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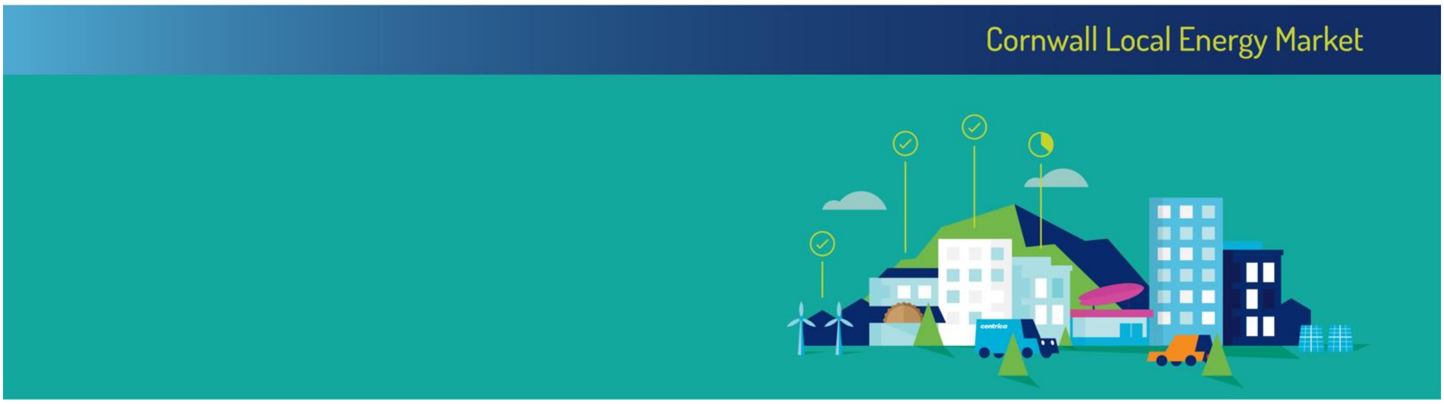

LEM Residential MetaData Summary Report

Cornwall Local Energy Market, Centrica plc

Prepared By:

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Revision Control

Rev No	Date	Edited By	Changes
0	2020-10-05	Andrew Peacock	DRAFT circulated to Dan Nicolls & David Parrish (Centrica) for review
1	2020-11-23	David Kane	FINAL version, released to Dan Nicholls & David Parish at Centrica

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Table of Contents

Executive Summary

This document summarises the metadata datasets available across the fleet, where the distribution of properties in the fleet is described using pertinent combinations of metadata. The limited correlation demonstrated in the results highlights the difficulty in using metadata to predict consumption, and makes the case for easy access to historic metering data.

A Data Dictionary describes the purpose of each column of each dataset, and the coverage of each metadata dataset is described; all datasets cover less than 100% of the fleet.

Household electrical consumption and Solar PV production data collected during the trial is compared with the data and estimates collected/made during questionnaires, surveys & design, in order to assess the effectiveness of Sizing Assumptions. The results reinforce the value of metering data and of effective survey to predict solar PV production.

1. Introduction

This document addresses metadata for the residential workstream of the Cornwall Local Energy Market [LEM] project, with several purposes;

- In the This document is intended for those who will analyse the performance data from the LEM residential workstream, in order to understand the associated meta data.

This document is accompanied by an appendix with charts exploring potential metadata correlations in the document titled *"LEM Residential Metadata Summary Appendix B Correlation Plots*", and an export of data in the document titled *"Tables of MetaData captured in "LEM Resi MetaData Tables.xlsx".*

This document is referred to by the document titled *"LEM Residential Data Dictionary".*

This document supports the analysis of site performance as presented in the document titled *"LEM Residential Fleet Self-Consumption Summary Report".*

This document complements the residential participants selection methodology captured in the document titled *"Selecting participating properties – methodology and outcome*".

- Data Dictionary & Coverage Summary section, metadata columns are described, and the coverage of metadata across the fleet is summarised
- In the Fleet MetaData Assessment section, the distribution of properties in the fleet is described using pertinent combinations of metadata
- In the
- Assessing Sizing Assumptions section, the consumption and production data collecting during the trial is compared with the data and estimates collected/made during questionnaires, surveys & design

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2. Data Dictionary & Coverage Summary

2.1 Overview

There are several metadata datasets available, based on the time & means of data collection, as follows:

1. **Household Information;** Detail of the household information recorded in the anonymised dataset
2. **Household Questionnaire;** completed by 66 of the 100 participants. This was created and administered by Centrica's LEM Residential Operations Team
3. **Desktop, Site Surveys, Installation & Total system costs;** completed by SunGift (Installation Contractor) on behalf of Sonnen (BESS Vendor) – *Install & BESS costs available for 71 sites; Total install & system (PV & BESS) costs available for 38 sites*
4. **Design & Installation Records**; completed by SunGift and - *results available for 71 sites*
5. **Summary of EPC data**; data retrieved from the EPC register[1] completed by TLC - *results available for 75 sites*

2.2 Household Information

Newsite (site ID)	Post Code
Numerical site identifier (1-100)	First section of the postcode

[1] EPC Register (England & Wales), https://www.epcregister.com/, accessed October 2020

2.3 Household Questionnaire

The datapoints collected during the original web questionnaire are presented in table below. This was created and administered by Centrica during the project.

Question	Response Field	Unit	Comment
Are you the person in your houshold who is responsible, either solely or jointly, for paying your gas or electricity bills?	Yes/No		
Payment Method	Direct Debit/On reciept of Bill		
Avg Monthly Electricity bill	Household estimate	£ per month	
Electricity Bills Shared	Yes/No		
Current Supplier	Company Name		
Installed Smart Meter	Yes/No		
No. Resident Adults (ages 16+)	Integer	No of Occupants	
No. Resident Adults (over 65)	Integer	No of Occupants	
No. Resident Children (under 16)	Integer	No of Occupants	
Does the household generally leave for work or school in the morning and come back in the evening during weekdays?	Yes/Often/Rarely/No		
Is there generally someone in the household at home all day during weekdays and weekends?	Yes/Often/Rarely/No		
Is there anyone in the home that requires a continuous electricity supply, for example, for medical reasons?	Yes/No		
Household Annual Income (£)	<16,0000; 16,001-25,000; 25,001-45,000; 45,0001-70,000; 70,001-100,000	£	
Property Type	Bungalow; Detached; Semi-Detached; Terraced; Other		
Approx Year of Build	Pre-1945; 1945-1980; 1980-2016; Brand New		
Property in Conservation Area	Yes/No		
If yes, what AREA and what TYPE ie. AONB / heritage etc.?	aonb; Conservation Area; Great Landscape Value; Heritage Area (PV already Installed); Worldheritage		
Property Heat Source	Main gas		
If you use an Economy 7 tariff, do you have an off-peak meter?	Yes/No		
If you use Electricity (Economy 7 tariff), do you have Electric Storage Heaters in your home?	Yes/No		
No. of Storage Heaters	Integer		
Have you already installed a renewable technology (eg. solar photovoltaics, wind turbine, air source heat pump, etc.) in your home?	Yes/No		
Renewable Source 1	Solar PV		
Renewable Source 2	Solar Thermal		
Renewable Source 3	Biomass Boiler		
Renewable Source 4	ASHP		
Renewable Source 5	GSHP		
Renewable Source 6	Diverter; HR; Immersion heater from PV; MVHR; Solar Space		
If yes, please confirm if your renewables were installed under G83 or G59?	Don't Know; G83		
When you installed your renewable energy technology, which of the following best represented your reason for doing so?	Free script		

Question	Response Field	Unit	Comment
Do you have (and use) the following electrical appliances in your home?	Fridge		Presence of text denotes ownership
Do you have (and use) the following electrical appliances in your home?	Freezer		
Do you have (and use) the following electrical appliances in your home?	Microwave		
Do you have (and use) the following electrical appliances in your home?	Oven		
Do you have (and use) the following electrical appliances in your home?	Toaster		
Do you have (and use) the following electrical appliances in your home?	Kettle		
Do you have (and use) the following electrical appliances in your home?	Dishwasher		
Do you have (and use) the following electrical appliances in your home?	Washing Machine		
Do you have (and use) the following electrical appliances in your home?	TV		
Do you have (and use) the following electrical appliances in your home?	Digital/Sky Box/ Apple TV		
Do you have (and use) the following electrical appliances in your home?	Game Console		
Do you have (and use) the following electrical appliances in your home?	Stereo		
Do you have (and use) the following electrical appliances in your home?	PC/Laptop		
Do you have (and use) the following electrical appliances in your home?	Tablet		
Do you have (and use) the following electrical appliances in your home?	Smart Phone		
Do you have (and use) the following electrical appliances in your home?	Hair Dryer		
Do you have (and use) the following electrical appliances in your home?	Hair Straightners		
Do you have (and use) the following electrical appliances in your home?	Vacuum		
Do you have (and use) the following electrical appliances in your home?	Other - Free Script		
Do you own / lease an electric vehicle (EV)?	Yes/No		
EV Vehicle Make	free Script		
What is the main uses for your electric vehicle?	Commuting		
What is the main uses for your electric vehicle?	Shopping		
What is the main uses for your electric vehicle?	Leisure		
Approx No. of trips per day	Integer		
Approx No.of trips per week	Integer		
Average Weekly Mileage in Electric Vehicle	Integer	Miles	
Do you have a dedicated charger for your electric vehicle (not a 3-pin plug)?	Yes/No		
Broadband Always On	Yes/No		
Broadband Download Speed	Integer	Mbps	
Broadband Upload Speed	Integer	Mbps	
Does your router have any Ethernet sockets?	Yes/No		
No. of Ethernet Sockets	Integer		
Do you already operate Powerline Ethernet adapters at your property?	Yes; No; N/A		
Do you already operate Powerline Ethernet adapters at your property?	Integer		
Which way does your roof face?	E/W; NE/SW; N;S; SE/NW; N/A		
Is your roof shaded, for example, from trees?	No;Some;N/A		

<table>
<tr><th colspan="2">Question</th><th>Response Field</th><th>Unit</th><th>Comment</th></tr>
<tr><td colspan="2">Do you have aÂ pitched roof?</td><td>Yes; No; N/A</td><td></td><td></td></tr>
<tr><td colspan="2">Does your property have a garage?</td><td>Yes/No</td><td></td><td></td></tr>
<tr><td colspan="2">If yes, will your garage accommodate a battery with the dimensions of (H)150cmÂ x (W)80cmÂ x (D)30cm?</td><td>Yes/No</td><td></td><td></td></tr>
<tr><td colspan="2">If you do NOT have a garage, will your property accommodate a battery with the dimensions of (H)85cm x (W)80cm x (D)30cm?</td><td>Yes/No</td><td></td><td></td></tr>
<tr><td rowspan="7">What are your motivations for participating in the Cornwall LEM project?</td><td>Environmental concerns</td><td>Rank using a scale of 1-6, 6 being high</td><td></td><td></td></tr>
<tr><td>Reduce bills</td><td>Rank using a scale of 1-6, 6 being high</td><td></td><td></td></tr>
<tr><td>To be part of an exciting Cornish project</td><td>Rank using a scale of 1-6, 6 being high</td><td></td><td></td></tr>
<tr><td>Interest in new technologies</td><td>Rank using a scale of 1-6, 6 being high</td><td></td><td></td></tr>
<tr><td>Reduce dependency on the grid</td><td>Rank using a scale of 1-6, 6 being high</td><td></td><td></td></tr>
<tr><td>Other</td><td>Rank using a scale of 1-6, 6 being high</td><td></td><td></td></tr>
<tr><td>If your answer above is other, please specify</td><td>Free script</td><td></td><td></td></tr>
<tr><td colspan="2">Is there anything that you would like to tell us about you and your property?</td><td>Free script</td><td></td><td></td></tr>
</table>

2.4 Desktop, Site Surveys, Installation & Total system costs

Survey description	data field	Description	Unit	Comment
Desktop Survey	Roof Orientation	orientation of elevation on which PV will be installed	N; NE; E; SE; S; SW; W: NW	Partial list - data available for 28 sites; data has been used for SAP analysis
	House Shape	physical description of house shape	script	
	Shading	description of possible shading	script	
	Nearby Power Lines	description of nearby powerlines	script	
Technical survey	Tech survey date	Date survey was undertaken	date	
	Size of PV installed (kW)	Size of PV system to be installed	kW	data for 45 sites
	Tech survey report issued		Y/N	Install process tracking
	Quote received		Y/N	
	Mobile signal at property		Y/N	
	Tech survey reviewed		Y/N	
	Offer issued to householder		Y/N	
	Offer accepted by householder	Date offer was accepted by households	date	
Sun Gift Installation Quotes	Daily Usage (kWh)	Estimated daily electricity demand	kWh	Partial list - data available for 70 sites
	Battery to be installed	Detail of BESS type and capacity to be installed in dwelling	9.43 OR 9.53; 5, 7.5; 10kWh	
	Cost of BESS	BESS Capital cost	£	
	Standard Parts and Labour	BESS itemised installation Costs	£	
	Neutral Blocks		£	
	Extra Cable and cable route materials		£	
	Powerline Adaptors		£	
	Data Cable Extras		£	
	Double Socket		£	
	LAN Switch		£	
	Additional travel over 125miles		£	
	Safe Access for Cable Routes		£	
	Installation and Commissioning of Independent Monitoring System	Independent monitoring system (IMS) install cost	£	
	Total Price (Excluding VAT)	Total install costs (BESS + IMS)	£	
	Install + BESS Cost (Ex. VAT)	Total system costs (BESS install + IMS install + BESS capital)	£	
	Additional Notes	Install notes	script	
	Additional Notes		script	
PV System Install Quote	PV System Size kWp	Size of PV system to be installed	kW	
	No. of Modules		Integer	
	Roof Orientation		N; NE; E; SE; S; SW; W: NW	
	Predicted Yield	Predicted annual electricity generation from PV system to be installed	kWh	

Survey description	data field	Description	Unit	Comment
	Mounting System		K2 or other	
	Scaffold Type	scaffold description	0; 1/1; 1/2; 1/3; 2/1; 2/2	
	Standard Parts Cost	Standard parts (PV installation) costs	£	
	Standard Install and Commissioning Cost	PV install and commissioning cost	£	
	Mounting System Additional Cost		£	
	Cable Additional Cost		£	
	Cable Materials Cost		£	
	Scaffold Additional Cost		£	
	Asbestos Slates		£	
	Other Costs		£	
	PV Instal Total (ex VAT)		£	
	Total Project Price (Ex. VAT)		£	
	Total Project price + BESS Cost (Ex. VAT)		£	
	Additional Notes		Script	

2.5 Design & Installation Records

Survey description	data field	Description	Unit	Comment
Installation	Size PV to be installed	Capacity of PV system to be installed on property	kW	Only refers to new PV systems being installed
	PV Elevation	Description of location on which PV will be installed	script	
	Size BESS to be installed	BESS size to be installed in property	kWh	
	Location of BESS	Description of BESS install location	script	
	AC/DC BESS	Type of BESS being installed	AC or DC coupled	
	IBOOST present	Whether IBOOST is present	Y/N	IBOOST diverts surplus PV to electric immersion heater
Information from Single Line Diagram Form	Length of AC Cable Required (m)		m	
	Length of Metering Required (m)		m	
	Length of Router Cbale Required (m)		m	
	Length of DC Cable (m)		m	
	Rating of DNO Cutout (Amps)		Amps	
	Rating of Main Switch (Amps)		Amps	
	Rating PV Circuit Board (Amps)		Amps	
	Henley Blocks Used		Y/N	
	Make of Main Switch		Script	Partial list
	Switch Model No.		Script	Partial list
	Make of PV CB		Script	Partial list
	CB Model No.		script	Partial list

2.6 EPC Data

Data Field Name	Description	Unit	Comment
Date of EPC	Date of EPC certification	date	Red indicates expired certificate (i.e. > 10 years old from 04/10/20)
dwelling type 1	dwelling form	detached; semi-detached; mid-terrace; end-terrace	
dwelling type 2	dwelling type	bungalow; house	
floor area	floor area	m^2	
walls	wall type;	script OR $W/m^2.K$	on more recent certificates U-values are specified rather than wall type
roof	roof insulation level;	mm OR $W/m^2.K$	on more recent certificates U-values are specified rather than insulation level
glazing	glazing type	single, partial double; mostly double;double;high performance	
heating type	type of prime mover and emitter (if not radiator)	script	
heating fuel	heating fuel	electric; mains gas; LPG; oil; coal; wood	
controls	type of heating control	script	
hot water	Description of hot water system		typically from the heating system
heat demand	Estimated heating demand	kWh pa	partial list - not included on all certificates
water heat demand	Estimated hot water demand	kWh pa	partial list - not included on all certificates

3. Fleet MetaData Assessment

3.1 Overview

The selection process for participating dwellings had a number of criteria that led to the final selection resulting in a cohort sample that was not representative of the Cornish nor English housing stock or householders. Two features of the process were instrumental in this; the first was that initial identification of participants was through open advertisement, with interested parties self-selecting for trial consideration. The subsequent process of identifying the 100 dwellings only permitted owner occupiers for participation. As a consequence a number of stock and household biases emerged, which are described in detail below. Participants were widely distributed throughout Cornwall (Figure 1).

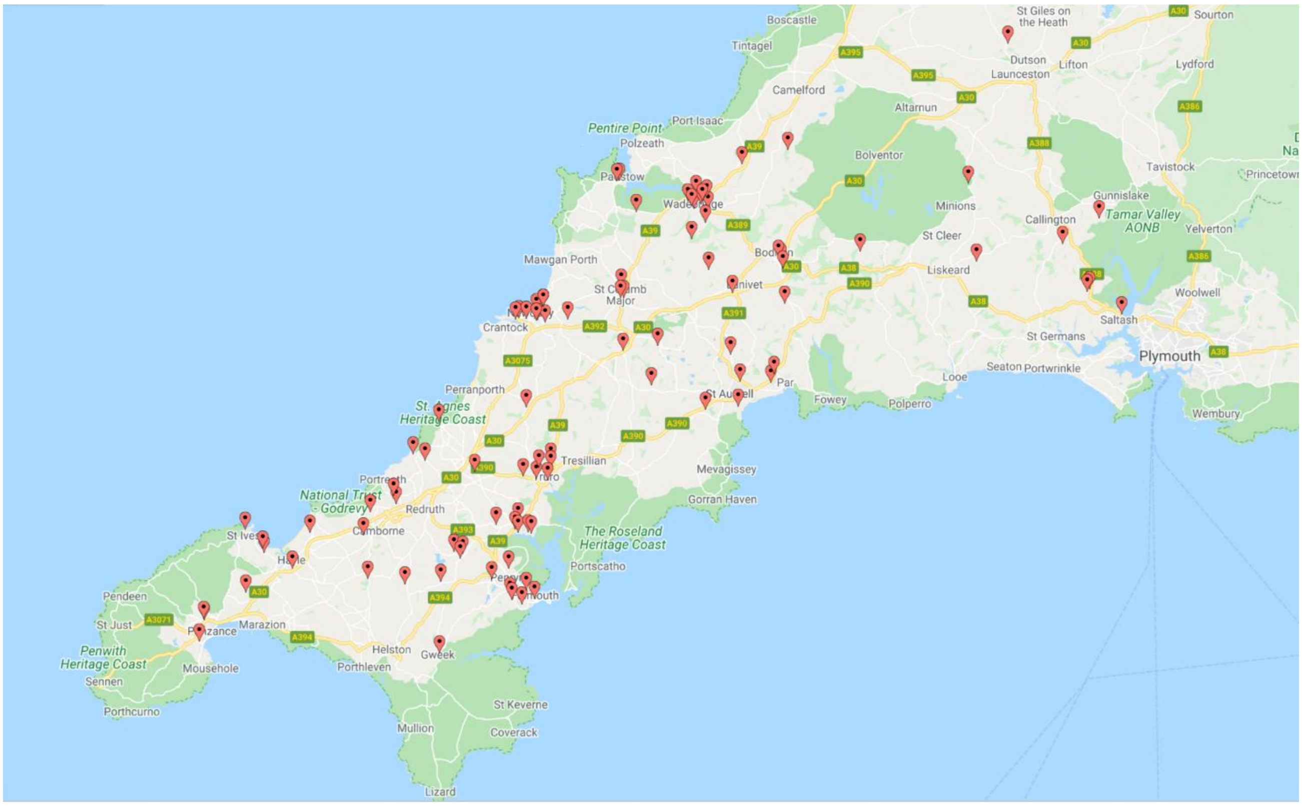

Figure 1: Locational map of participating dwellings

3.2 Building Characteristics & Stock Comparison

The participant dwellings were predominantly detached houses and bungalows, largely a function of the rural location of the trial, the requirement that only homeowners were allowed to participate and their attendant income levels. Across all house types (N=4) represented in the trial, floor areas were higher than English averages.

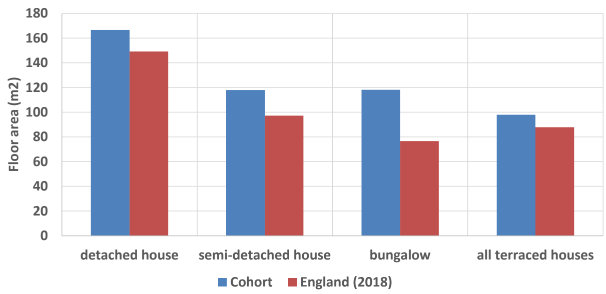

Fig 2: Floor area disaggregated by house type

The median floor area was 100-150m^2, retrieved from EPC data that was available for 83 of the 100 dwellings. Average floor area across all house types was 135m^2, compared to an average (excluding bedsits) for South-West England from the 2018/19 EHCS of 108m^2.

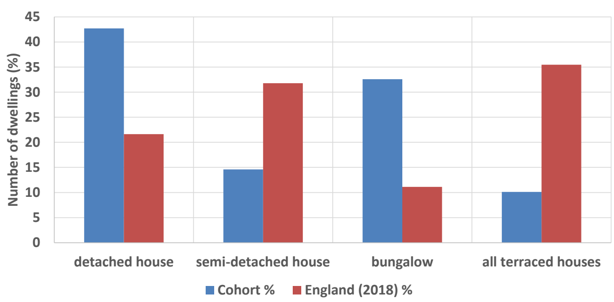

Fig 3: Proportion of house types compared to English stock

The age of the participating housing stock contained a lower proportion of pre-1945 dwellings and a higher proportion of dwellings built after 1981. The overall energy efficiency of these dwellings would therefore be higher than the stock at large, this being particularly relevant in this trial for dwellings using electricity as a heating fuel. The participating cohort could not therefore be viewed as being representative of the housing stock at large; all be it that this was not the intention of the initial household selection process.

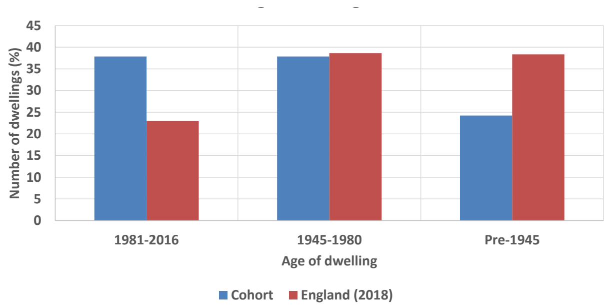

Fig 4: Age of stock; participating dwellings vs English Stock

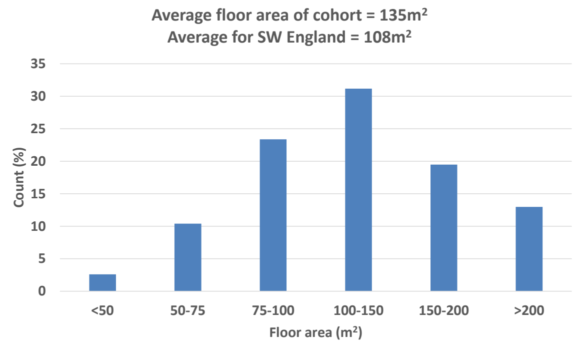

Fig 5: Floor area distribution

3.3 Heating Systems

3.3.1 Heating Fuel

In 2018, the proportion of dwellings that were connected to the gas network in Cornwall as a whole was estimated as being 53%[2]. The proportion of participating dwellings in the LEM residential trial who did not use mains gas as the fuel source of their primary heating system was found to be 49%, broadly in line with this 2018 estimate. Heating fuel used by dwellings not on the gas network was fairly evenly split between electric and oil, with smaller contributions from wood, coal and LPG.

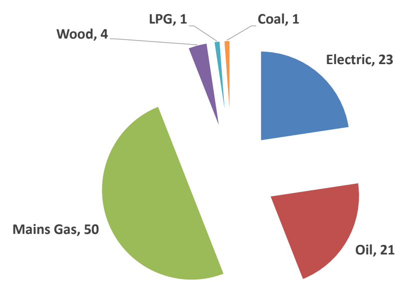

Fig 6: Heating fuel

3.3.2 Heating Systems

The predominant heating system found among the participating dwellings was the boiler. From a trial perspective, non-boiler heating systems act as a major load that may influence BESS performance. With electrified systems, space and water heating provision, either directly from the prime mover (in the case of a heat pump) or from immersion heaters (electric storage) ensures that a significant power and energy demand is present in the dwelling throughout the year. This is likely to ensure that the battery will be fully discharged before the on-set of any next day surplus ensuring BESS does not become saturated.

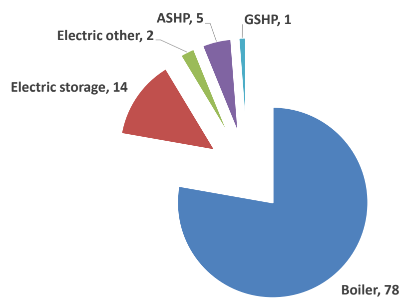

Fig 7: Heating system

3.4 All Major Loads

The monitoring infrastructure that was deployed as part of the trial was designed to provide an independent assessment of energy consumption and generation in each dwelling, including the operation of the battery. Consumption monitoring was designed to allow discrete data collection from major loads in the dwelling; recognising that the operation of these was likely to have a significant impact on consumption and on how the battery operated in self-consumption mode. Major loads were identified at different stages of the house selection and installation process. The Household questionnaire asked a series of questions about ownership of different appliances, heating systems and

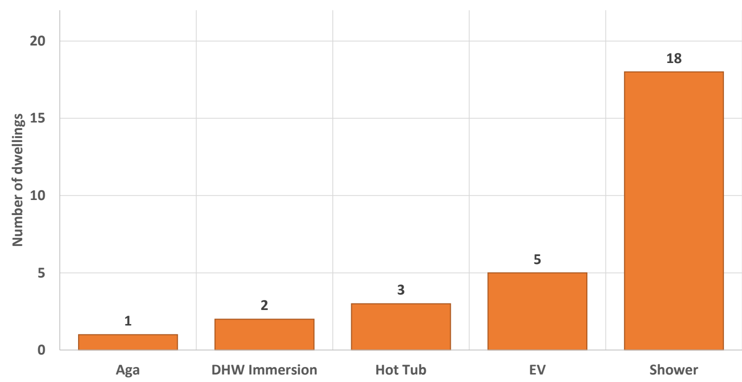

Fig 8: No of dwellings with major loads

[2] UK Government, (2018), https://www.gov.uk/government/statistics/sub-national-estimates-of-households-not-connected-to-the-gas-network, accessed Sept 2020

EV's. This was then supplied to the survey teams who confirmed the presence in the dwelling of loads that were deemed worthy of discrete monitoring. The majority of major loads were electric showers (N=18). Five dwellings had an electric vehicle with home charging.

3.5 Household Characteristics & Stock Comparison

The participating cohort contained a lower proportion of single person households than is seen in the UK housing stock, again a reflection of the participation rules. Consequently, the average household size of trial participants was 2.79 compared to a UK average of 2.36.

The median household income level of participants was £45-75k. Estimated average household income levels of the cohort (calculated using the middle points of the designated ranges) was 35.8k.

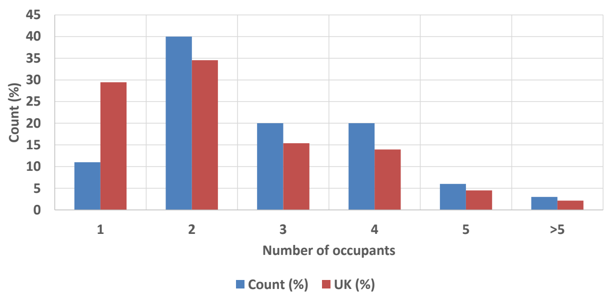

Fig 9: No of occupants per dwelling

Over 50% of household included one or more resident adults above retirement age; with 35% of households being only made up of occupants over the age of 65.

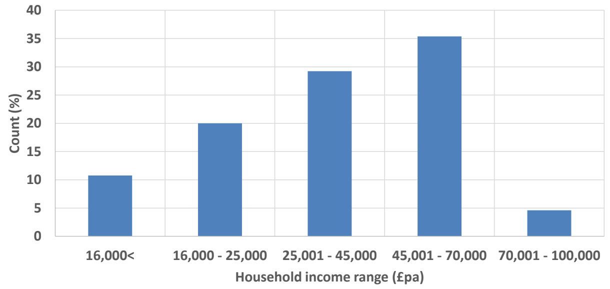

Fig 10: Household income

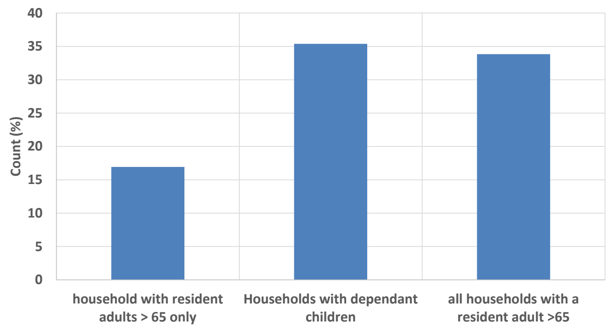

Fig 11: Household age profile

3.6 Energy Use Pattern Indicators

Two questions were included in the Household Questionnaire that could be used, as meta-data to segregate households by their occupancy behaviour. These asked:

Does the household generally leave for work or school in the morning and come back in the evening during weekdays?
No; Rarely; Often; Yes
Is there generally someone in the household at home all day during weekdays and weekends?
No; Rarely; Often; Yes

The way in which these questions were interpreted by responders suggested that they considered the individual actions of householders when answering. In this manner they could answer that the household did, or often did leave for work/school in the morning and come back in the evening and that there was or often was someone at home all day. Considering the combination of responses possible, three occupancy conditions were discernible.

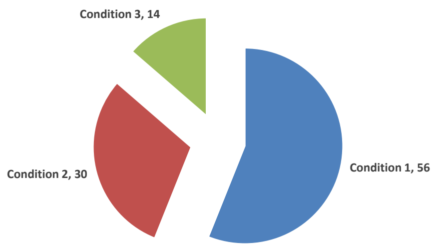

Fig 12: Daily occupancy condition

Condition 1: The Household rarely or never left in the morning and returned in the evening AND there was often or always someone at home during the day. This was the largest group, represents 56% of the households who responded to these questions (N= 66)
Condition 2: The household did, or often did leave the house in the morning and return in the evening AND there was always someone in during the day. This was the second largest group (30%)
Condition 3: The Household always or often left during the morning and returned in the evening and there was rarely or never someone in the house during the day. This was the smallest group (14%).
These results suggest that daytime occupancy was prevalent, reflective of the age profile of household occupants which may not be representative of the stock at large.

4. Assessing Sizing Assumptions

4.1 Annual Energy Use Indicators

4.1.1 Using Household Monthly Bill Estimates to Predict Consumption

The household questionnaire asked respondents (N= 63) to provide an estimate of their monthly electricity bill (in £ per month). This was translated into a kWh consumption value by assuming (i) an electricity tariff of £0.155 per kWh and (ii) £0.20 per day standing charge and compared to the monitored consumption level of the dwelling. The respondents displayed a distinct inability to estimate their consumption level for the period April 2019 to March 2020. This inability was more pronounced as the annual consumption levels increased, with dwellings who consumed over 8000kWh pa all significantly underestimating their consumption levels. The average electricity consumption of those who responded to the monthly bill question was 7302kWh pa and the RMSE was 5316kWh.

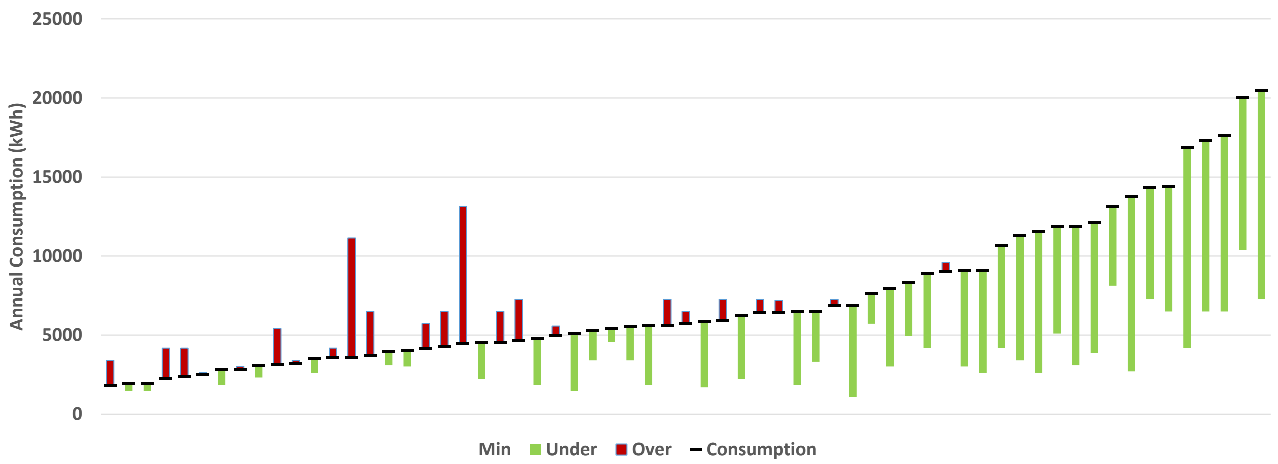

Fig 13: Comparison between monitored electricity consumption and estimates derived from householder information

Clearly, the tariffing assumptions that have been made will be a contributing factor to the estimating error reported. The extent of their contribution was tested by using different tariff and standard charge rates (Figure 14). The RMSE was reduced by ignoring any standing charge and reducing the tariff to £0.125. However, an RMSE of 4914kWh was still returned on a mean consumption level of 7302kWh indicating a lack of awareness among the cohort about their level of consumption. It is plausible that this is a function of energy invisibility which can be considered on three levels (Peacock et al., 2018[3]):

i) The method of delivering energy to the home is invisible, arriving unseen through wires and pipes which themselves are concealed in the building fabric.

ii) The services to which energy consumption is directed are often habitual in nature, rooted in unquestioned social practices and routines (Strengers, 2011[4], Gram-Hanssen, 2008[5], Shove and Walker, 2007[6]). These include matters such as cleanliness and conventions around clothes or dishwashing, for example. Social practices such as these make it difficult for consumers to establish linkages between their (unquestioned) activity and their actual consumption.

iii) Finally, over half of UK dwellings purchase their electricity via direct debit further removing a direct economic link between awareness and consumption. (DECC, 2015[7]).

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[3] Peacock, A.D., Chaney, J., Goldbach, K., Walker, G., Tuohy, P., Santonja, S., Todoli, D. and Owens, E.H., 2017. Co-designing the next generation of home energy management systems with lead-users. Applied Ergonomics, 60, pp.194-206.

[4] Strengers, Y., 2011. Negotiating everyday life: The role of energy and water consumption feedback. Journal of Consumer Culture, 11(3), pp.319-338.

[5] Gram-Hanssen, K., 2008. Consuming technologies–developing routines. Journal of Cleaner Production, 16(11), pp.1181-1189.

[6] Shove, E. and Walker, G., 2007. CAUTION! Transitions ahead: politics, practice, and sustainable transition management. Environment and planning A, 39(4), pp.763-770.

[7] *DECC (2015), Regional Variation of Payment Method for Standard Electricity (QEP 2.4.2), Department of Energy and Climate Change, UK Government (2015)*

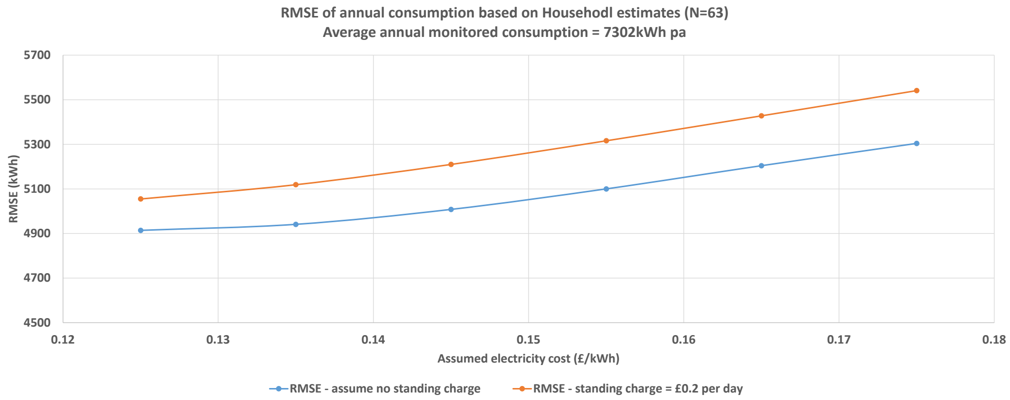


Fig 14: Comparison between monitored electricity consumption and estimates derived from householder information

4.1.2 Impact of Meta-data on Annual Electricity Consumption

4.1.2.1 Electric vs Non-Electric Space Heating

From the meta-data it was possible to determine the space heating fuel used by 91 of the 100 participants. From these dwellings, floor area information, provided by EPC data was available for 78 dwellings. These could be disaggregated in electric space heating (N=28) and non-electric space heating (N=50) dwellings. Further analysis excluded three of the non-electric space heating dwellings as having significant major loads that influenced consumption; two with high use EV and one with a hot tub. This left a data-set for analysis of electric (N=28) and non-electric (N-47) dwellings. The consumption of dwellings that use electric space heating reveals the tail of high consumption values expected (Fig 15). This contributes towards the statistically significant difference between the average of the two populations; 72kWh/m^2 and 44kWh/m^2 for electric and non-electric dwellings respectively. These compare to the UK average (Floor Area average[8] = 92m^2 and electricity consumption average[9] of 3861kWh pa) of 42kWh/m^2.

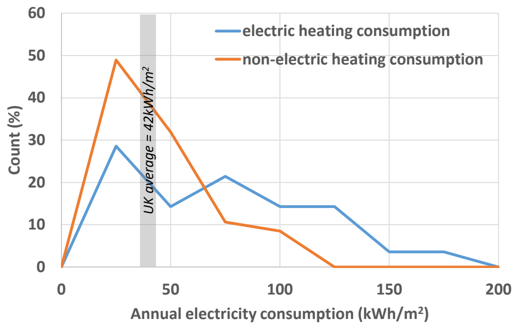


Fig 15: Consumption distribution in electric & non-electric dwellings

SUMMARY				
Groups	*Count*	*Sum*	*Average*	*Variance*
electric heating consumption	28	2018	72	1818
non-electric heating consumption	47	2083	44	511
ANOVA				
Source of Variation	*SS*	*df*	*MS*	*F*
Between Groups	13494	1	13494	13.57
Within Groups	72591	73	994	*P-value*
Total	86085	74		0.00

Table X: ANOVA of consumption of electric and non-electric dwellings

4.1.2.2 Isolating indicators of electricity consumption from the meta-data

Level of occupancy, presence of occupants over the age of 65, household income level and household occupancy during the day did not have any significant impact on the level of electricity consumption in the dwelling. Figure 16 shows a plot of electricity consumption (kWh/m^2) vs Floor Area (m^2) showing a diminishing consumption level as household size increases. This emphasises that electricity consumption is likely to be concentrated in the kitchen area, where most high consuming appliances are found.

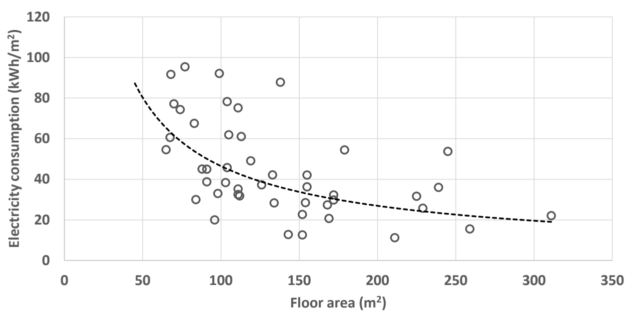


Fig 16: Relationship between floor area and electricity consumption per unit floor area

[8] *UK Government (2018), https://www.gov.uk/government/publications/floor-space-in-english-homes, accessed October 2020*
[9] *UK Government (2020), https://www.gov.uk/government/statistics/energy-consumption-in-the-uk, accessed October 2020*

4.2 Annual PV Generation Indicators for Existing PV

Three different methods of estimating annual electricity generation from rooftop PV systems were assessed here; namely SunGift estimation, SAP estimation and simple unit kWp output based on the monitored generation data.

4.2.1 SunGift Estimation

The first estimation was provided by SunGift as part of the PV System Install Quote. These were created for each participating dwelling where both a BESS and a PV system was being installed as part of the trial and 32 results were retuned in the meta-data library. The SunGift method typically underestimated generation (N=21), (Fig 17). Overall this estimation produced RMSE of 952kWh against an average generation per dwelling from the cohort of 3424 kWh pa.

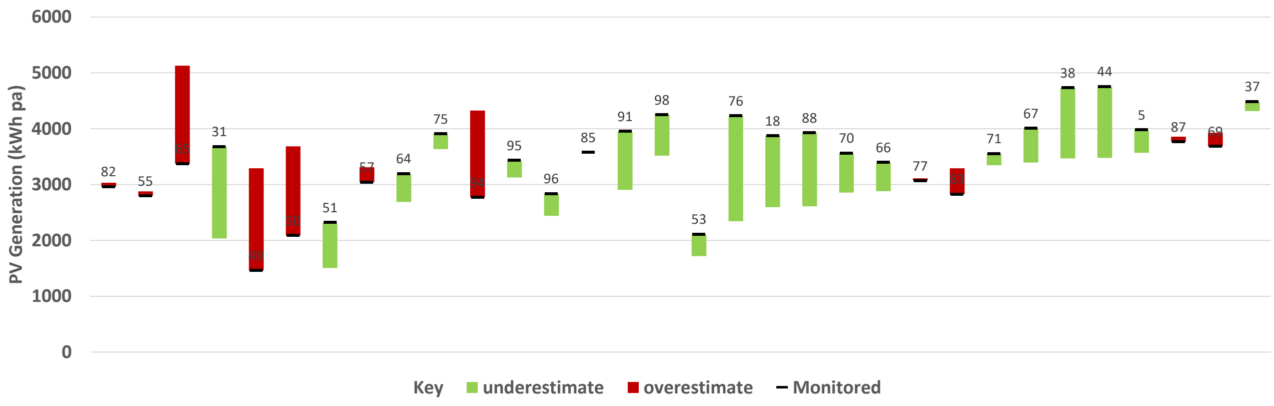


Fig 17: Annual PV generation estimation provided by SunGift compared to monitored output

4.2.2 SAP Estimation

The Standard Assessment Procedure contains a method for estimating output from PV systems based on kWp, location (South-West England in this case), orientation, shading and collector tilt (45° for typical rooftop system). Orientation and shading data was provided for 17 of the 32 dwellings where SunGift had provided an estimate. It was therefroe possible to compare the SAP estimation with the SunGift estimation directly for these 17 dwellings (Figures 18a and b respectively).

Both approaches were highly correlated (Pearson's correlation coefficient of 0.85) and produced similar RMSE values. The pattern of under and over estimation compared to monitored data was distinct however, with, for instance in dwelling ID 65 PV generation being overestimated by SunGift by 1756kWh and underestimated by SAP by 453kWh.

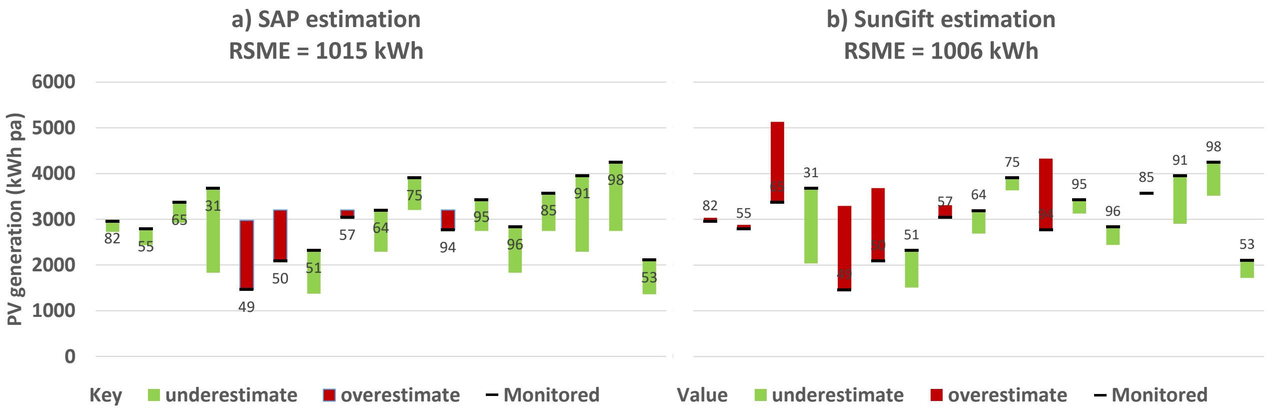


Fig 18: Comparison between estimated and monitored PV generation using a) SAP and b) SunGift methods

4.2.3 Empirical kWh per kW estimate

The third estimation method used the monitored PV output to create a simple kWh per installed kWp. The trial set-up permits the per kW unit output of the existing systems to be compared with those system that were installed as part of the trial. In Figure 19, frequency distribution of kWh/kWp value for the period April 2019 to March 2020 was created for new and existing systems binned to nearest 50kWh value. Existing dwellings produced a higher average kWh/kWp value, with a pronounced population appearing with a value higher than 1000kWh. This did not occur with the new PV systems and may point to bias in the data associated with either orientation or shading, neither of which was captured for every dwelling included in the analysis.

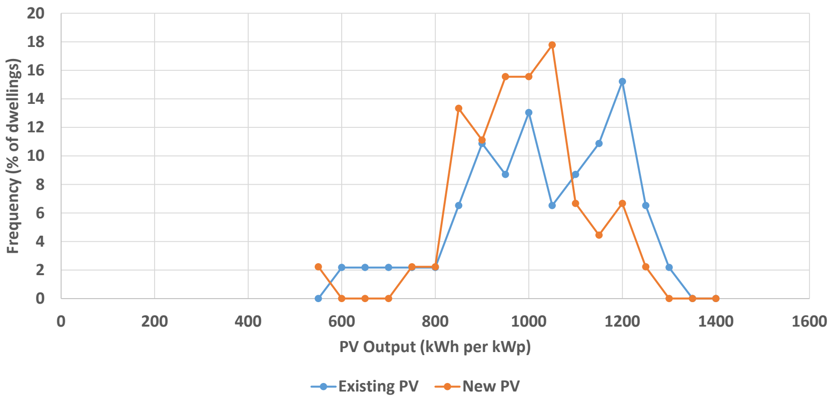


Fig 19: Frequency Distribution of kWh/kWp for new and existing PV

The statistical relevance of this difference was tested using analysis of variance at 95% confidence interval (Table X). The average output of the existing systems was marginally higher than that of the new system, but the *P-value* of 0.1 indicated that this was not highly statistically significant. To avoid obvious bias of internalising the forecasting procedure, the average output (1022kWh) from the existing systems was used as predictor of their output. This avoided using kWh per kWp values from new PV systems to predict their output and was justified by the low statistical significance of the variance between the two populations.

Groups	*Count*	*Sum*	*Average*	*Variance*		
kWh per kWp Existing	46	47031	**1022**	28596		
kWh per kWp New	54	51893	**961**	23737		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	93750	1	93750	**3.6**	**0.1**	**3.9**
Within Groups	2544851	98	25968			
Total	2638601	99				

Table X: ANOVA of kWh/kWp output from new (N=54) and existing PV systems (N=46)

Figure 20 indicates the extent of over and under estimation compared to monitored generation using the kWh/kWp predictor. The average, monitored annual generation of the cohort was found to be 3192kWh per dwelling whereas predicted average yield 3404kWh per dwelling, with a RMSE of 548kWh. System output was typically overestimated (N=35 of 54).

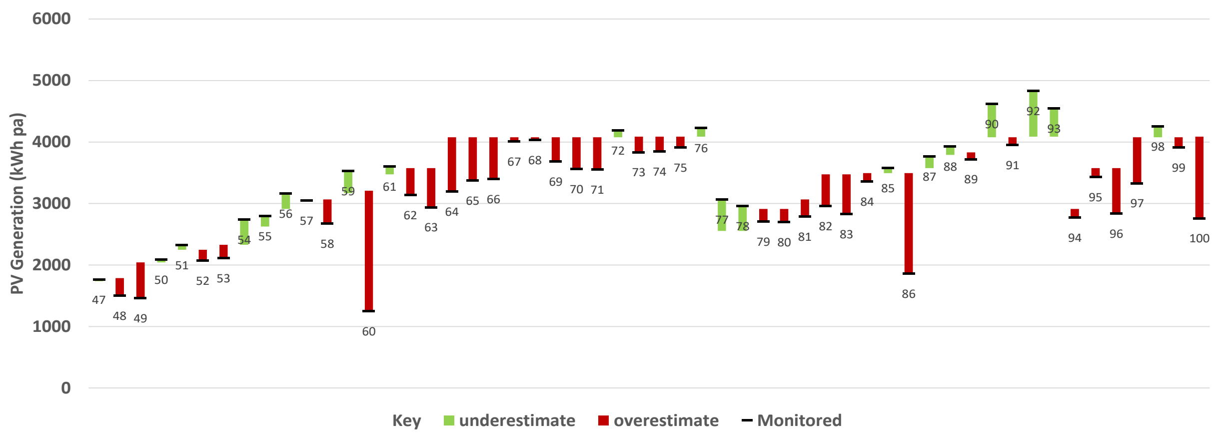


Fig 20: Annual PV generation estimation provided by kWh/kWp value derived from existing PV systems and applied to new PV systems

To provide a direct comparison between the three methods, the kWh/kWp method was applied to the 17 dwellings where both SunGift and SAP methods had been applied (Fig 21). The RMSE of the simplistic, 'rule of thumb' approach whilst having the highest RMSE was only marginally outperformed by the two modelled approaches.

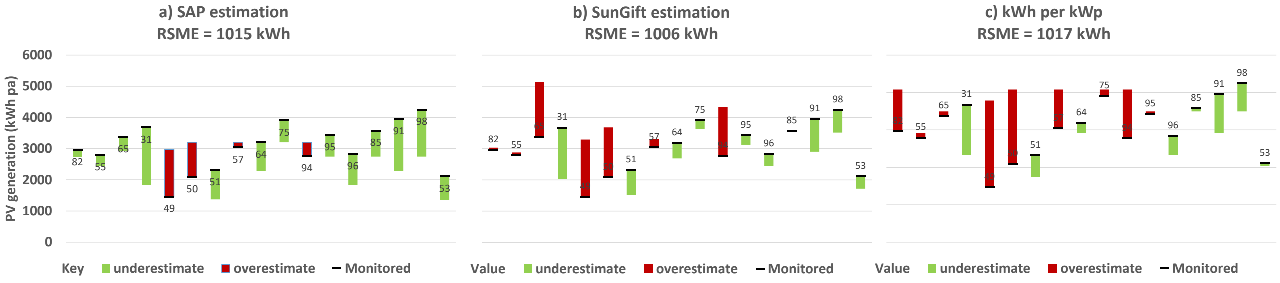


Fig 21: Comparison between estimated and monitored PV generation using a) SAP, b) SunGift methods & c) kWh/kWp methods

4.2.4 Possible Lessons for Estimating PV Generation

The estimation of PV generation is the most critical forecast that should be made when determining BESS performance in self-generation mode. Dwelling consumption, both its magnitude and the timing of demand does play in a role in BESS performance outcome, but the primary determining factor is the volume of PV generation available in the first instance. Forecasting PV generation with limited knowledge of system and installation specificity (i.e. system efficiency, condition, location, orientation and shading) will produce significant errors. Simplistic rule of thumb approaches may be sufficient for a first pass assessment, where the aim of the forecast is to segregate dwellings with existing PV into those that are likely to produce conditions for high performing BESS and those that are not. In this manner, coarse geographical location plus PV capacity from Global Solar Atlas may provide sufficient data. As discussed in the self-generation report, more forensic knowledge of system and locational attributes are required is more detailed information is required. Applying the relatively simplistic modelling approaches will only yield additional insight if the quality of the survey data is good. An example of how possibly imprecise data can provide false insights can be described using the data collected in the residential LEM trial.

It was possible to combine the meta-data from the Household Questionnaire that defined the roof orientation to disaggregate the per kW unit output (Fig 22). The expected hierarchy of orientation S; SE/SW; E/W was not returned by this disaggregation, indicating either that the quality of the meta-data is inadequate in defining PV orientation or that system or shading data, not included in this assessment is biasing the results.

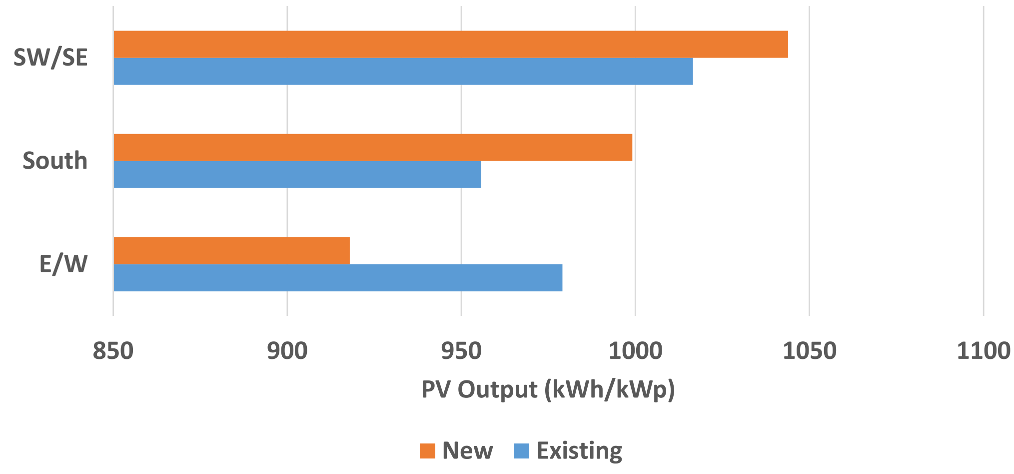


Fig 22: PV output (kWh/kWp) disaggregated by new and existing systems and by returned orientation data

5. Appendix A: The Difficulty in Predicting Annual Consumption from Survey Metadata

5.1 Overview

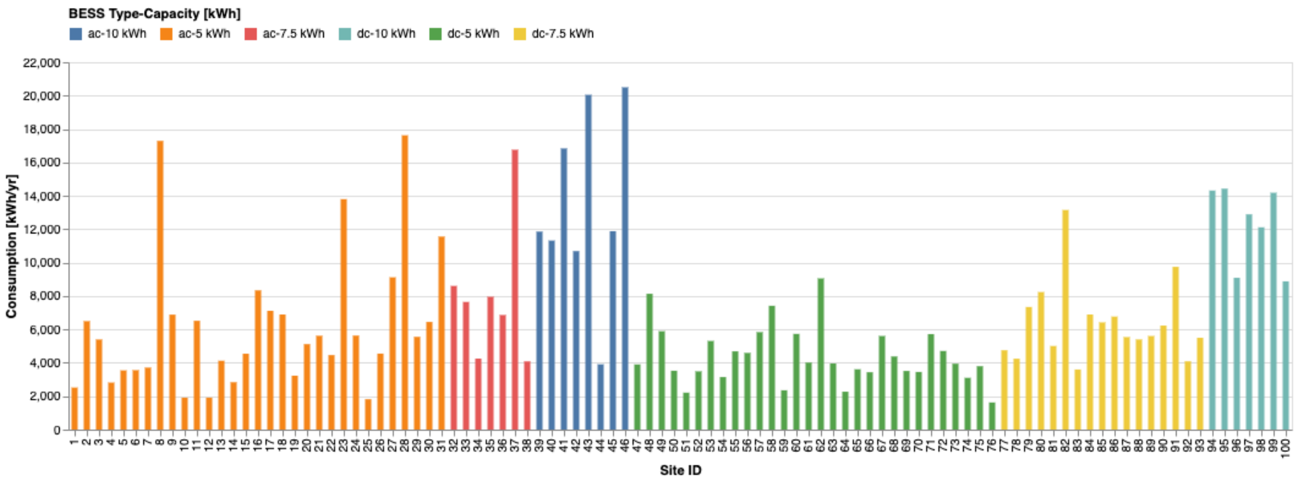
In this section, we present selected charts that illustrates the difficulty in predicting annual electricity consumption using building and household meta-data. The overarching conclusion is that whilst broad correlations between some metadata parameters and consumption may exist, a more complex, multi-parameter analysis is required if reasonable prediction accuracy is required. Examples of plots using multi-parameter criteria as a precursor of annual electricity consumption are shown in Section 5.3 below, chiefly to illustrate the issue associated with exploring meta-data correlations in a small sample size. Unfortunately, the size and completeness of the metadata is limited, and hence such analysis is not possible with this dataset.

The analysis that is being conducted for the report that will explore BESS operation with a particular emphasis on headroom availability for non-self-consumption operation will return to the investigation of meat-data indicators. Different methods will be employed that seek to cluster BESS performance based on statistical techniques (e.g. k-means clustering). If different aggregates of BESS performance are isolated using this technique, the meta-data will be used as an aid for creating narratives that might describe these aggregated groupings. If success is found with this data led approach, which will not be restricted to meta-data presence, then it will be applied to the household electricity consumption.

5.2 Distribution of Consumption

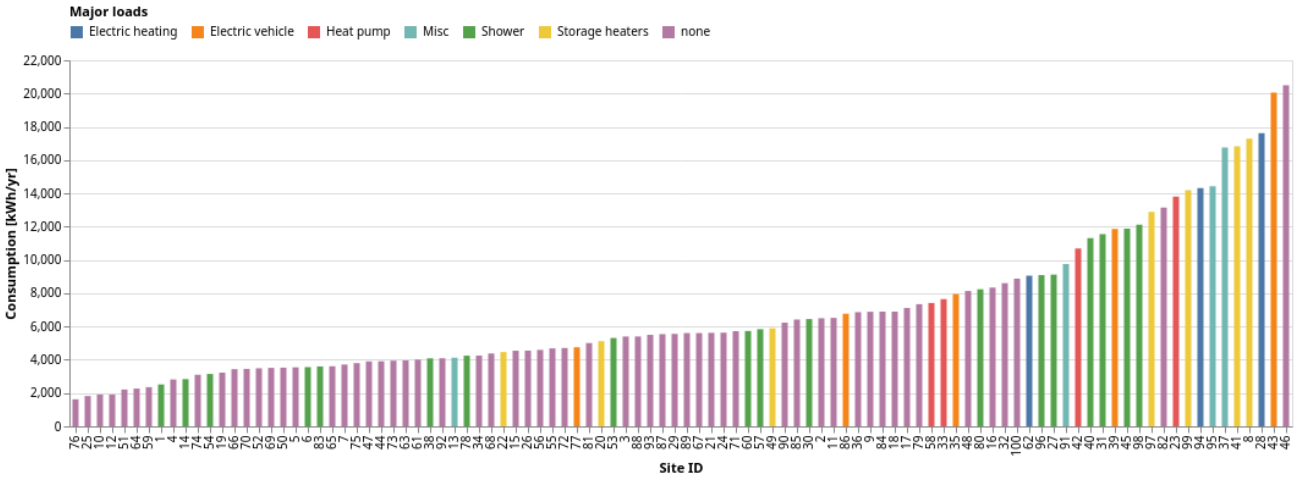
5.2.1 BESS Type-Capacity

The selection methodology used for assigning a BESS of specific kWh capacity to a dwelling involved estimating daily electricity consumption from household bill estimates. Those dwellings with higher assumed electricity consumption were than deemed applicable for the larger capacity BESS. Assignation of systems was then carried out within budgetary constraints and a desire to achieve a targeted spread of BESS capacities throughout the fleet. As a consequence, it was plausible, indeed desirable that household electricity consumption be correlated with BESS capacity. The average household electricity consumption was 5301, 6862 and 12862kWh for the 5kWh, the 7.5kWh and the 10kWh capacity cohort respectively with the difference between the groups found to be highly significant. The individual consumption values for each dwelling are disaggregated by battery type (Eco-ac and Hybrid-dc) and battery size is shown in the graph below.



5.2.2 Major Load Type

The number of factors that are responsible for determining level of household consumption are broad and presence of major load would not in and of itself be a determining factor. A wide variety of use cases were also found for a major load, depending on occupancy levels and whether alternatives for delivery of service provision were available. The presence of electric showers is a case in point in this regard, with some dwellings recording almost no use of electric showering, despite its presence suggesting an alternative, non-electric option was available.

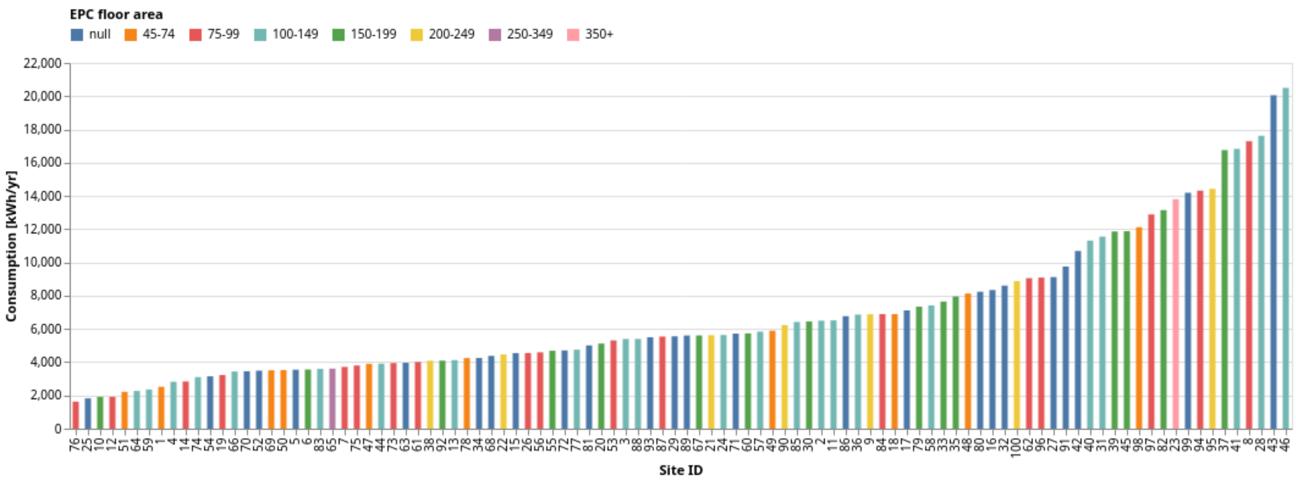


5.2.3 *Building Floor Area*

Electricity consumption is to some extent linked to floor area. For instance, the National Calculation Methodology, SAP[10] which is used for building regulation compliance computes annual energy use for electrical appliances using the formula:

$E_A = 207.8 * (TFA * N)^{0.4714}$ *where TFA is the total floor area and N is the number of occupants.*

However, total floor area is one of a number of competing factors particularly in a dataset containing a significant number of dwellings that are not connected to the gas grid, and whose cooking, space heating and hot water loads are therefore likely to be atypical. Even in buildings that are on the gas grid, the introduction of LED lighting and a general improvement in appliance energy efficiency has weakened what was an already loose correlation. No correlation between floor area and household electricity consumption could be found in the cohort of dwellings isolated for analysis in section 4.1.2.2



5.2.4 *Building Age*

Building age can be used as an indicator of building primary energy demand because of its likely impact on thermal properties of the dwelling. Broadly speaking, solid wall dwelling was the predominant construction methodology, replaced by cavity wall dwelling from c1935 onwards and phased out completely by the 1960's. The introduction of Building Codes in the 1980's made age banding of dwelling thermal properties possible, linked to revisions of the code, this being a popular technique in building stock modelling approaches aimed at producing national estimates of Domestic energy consumption. In small pilot of the size monitored here, any trend analysis of this nature will be swamped by individual anomalies. In buildings where the space heating is delivered by non-electric fuel, it would not in and of itself be expected to be a primary indicator of electricity consumption.

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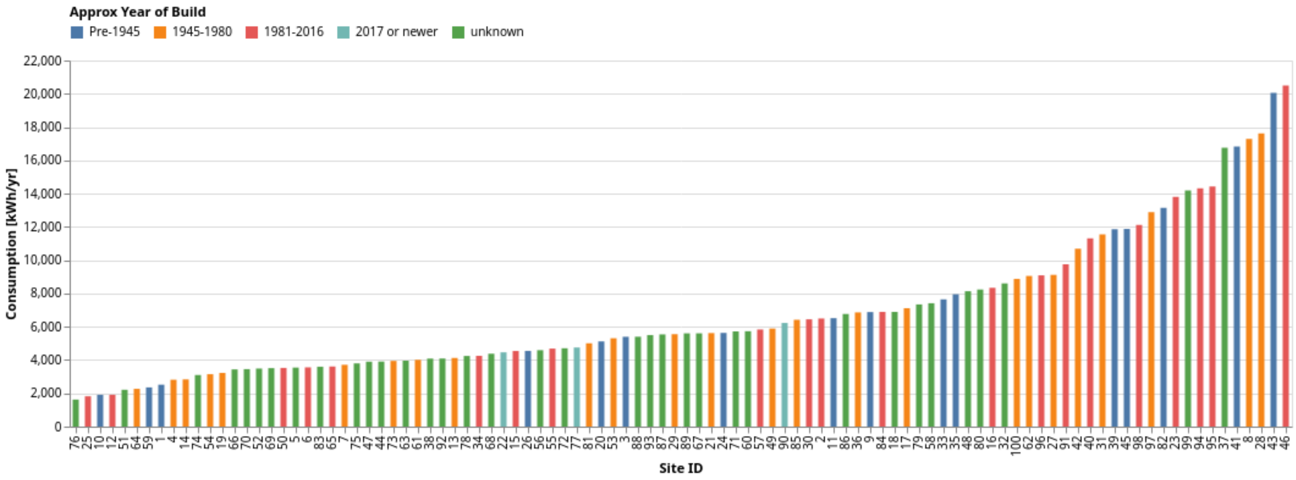
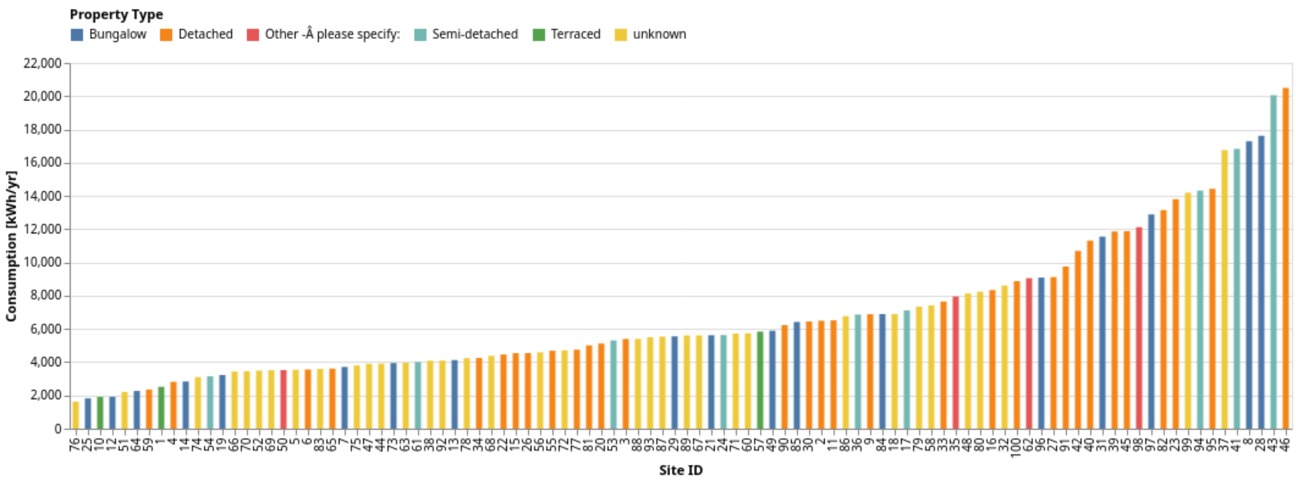
[10] *UK Government (2014), BRE, Standard Assessment Procedure, 2012 edition*



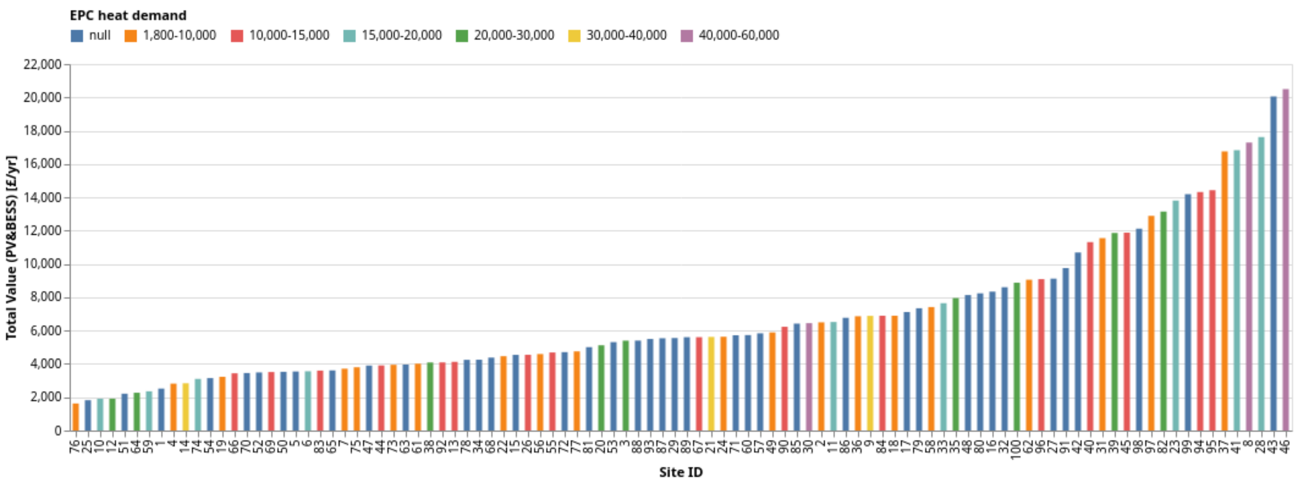
5.2.5 Building Type

Many of the comments made in 5.2.4 can also be made for building type. Clearly, the thermal demand of a given dwelling is highly affected by the building type and in larger sample sizes would be expected to be a critical disaggregating parameter. In buildings with non-electric space heating it would not be expected to be a determinant of electricity consumption.



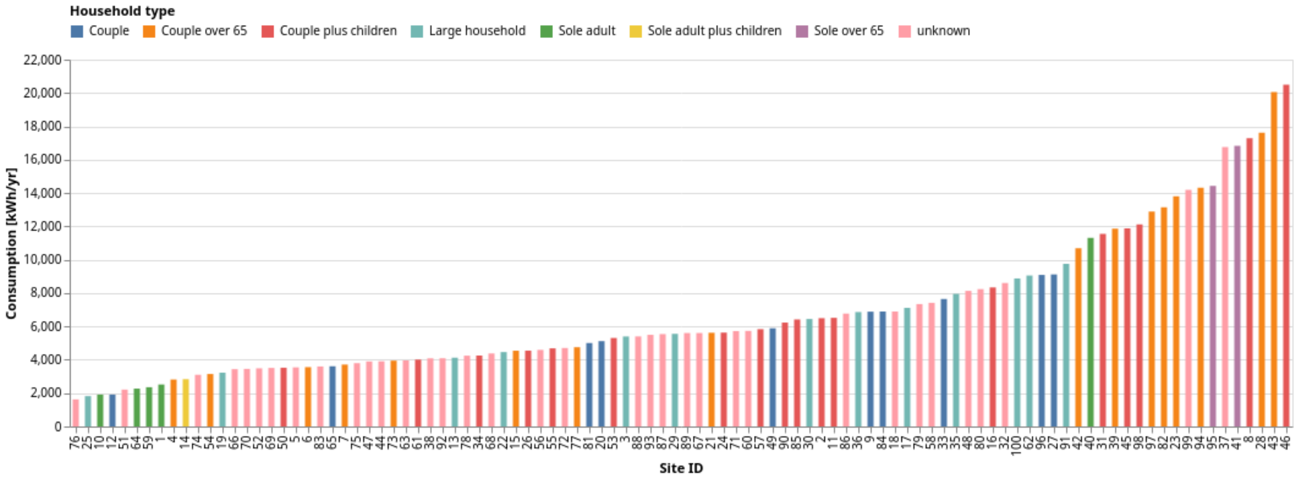
5.2.6 EPC Estimated Heat Demand

The EPC database, conceptually offers a potentially valuable, remote source of building meta-data. Caution should be applied to the use of the database as studies have shown that the level of quality, and outputs, from a standardised energy assessment can be variable (Jenkins et al., 2017). Heat demand, as estimated on retrieved EPC certificates was explored here as a determinant of total value from a PV/BESS system because of its possible correlation with electrical demand, particularly in dwellings off the gas grid. No correlation could be found, which may be a result on the inherent variability of the estimation process or because of the number of non-electric heated dwellings included in the sample.



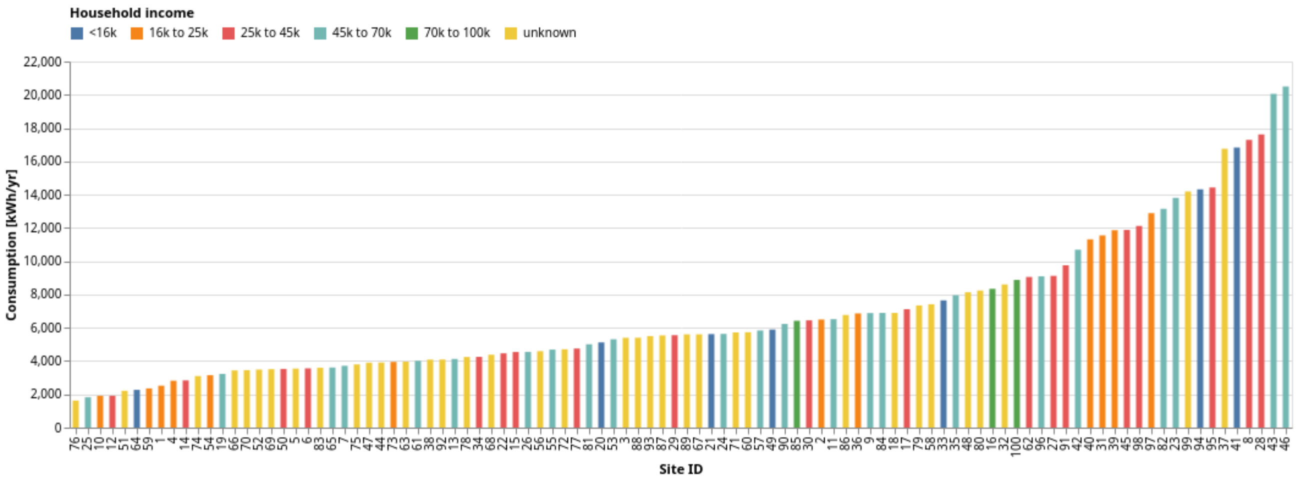
5.2.7 Household Composition

As mentioned in Section 4.1.2.2, household composition was not found to have an impact on electricity consumption. The conditions tested was occupant number per dwelling, presence of individuals over the age of 65 and presence of children. These were tested for households with and without electric space heating, and for the entire participating cohort.



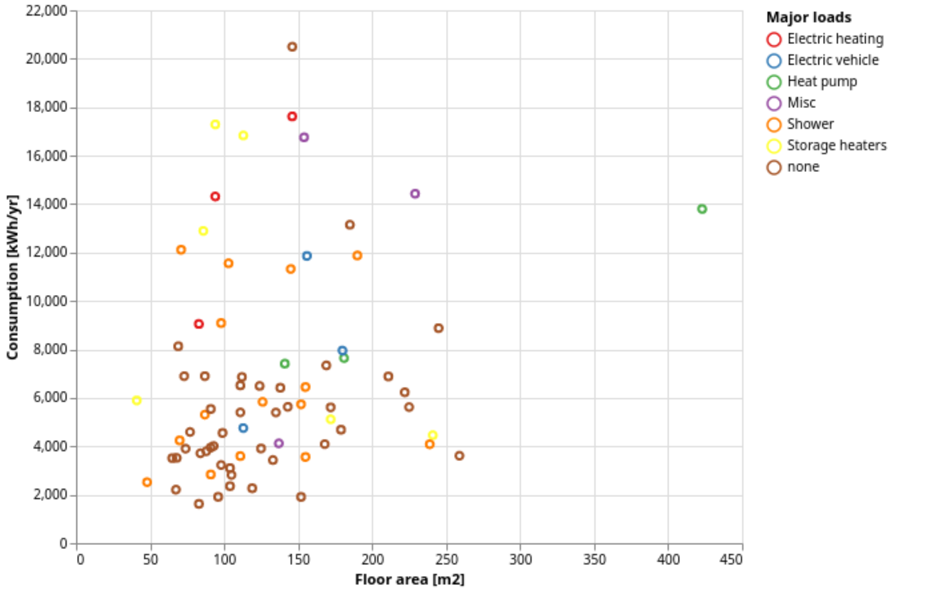
5.2.8 Household Income

As mentioned in Section 4.1.2.2, household income was not found to have an impact on electricity consumption. Whilst five income bands were included in the survey, only three were tested to ensure sufficient numbers were consisted in each group, i.e. <25k; 25-45k and >45k. The high income band (£70-100k) housed on non-electric space heating dwellings were found to have significantly higher electricity consumption per kWh, however the significance of the finding could not be assessed because of the low sample size (N=2).

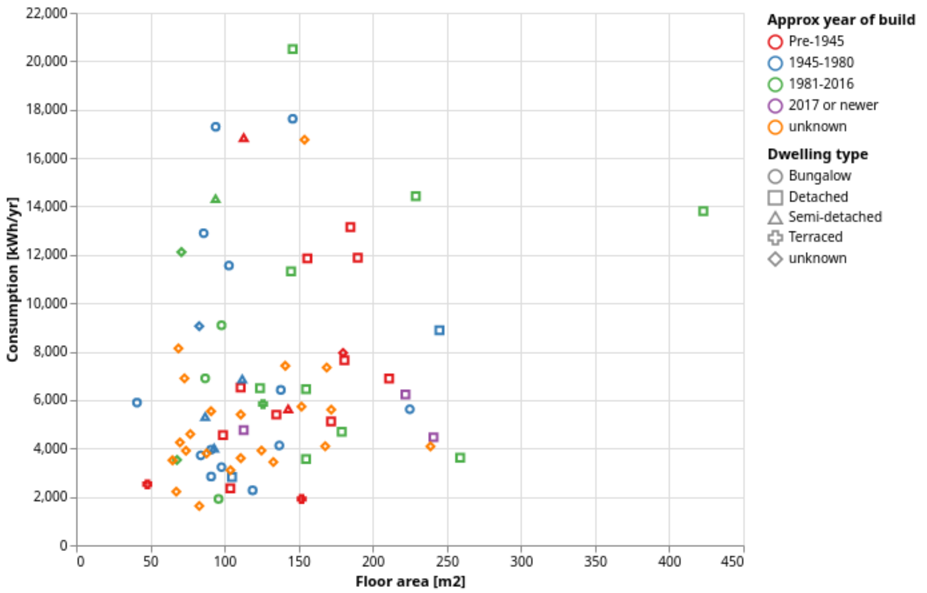


5.3 Multi-Parameter Relationships for Consumption

5.3.1 Major Loads & Floor Area



5.3.2 Building Type, Building Age & Floor Area



5.3.3 *Household Composition & Floor Area*