commissioning set up and operating practices.
2. Outliers – there has been a significant breakdown between intended design and the installed & commissioned system.

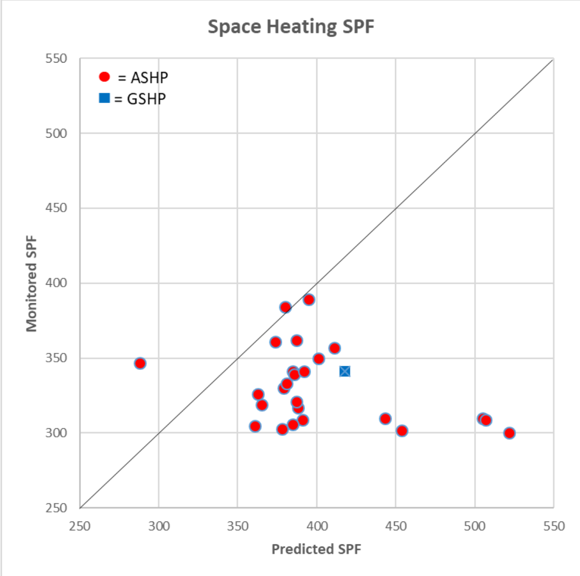

Figure 9 Space Heating: SPF Scatter Plot

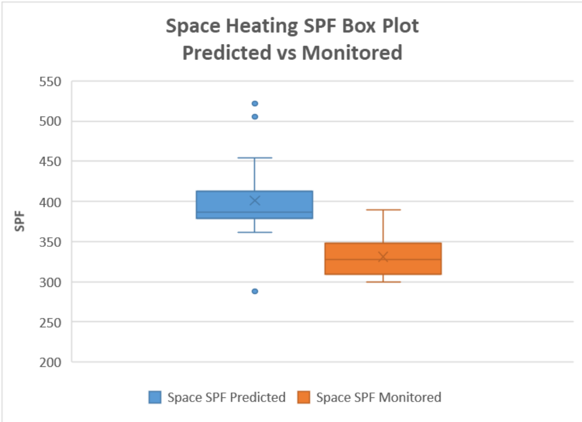

Figure 10 Space Heating: SPF Box Plot

Table 5 Space Heating: SPF Comparison

	Space SPF Predicted	Space SPF Monitored	% Diff. between Predicted and Monitored
Min	288	300	-4%
Q1	379	309	18%
Median	387	328	15%
Q3	409	346	15%
Max	522	389	25%
Mean	401	331	17%
Range	234	89	62%
IQR	29	36	-24%

6.3 Energy Consumed

Looking at energy consumed for space heating, the trend is clear – almost all systems consumed more energy that DEAP predicted they would, in some cases as much as twice as much. From the previous 2 sections, the trend has been that more thermal energy is used at a lower SPF than DEAP predicted and so when these two factors combine overall quantity of energy consumed increases.

The total energy consumed for this group of houses increased from a predicted 77,553 kWh to an actual 101,787 kWh, an increase of 24,234 kWh or 31%.

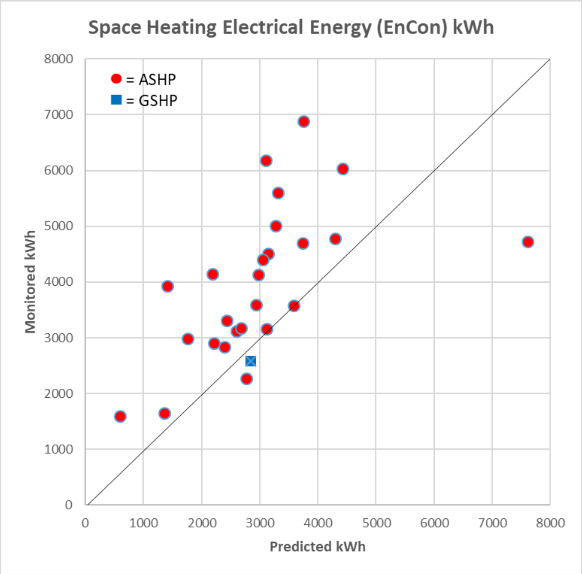

Figure 11 Space Heating: Electrical Energy Scatter Plot

6.4 Normalised space heating

The thermal energy data was normalised to account for the variation in house size with Figure 12 showing the resulting scatter plot. The picture is quite similar to that of figure 10 with a slight majority of entries above the diagonal.

The variation in the mean value is similar to that from section 6.1, -11% compared to -12%.

Figure 13 further breaks down this normalised data by BER rating. It should be noted that the different BER bands are not equally represented, the breakdown being as follows:

Table 6 BER rating Breakdown

BER rating	No. dwellings
A2	4
A3	17
B1/B2/B3	3/1/1

Looking at the IQRs for the A2 and A3 groups, the predicted and actual Q1 for both groups are similar while in both cases Q3 is significantly greater for the measured data showing the trend that the dwellings are using more thermal energy per square meter than DEAP had predicted. For the admittedly small sample of B rated dwellings, there is a wider band with significant overlap and instead the tendency is for the actual to fall below the predicted range.

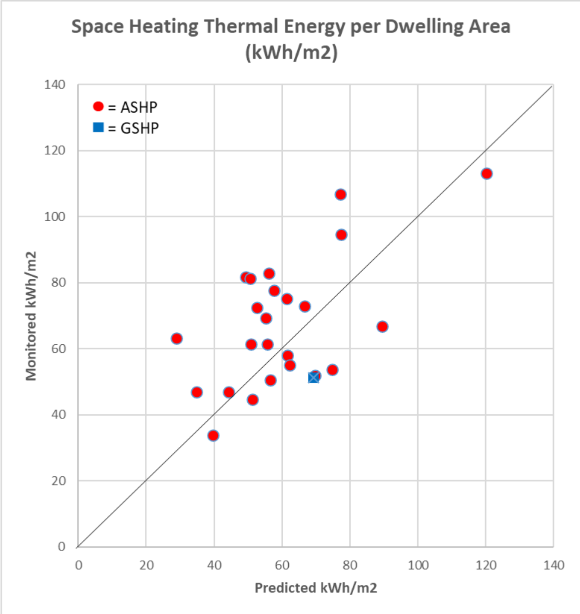

Figure 12 Space Heating: Normalised Scatter Plot

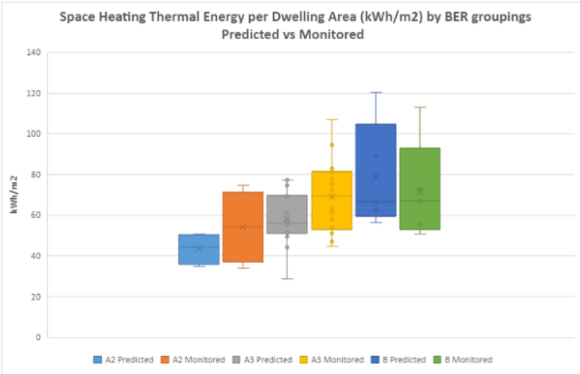

Figure 13 Space Heating: Energy per BER Rating Box Plot

7.0 DHW Only

7.1 Thermal Output

Figure 14 shows the comparison of predicted and actual thermal output required for DHW for 26 systems. The plot shows that the measured thermal energy used for DHW was considerably less than predicted by DEAP.

The box plot (Figure 15) shows that the two IQRs do not overlap, such was the variance between the two datasets. Median and mean values were very similar with mean predicted energy of 4,147kWh and mean actual energy of 2,044.

The following calculations are an estimate of the volume of hot water that could be attributed to these average thermal energy quantities.

Table 7 Domestic Hot Water: Calculations

	Predicted	Actual
Mean EnPro kWh	4,147	2,044
Less losses kWh	3,732	1,840
m3 / year	292.5	144.2
m3 / day	0.80	0.39
L/day	801.4	395.0
Mean occpancy	4.98	4.98
L / occupant	160.9	79.3

Normally heat pumps are controlled to maintain the temperature in the hot water cylinder at around 50°C, with periodic operation of electric immersion heaters used for legionella protection. In these situations, the temperature in the tank might be maintained within a range of 10-15°C. In the example above, a ΔT of 11°C is used.

The occupancy levels above are the average for all the houses as obtained from DEAP. The predicted daily quantity of 160 L/person, twice the amount calculated on the basis of actual DHW thermal energy.

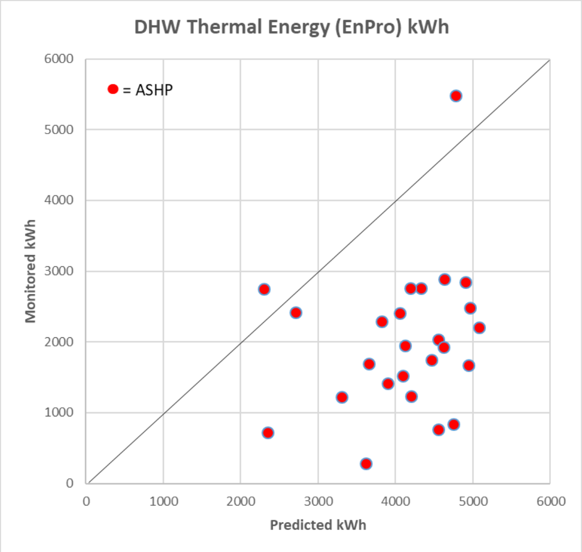

Figure 14 Domestic Hot Water: Energy Scatter Plot

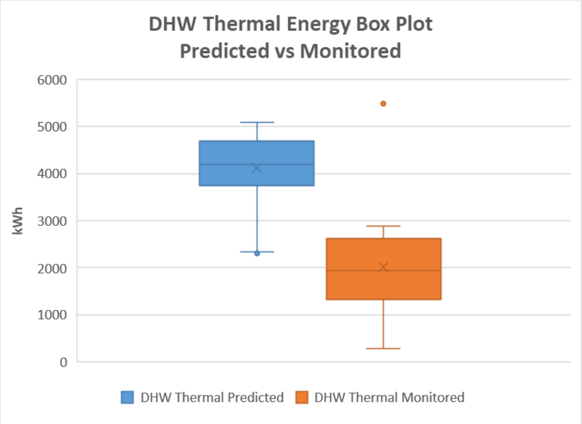

Figure 15 Domestic Hot Water: Energy Box Plot

Table 8 Domestic Hot Water: Thermal Output Comparison

	DHW Thermal Predicted	DHW Thermal Monitored	% Diff. between Predicted and Monitored
Min	2,303	278	88%
Q1	3,902	1,525	61%
Median	4,197	2,013	52%
Q3	4,631	2,482	46%
Max	5,083	5,484	-8%
Mean	4,147	2,044	51%
Range	2,780	5,206	-87%
IQR	729	957	-31%

7.2 SPF

As evidenced in figure 16, the DEAP estimate for DHW SPF for most of the systems in this group was around 200%. 4 had predicted SFP at around 250% and one outlier at 280%. The average predicted SPF was 207%.

With the exception of 3 systems, all observed SPF were equal to or better than the DEAP prediction with the average observed SPF being 243%.

Considering that all of these systems were ASHPs, it is possible that local temperature variations could be a factor influencing the variation in SPF. Other factors could be the design of the hot water tank heat exchanger and the design of interconnecting pipework.

The box plot of monitored SPF shows that the IQR was between 222 and 262% compared to the much narrower range of 200-207 for the predicted IQR.

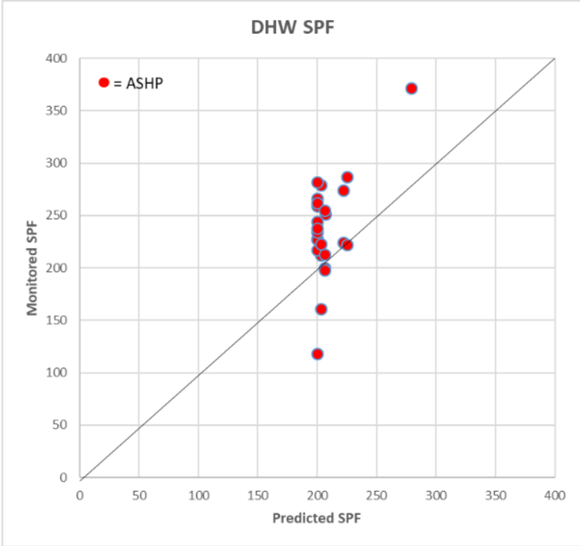

Figure 16 Domestic Hot Water: SPF Scatter Plot

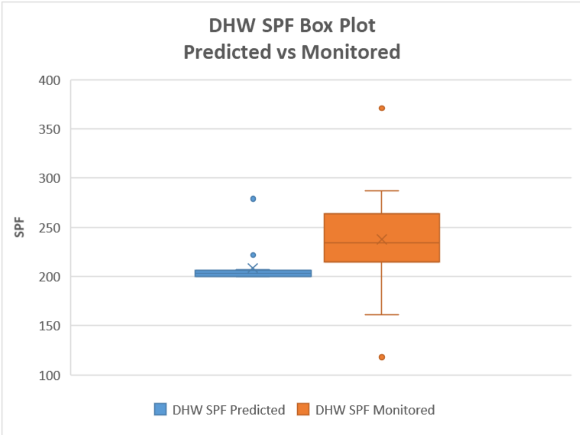

Figure 17 Domestic Hot Water: SPF Box Plot

Table 9 Domestic Hot Water: SPF Comparison

	DHW SPF Predicted	DHW SPF Monitored	% Diff. between Predicted and Monitored
Min	200	161	20%
Q1	200	222	-11%
Median	203	238	-17%
Q3	207	262	-27%
Max	279	371	-33%
Mean	209	243	-16%
Range	79	210	-166%
IQR	7	40	-471%

7.3 Energy consumed

Because of the much lower quantities of thermal energy produced and the trend for the DHW SPF to be higher than predicted, it is not surprising that there would be a significant gap between the predicted and monitored values for energy consumed in DHW mode. The scatter plot in figure 18 shows all bar 2 of the entries are below the diagonal while the IQRs on the box plots are very far apart.

The average energy consumed in DHW mode was less than half that predicted, 845 kWh against 1,999 kWh.

For the group of houses, the total predicted energy consumed was 49,651 kWh while in practice, a total of 21,304 kWh was monitored. This overestimation of 28,347 is large enough to mask the underestimate of 24,231 kWh for space heating for the same group of houses in section 6.3.

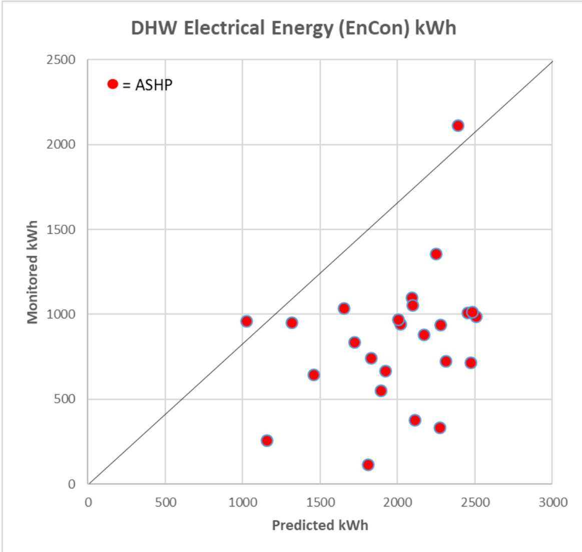

Figure 18 Domestic Hot Water: Electrical Energy Scatter Plot

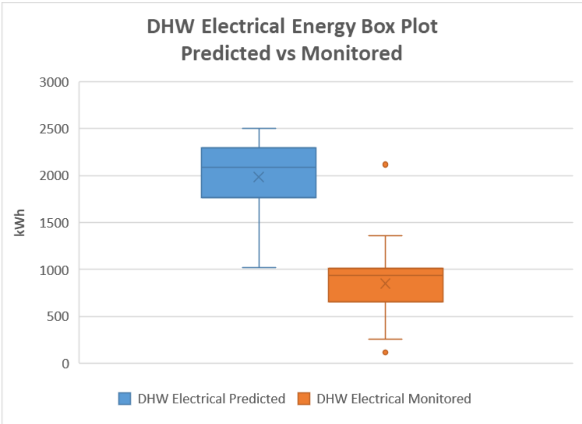

Figure 19 Domestic Hot Water: Electrical Energy Box Plot

Table 10 Domestic Hot Water: Electrical Energy Comparison

	DHW Electrical Predicted	DHW Electrical Monitored	% Diff. between Predicted and Monitored
Min	1,024	117	89%
Q1	1,828	668	63%
Median	2,091	882	58%
Q3	2,276	987	57%
Max	2,504	2,116	15%
Mean	1,999	845	58%
Range	1,480	1,999	-35%
IQR	448	319	29%

7.4 Normalised DHW

The number of occupants per house in DEAP ranged from 2.41 to 6.69. Figure PPP shows the DHW data normalised to show kWh thermal energy for DHW per occupant.

The trend is very similar to that of figure 20 in that a few outliers are close to the diagonal line but the majority are showing over prediction of thermal energy for DHW. The mean predicted value was 820 kWh per person per annum while the mean monitored value was 385 kWh.

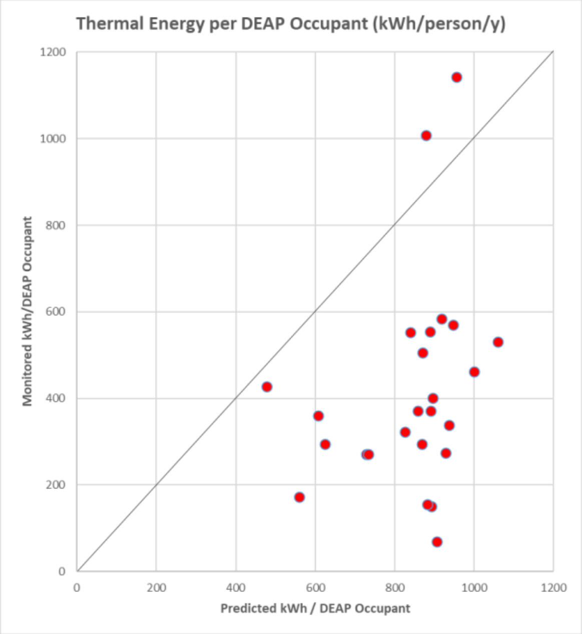

Figure 20 Domestic Hot Water: Normalised Usage Scatter Plot

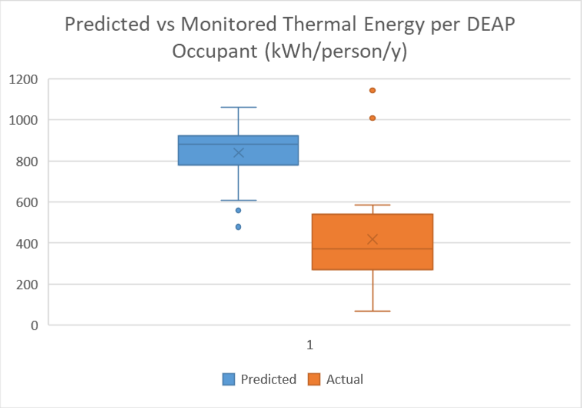

Figure 21 Domestic Hot Water: Normalised Usage Box Plot

8.0 PV

Comparison of PV system output was possible for 5 houses from this study group. There was a very strong correlation between predicted and monitored data with an R^2 value of 0.9851.

Monitored data was obtained from the PV inverter data logging systems and it tended to be slightly higher than DEAP's predictions.

3 of the systems were rated at 1.5kW peak, one at 2.2kW and the other system at 4kW. Figure 22 shows the grouping of the 3 smaller systems and the fact that the other two fit well to the correlation line.

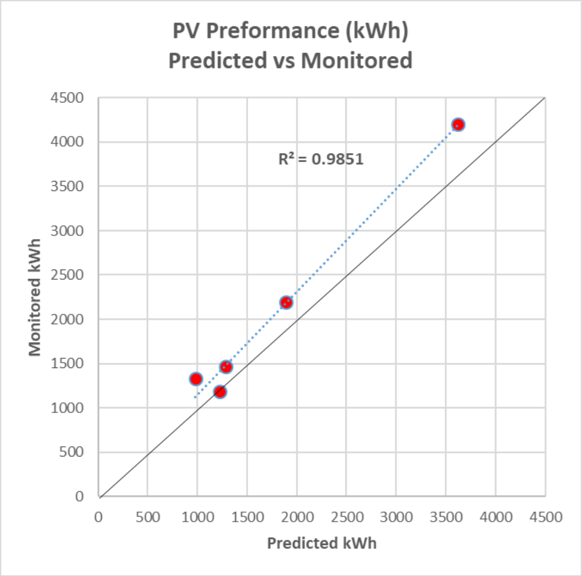

Figure 22 PV performance: Scatter Plot

9.0 Conclusions

The activities of this project were summarised in 3 main goals at the start of this report.

The first goal was to assemble a group of participants willing to have the performance of their heating and PV systems monitored and compared to the predictions of DEAP, install additional meters where required and to establish a robust system for collecting and managing this data. 42 dwellings went through the building identification and meter installation phases of the project. A wide variety of challenges were met along the way highlighting the fact that acquiring data of this quality is not an easy task. The challenges included time taken to engage with homeowners, BER assessors and installers, procurement lead times for monitoring equipment, configuration issues, internet safety issues and the costs associated with these issues. Once all of these issues had been worked through, the FactHP still had 36 heat pump systems and 5 PV systems gathering high quality performance data from the systems of very enthusiastic homeowners.

The second goal was to complete analysis of the data to identify and describe any performance gaps between predicted and monitored energy performance arising from DEAP predictions of thermal requirements for space and hot water heating, heat pump SPF and PV electrical output. Starting with heat pumps, the analysis sections of this report have shown that the first perspective can be the overall consumption and production, where space heating and DHW modes of operation are combined. This perspective showed that the 3 metrics used, thermal energy, SPF and electrical energy consumed were evenly distributed around the predicted values, roughly similar numbers of systems being under predicted and over predicted. The average predicted SPF for the 36 systems was 314% while the average monitored SPF was 322%, a difference of only 2%.

However, this picture masks some important differences that were only discernible through analysis of separate analysis of space heating and DHW modes of operation. This was made possible by the fact that 26 of the systems involved were equipped with a data logging system that allowed data to be filtered by operating mode. This analysis led to the following key findings:

1. In Space Heating mode, heat pumps produced an average of 12% more thermal energy than predicted.
2. Space heating SPF was 17% lower than predicted.
3. In DHW mode, heat pumps produced an average of 51% less thermal energy than predicted.
4. DHW SPF was 16% higher than predicted.
5. Looking at combined data for space heating and DHW modes led to a false picture of prediction matching measured performance. By chance in this case, the errors for both modes almost cancelled each other out.

For the 5 PV systems assessed in the project, the performance as monitored by the PV Inverters showed that on average, the systems produced 16% more energy than DEAP predicted.

The third goal was to determine if an “In-Use” factor should be applied to the use of Heat Pumps in DEAP. This report concludes that a single “In-use” factor would not be appropriate as the findings above show that such a calculation would need to take into account the 4 key parameters where monitored values varied from predicted values in different directions and magnitudes.

10.0 Recommendations

Monitoring of heat pumps should be seen as a critical activity in the coming years are there is likely to be a large increase in the number of installations and consequently a related increase in the use of electricity for space heating. In all things energy related, reducing demand should be the first step, followed by ensuring efficient use of energy thereafter. To do this, it is necessary to measure the use of heat and then calculate how efficiently that heat has been generated. Metering of heat produced by heat pumps is therefore a critical tool to ensuring heat pumps play the role expected of them in reducing heating related carbon emissions.

Observations and challenges arising during this project suggest the following key areas for future research:

1. Further monitoring and analysis work which provide more details on occupancy, internal temperatures, use of secondary space heating, metering the quantities of hot water used, all in conjunction with engagement with the developers of the DEAP software. The underperformance of SPF in space heating mode could be further investigated with greater information about emission system design and the control strategies employed.
2. A wider rollout of data collection and analysis to keep pace with the increase in installations. This must be adequately funded to allow for a high quality, manufacturer independent meters, data loggers and reporting systems.
3. Development of Manufacturer Independent data monitoring and collection systems for heat pumps where space heating and DHW modes can be analysed separately.
4. Research into data logging and transmission systems – ideally with 15 minute interval and that resistant to external interference.

Appendices

Appendix A – Dwelling Details

Dwelling ID	Dwelling Type	HP Type / Collector	HP Manufacturer	Heat Emitter Type
ACN029	New	ASHP	Thermia	UFH
ACN030	New	ASHP	CTC	UFH
ACR026	D Retrofit	ASHP	Nibe	Radiators
ACR027	D Retrofit	ASHP	Nibe	Radiators
ACR028	D Retrofit	ASHP	Panasonic	Radiators
ARS012	D Retrofit	ASHP	Mitsubishi	Radiators
ASR001	D Retrofit	ASHP	Mitsubishi	Radiators
ASR002	D Retrofit	ASHP	Mitsubishi	Radiators
ASR003	D Retrofit	ASHP	Mitsubishi	UFH + Radiators
ASR004	D Retrofit	ASHP	Mitsubishi	UFH + Radiators
ASR005	D Retrofit	ASHP	Mitsubishi	UFH
ASR006	D Retrofit	ASHP	Mitsubishi	Radiators
ASR007	D Retrofit	ASHP	Dimplex	UFH
ASR008	D Retrofit	ASHP	Mitsubishi	Radiators
ASR009	D Retrofit	ASHP	Mitsubishi	Radiators
ASR010	D Retrofit	ASHP	Mitsubishi	Radiators
ASR011	D Retrofit	ASHP	Mitsubishi	UF + Radiators
ASR013	D Retrofit	ASHP	Mitsubishi	Radiators
ASR014	D Retrofit	ASHP	Mitsubishi	Radiators
ASR015	D Retrofit	ASHP	Mitsubishi	Radiators
ASR016	D Retrofit	ASHP	Mitsubishi	Radiators
ASR017	D Retrofit	ASHP	Mitsubishi	Radiators
ASR018	D Retrofit	ASHP	Mitsubishi	Radiators
ASR019	D Retrofit	ASHP	Mitsubishi	Radiators
ASR020	D Retrofit	ASHP	Mitsubishi	Radiators
ASR021	D Retrofit	ASHP	Mitsubishi	Radiators
ASR022	D Retrofit	ASHP	Mitsubishi	Radiators
ASR023	D Retrofit	ASHP	Mitsubishi	Radiators
ASR024	D Retrofit	ASHP	Mitsubishi	Radiators
ASR025	D Retrofit	ASHP	Mitsubishi	Radiators
GCN031	New	GSHP Borehole	Heliotherm	UFH
GCN032	New	GSHP Borehole	Water Furnace	UFH
GCN033	New	GSHP Borehole	Danfoss	Radiators
GCN034	New	GSHP Horizontal	Smartheat	UFH
GCR035	HP Grant	GSHP Horizontal	Water Furnace	UFH
GCR036	S Retrofit	GSHP Borehole	Danfoss	Radiators

Appendix B – Predicted dataset

Dwelling ID	Predicted Space Heating Thermal Energy (kWh)	Predicted Space Heating Electrical Energy (kWh)	Predicted Space Heating SPF	Predicted DHW Thermal Energy (kWh)	Predicted DHW Electrical Energy (kWh)	Predicted DHW SPF	Predicted Combined Thermal Energy (kWh)	Predicted Combined Electrical Energy (kWh)	Predicted combined SPF
GCR036	8721	1848	472	3760	2000	188	12481	3848	324
GCR035	12926	2559	505	4089	2151	190	17015	4710	361
GCN034	11943	2857	418	0	0	0	0	0	0
GCN033	8784	1651	532	4948	2633	188	13732	4284	321
GCN032	3291	634	519	4778	2513	190	8069	3147	256
GCN031	996	198	504	5177	2406	215	6173	2604	237
ASR025	2302	593	388	2303	1024	225	4605	1617	285
ASR024	8773	2188	401	4328	2091	207	13101	4279	306
ASR023	6853	1753	391	4550	2270	200	11403	4023	283
ASR022	7357	1409	522	3818	1720	222	11175	3129	357
ASR021	11756	3143	374	2345	1155	203	14101	4298	328
ASR020	5991	1352	443	3902	1922	203	9893	3274	302
ASR019	15506	4295	361	3657	1828	200	19163	6123	313
ASR018	10023	2603	385	4900	2450	200	14924	5053	295
ASR017	12523	3047	411	4098	2019	203	16621	5066	328
ASR016	10309	2678	385	4197	1891	222	14506	4568	318
ASR015	12094	3314	365	4777	2389	200	16871	5702	296
ASR014	10037	2211	454	4551	2276	200	14588	4487	325
ASR013	12384	3276	378	4619	2309	200	17003	5585	304
ARS012	13014	3585	363	4939	2469	200	17953	6054	297
ASR011	21900	7604	288	5083	2504	203	26983	10108	267
ASR010	9237	2431	380	4962	2481	200	14199	4912	289
ASR009	10696	2771	386	3616	1807	200	14312	4578	313
ASR008	14162	3738	379	4744	2111	225	18906	5849	323
ASR007	17479	4425	395	4057	1456	279	21536	5881	366
ASR006	14524	3753	387	4122	2001	206	18646	5754	324
ASR005	15662	3101	505	4631	2248	206	20293	5349	379
ASR004	14901	2939	507	4464	2167	206	19365	5106	379
ASR003	11895	3122	381	4188	2094	200	16083	5216	308
ASR002	11640	2969	392	2712	1317	206	14352	4286	335
ASR001	9275	2396	387	3304	1652	200	12579	4048	311
ACR028	13132	3047	431	2939	1468	200	16071	4515	356
ACR027	16471	6123	269	3898	1499	260	20369	7622	267
ACR026	8961	1757	510	4688	2084	225	13649	3841	355
ACN030	6681	1730	386	3566	1576	226	10247	3306	310
ACN029	4809	1017	473	4240	2157	197	9049	3174	285

Appendix C – Monitored Dataset

Dwelling ID	Monitored Space Heating Thermal Energy (kWh)	Monitored Space Heating Electrical Energy (kWh)	Monitored Space Heating SPF	Monitored DHW Thermal Energy (kWh)	Monitored DHW Electrical Energy (kWh)	Monitored DHW SPF	Monitored Combined Thermal Energy (kWh)	Monitored Combined Electrical Energy (kWh)	Monitored combined SPF
GCR036	0	0	0	0	0	0	17152	5473	313
GCR035	0	0	0	0	0	0	14434	3891.7	336
GCN034	8789	2576	341	0	0	0	0	0	0
GCN033	0	0	0	0	0	0	15832	4476	354
GCN032	0	0	0	0	0	0	14053	4021	349
GCN031	0	0	0	0	0	0	9117	1928	473
ASR025	5059	1596	317	2753	960	287	7978	2727	293
ASR024	14533	4153	350	2756	1099	251	17681	5459	324
ASR023	9231	2988	309	766	336	228	10624	3609	294
ASR022	11789	3928	300	2294	836	274	15018	5144	292
ASR021	16268	4507	361	725	260	279	17150	4885	351
ASR020	5132	1653	310	1413	668	212	6775	2581	262
ASR019	14607	4785	305	1690	744	227	16548	5703	290
ASR018	10671	3126	341	2844	1009	282	13757	4318	319
ASR017	15718	4397	357	1525	946	161	17539	5558	316
ASR016	9724	3179	306	1236	551	224	11290	3990	283
ASR015	17866	5598	319	5484	2116	259	23682	7908	299
ASR014	8767	2906	302	2035	939	217	11360	4165	273
ASR013	15153	5008	303	1929	724	266	17367	5915	294
ARS012	11652	3574	326	1675	717	234	13408	4484	299
ASR011	16383	4723	347	2200	987	223	19856	6406	310
ASR010	12710	3306	384	2482	1016	244	15478	4512	343
ASR009	7683	2265	339	278	117	238	8070	2566	314
ASR008	15489	4694	330	837	377	222	16345	5164	317
ASR007	23524	6041	389	2406	648	371	25930	6689	388
ASR006	22110	6886	321	1948	972	200	25002	8197	305
ASR005	19152	6177	310	2890	1357	213	22776	8074	282
ASR004	11105	3596	309	1749	882	198	13197	4735	279
ASR003	10543	3165	333	2760	1055	262	13590	4424	307
ASR002	14075	4127	341	2424	951	255	16842	5451	309
ASR001	10257	2833	362	1221	1037	118	11678	4045	289
ACR028	0	0	0	0	0	0	16931	5711	296
ACR027	0	0	0	0	0	0	23620	5973	395
ACR026	0	0	0	0	0	0	18467	5299	349
ACN030	0	0	0	0	0	0	25207	6089	414
ACN029	0	0	0	0	0	0	16882	4814	351