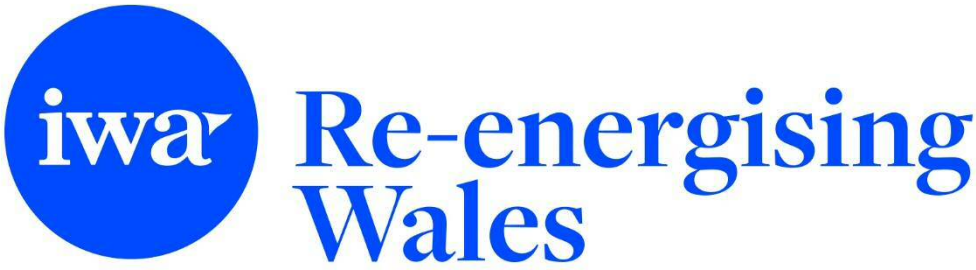

RE-ENERGISING WALES PROJECT
WORK PACKAGE 1 – HALF-HOURLY ENERGY DEMAND PROFILES FOR WALES FOR 2016

by

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The work was undertaken by the Welsh School of Architecture and Heledd Iorwerth as part of the Re-energising Wales project coordinated by the Institute of Welsh Affairs. Funding to support Heledd Iorwerth in producing the half hourly datasets was from the project.

BRE SAP Based modelling, Ordnance Survey GIS datasets, EPC data, DEC data, IEA ECBCS Annex 42 domestic building profiles and measured data provided by K2n Ltd from operational buildings were used to estimate the energy demand and profiles for every 'Unique Property Reference Number' corresponding to a building in Wales.

For data protection reasons, these estimates are then aggregated into half hourly heating and electrical demands by 2011 Census Output Area. The full derivation and validation of these estimates is presented in this report.

Grateful thanks are due to everyone who has assisted the production of this report, in particular:

- Professor Gareth Wyn Jones as co-leader of work package 1
- The IWA Re-energising Wales project steering group members
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- The Ordnance Survey for allowing the use of their April 2017 datasets in this work
- K2n Ltd for allowing the use of their non-commercial building datasets to produce the demand profiles by building type required to assess the annual energy use of a number of non-domestic building types.

This report was undertaken as part of work package 1 (WP1) for the Institute of Welsh Affairs' (IWA) 'Re-energising Wales' project (2016 to 2019.) The aims of the project are to provide a fact based plan to enable Wales to meet its projected energy demands entirely from renewable sources by 2035 and beyond. This will then achieve the targeted 80% reduction in energy-related greenhouse gas (GHG) emissions, based on 1990 emission figures.

To understand how the Welsh energy supply system should evolve to most effectively and efficiently meet these aims, we first have to understand when, where and why we use the energy currently consumed.

The work covered by this report has produced **estimates** of the energy demand of Welsh domestic and non-domestic buildings in **half-hourly intervals** for each of the 10,048 Census 2011 Output Areas (OA) in Wales (Office for National Statistics, 2011).

A bottom-up approach is used to assess the annual building energy demand for every building in Wales that appeared in the Ordnance Survey data for Wales in April 2017 (Ordnance Survey, 2017).

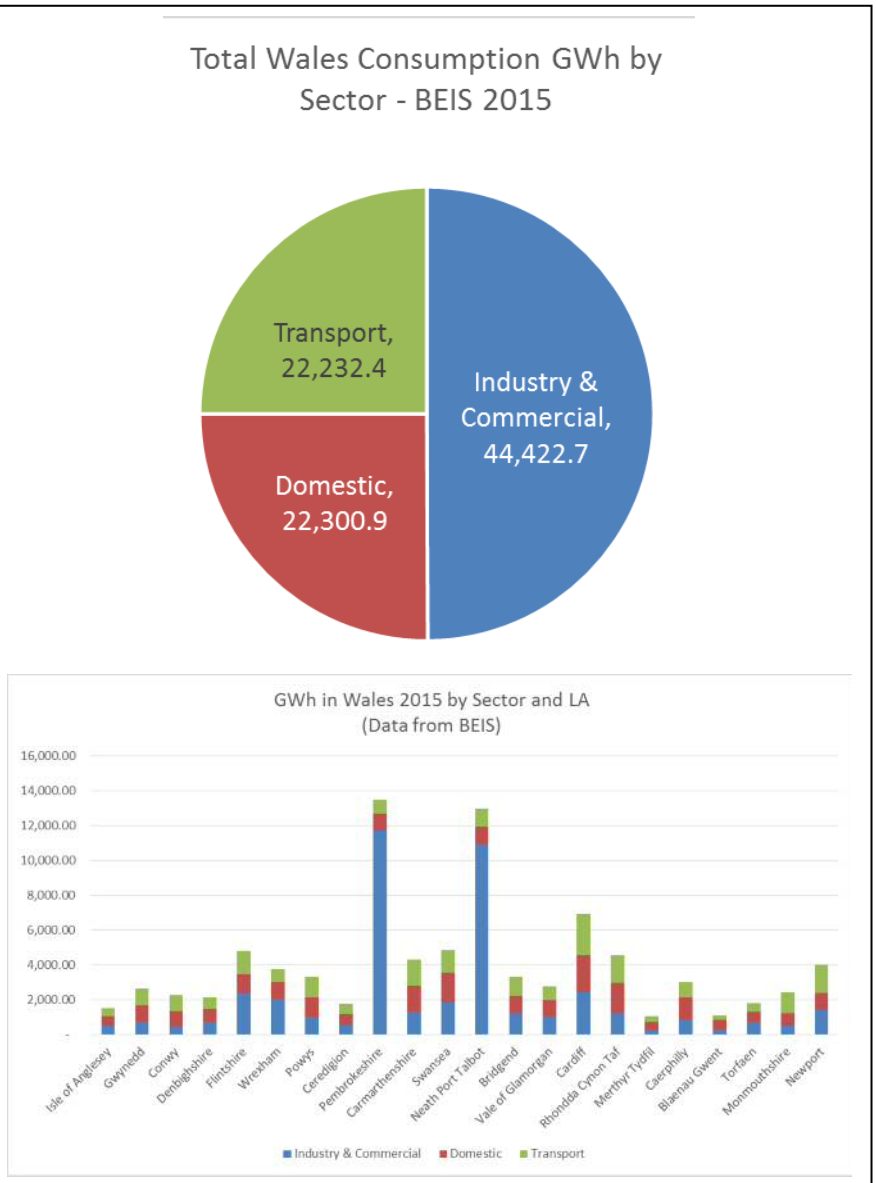


Figure 1: BEIS Consumption Estimates for Wales and Welsh Local Authorities for 2015

Industrial, transport and non-building commercial energy demands in Wales are not covered by this report, but their annual use can be estimated from BEIS 2015 figures for Wales (Department for Business, Energy & Industrial Strategy, 2017), a graphical overview of which is shown in Figure 1.

The information in this work package should be of value when assessing the potential for renewable energy to meet these geographically varying demands, which is one focus of work package 2 of the IWA project.

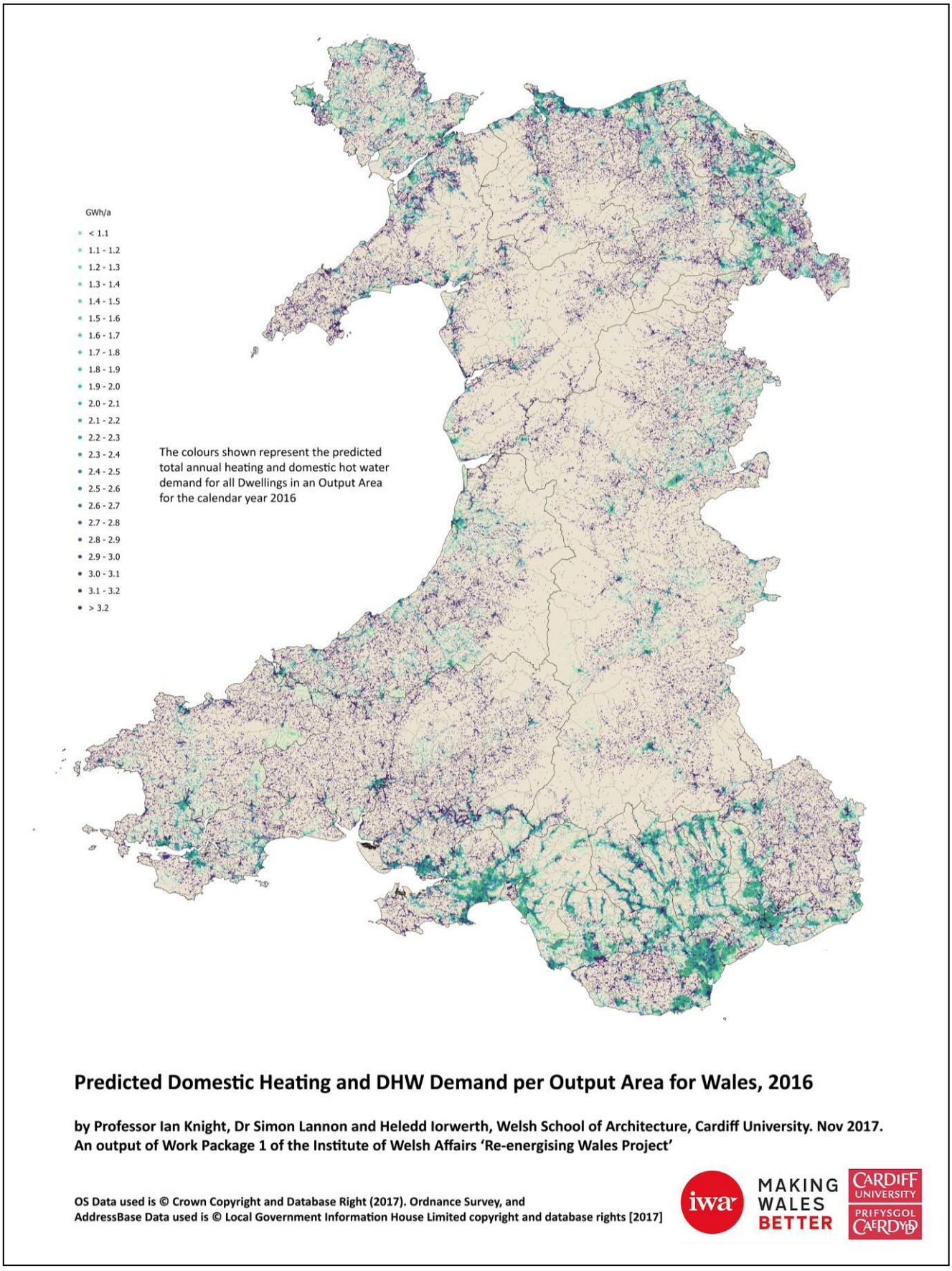
The detailed half-hourly datasets for each OA used by this report are available electronically, assembled for each Welsh Local Authority (LA), in excel spreadsheet format from the Cardiff University ORCA repository at http://orca.cf.ac.uk/107222/ .

Some of the information in these detailed datasets is explored and presented in the following sections of this report as findings for each of the 22 LAs, and 'all Wales' overviews.

By providing the detailed energy demand data outputs from this work in electronic format it is hoped that the data will assist in the production of increasingly accurate information in this area and therefore assist the

efficient transition to zero carbon emissions of Welsh energy supply systems. The data provided is supported by as much metadata as possible whilst keeping within data protection and OS commercial limitations.

The map shown in Figure 2 is an example of the GIS based presentation of aspects of this data. A full set of maps from Wales down to LA level is also provided in the ORCA Repository.



4 BACKGROUND

The primary purpose of this report was to provide a clear, data-based, picture of the nature, timing and location of half-hourly energy demands within Wales over a year if possible. The aim was to provide this dataset of energy demands for use in a variety of investigations and legislative needs.

For domestic and non-domestic building power demands, WP1 has produced separate estimates of half-hourly (HH) power demand profiles for electricity and heating in 2016 to meet the need for greater granularity in the timing of these demands. These should be detailed enough for comparison with intermittent renewable generation profiles to enable, for example, the calculation of storage demands required for a 100% renewable supply system for buildings. The production of these power demand profiles at OA level of detail, including estimated floor areas, means we can also compare sub-hourly demand with local renewables generation profiles to see where there is over and under-supply, and that we can estimate the impact of future buildings and/or changes to existing buildings, on local power demands. It is believed that this is the first time that information has been made publicly available at this level of detail in terms of sub-hourly demand figures and granularity of data by OA.

The initial intention for the profiles was to use the actual recorded annual energy use data by 'Meter Point Reference Number' (MPRN) for gas and 'Meter Point Administration Number' (MPAN) for electricity where this was available and apply measured half hourly profiles by building typology to apportion this consumption over the full year. At the time of writing, we had not been able to obtain the actual annual energy use data but efforts will continue to be made to obtain these before the end of the IWA project.

The other main purpose of this information was to inform work package 2 of the IWA project, which has the aim of estimating the size and location of the renewable resources available to the Swansea Bay City Region. It is not clear if there will be sufficient resources available to the project to provide a detailed location and timing link between renewable sources energy generation and the sub-hourly demand profiles presented in work package 1, but the information is now available to allow future work.

The outputs of WP1 refer to, and build on, information and methods published by or available from BEIS, Ordnance Survey, Cardiff University and K2n Ltd. In particular, the **non-domestic** electricity and heating demand profiles are from a unique unpublished commercial dataset derived from measured data/m^2 collected by K2n Ltd across a range of non-domestic typologies. The modelling involved in producing these profiles was primarily in estimating the area of each non-domestic UPRN from the Ordnance Survey Addressbase and GIS Datasets. The non-domestic datasets diverge from expectations from other published data. The lack of detail on the servicing and activities undertaken in the non-domestic buildings modelled has meant we were unable to always assign the correct demand profile to each building, though the ranges presented should encompass much of this uncertainty.

The energy data produced from WP1 is in the form of HH POWER demands for domestic and non-domestic properties. These estimated HH power demands, for the year 2016, are provided in excel format at half-hourly intervals for electricity and heating (space and domestic hot water) separately at the level of each 2011 Census Output Area (OA) for the whole of Wales.

The amount of data contained in these files means that they are provided at the LA level to enable them to be used on a reasonably powerful PC. The derivation of these profiles is covered in more detail later in this report. They are based on modelled annual energy use in the domestic sector, but it is hoped that actual annual energy consumption data can be used to confirm and/or amend these profiles before the project end.

The work package places this estimated domestic and non-domestic energy demand in the context of the BEIS 2015 annual energy demand figures for the whole of Wales, including transport, commerce and industry. Half-hourly data for some of the industrial consumers would have been possible to produce too, but for data privacy reasons this has not been done, though the major industrial energy consumers in Neath Port Talbot and Flintshire shown in Figure 1 are obvious.

With regards to the transition to a low or zero carbon energy supply system, the data required to help understand future transport energy and power demands is likely to be mostly about understanding daily scale of demand, if future transportation modes continue to rely almost entirely on stored energy systems. No attempt has been made to profile this use in this report due to a lack of expertise available to the project on this subject.

Figure 1 shows that BEIS estimates that, in 2015, domestic buildings accounted for about 25% of the total annual Welsh energy consumption, with transport and industry/commerce accounting for 25% and 50% respectively. For the IWA project aims we are interested in knowing the size, timing and location of demands on any future energy supply system. As intermittent renewables are likely to provide a significant portion of these demands, then improving understanding of when these demands occur should help to improve the efficiency of use of renewable energy.

5 MAIN FINDINGS AND OBSERVATIONS

5.1 Overall findings for Wales

Due to the amount of data produced, the main findings from the work for Wales, and LAs, are presented separately in terms of domestic or non-domestic consumption. These categories are further separated into 'Heating & Domestic Hot Water' (DHW) demand or 'Electricity Demand' as follows:

1. Total Annual Energy Demands – by LA and Wales as a whole
2. Average Annual Energy Demands per Unique Property Reference Number – by LA and Wales as a whole
3. Average Annual Energy Demands per m² floor area – by LA and Wales as a whole
4. Average Power Demands per m² floor area – by LA and Wales as a whole

The headline figures for Wales are shown in Table 1. They show that buildings consume around 28 TWh/a of the approximately 89 TWh/a of energy used annually in Wales for all purposes, as shown in Figure 1.

When disaggregated further by buildings only then, notwithstanding the caveats in this report, domestic buildings are by far the major consumers of energy as a whole. However, at individual building level then non-domestic buildings consume more per building than domestic buildings. This situation reverses when considering energy use per m², with domestic buildings now consuming more per m² for both heating and electricity.

The estimated domestic buildings only annual energy use amounts to 24.7 TWh, or 27.8%, of the total Welsh annual energy consumption of 89.0 TWh predicted by BEIS for 2015. The typical domestic property consumes around 14,400 kWh/a for heating and DHW, and 3,500 kWh/a of electricity. These energy consumption figures become 176 kWh/m².a and 43 kWh/ m².a respectively when normalised for floor area. On a power demand/m² basis averaged over the year, then these further translate to 20 W/ m² and 4.9 W/ m² respectively.

The estimated non–domestic buildings only annual energy use is around 3.5 TWh, or 3.9%, of the total Welsh annual energy consumption for 2015. The typical non-domestic property consumes around 19,400 kWh/a for heating and DHW, and 9,700 kWh/a of electricity. These energy consumption figures become 75 kWh/m².a and 38 kWh/ m².a respectively when normalised for floor area. On a power demand/m² basis averaged over the year, then these further translate to 8.6 W/ m² and 4.3 W/ m² respectively.

The main uncertainty for future power supply requirements appears to lie in the industrial sector, where the timing and size of existing process loads were unavailable to the project.

Table 1: Overview of Wales Building Energy Demands

Wales Annual Energy Demand Figures	TOTAL						DOMESTIC ONLY						NON DOMESTIC ONLY					
	Heating and DHW - Minimum	Heating and DHW - Predicted	Heating and DHW - Maximum	Electricity - Minimum	Electricity - Predicted	Electricity - Maximum	Domestic Heating and DHW - Minimum	Domestic Heating and DHW - Predicted	Domestic Heating and DHW - Maximum	Domestic Electricity - Minimum	Domestic Electricity - Predicted	Domestic Electricity - Maximum	Non Domestic Heating and DHW - Minimum	Non Domestic Heating and DHW - Average	Non Domestic Heating and DHW - Maximum	Non Domestic Electricity - Minimum	Non Domestic Electricity - Average	Non Domestic Electricity - Maximum
Total Energy – TWh*	11.44	22.22	45.40	3.31	5.99	10.06	10.21	19.86	41.15	2.84	4.81	7.99	1.23	2.36	4.25	0.48	1.18	2.07
Average Energy per UPRN - kWh/UPRN	7,624	14,814	30,268	2,209	3,996	6,709	7,403	14,408	29,849	2,058	3,492	5,796	10,137	19,430	35,035	3,926	9,721	17,092
Average Energy per m2 - kWh/m2	79	154	315	23	42	70	90	176	364	25	43	71	39	75	136	15	38	66
Average Power - W/m2	9.0	17.6	35.9	2.6	4.7	8.0	10.3	20.0	41.5	2.9	4.9	8.1	4.5	8.6	15.5	1.7	4.3	7.6

*1 TWh = 1,000,000,000 kWh

The non-domestic energy consumption figure is considered a conservative estimate of the energy use in this sector, mainly due to missing or significant uncertainty over the energy profiles for some of the non-domestic building types, and due to uncertainty of the OS data for some categories. For example, the OS data in Table 7 shows only one airport in Wales, and locates it in Swansea.

Table 2: Sample of All Wales OS Data classifications and counts used to assess energy use

OS Count	OS Code	OS Description
579,575	RD	Dwelling
240,133	RD04	Terraced
234,175	RD02	Detached
200,203	RD03	Semi-Detached
126,609	RD06	Self Contained Flat (Includes Maisonette / Apartment)
11,761	RI03	Residential Education
8,638	R	Residential
8,509	CR08	Shop / Showroom
8,030	CS	Storage Land
7,066	CO	Office
6,887	PS	Street Record
6,430	LW02IW	Static Water
5,169	RD01	Caravan
4,944	CO01	Office / Work Studio
3,927	CI03	Workshop / Light Industrial
2,865	RH02	HMO Bedsit / Other Non Self Contained Accommodation
2,711	C	Commercial
2,524	CH02	Holiday Let/Accommodation/Short-Term Let Other Than CH01
2,086	RD08	Sheltered Accommodation
1,814	PP	Property Shell
1,769	OR04	Additional Mail / Packet Addressee
1,705	OR03	PO Box
1,505	CI	Industrial Applicable to manufacturing, engineering, maintenance, storage / wholesale distribution and extraction sites
1,484	RI01	Care / Nursing Home
1,374	CI04	Warehouse / Store / Storage Depot

1,333	CR07	Restaurant / Cafeteria
1,254	X	Dual Use
1,238	CR	Retail
1,053	CA01	Farm / Non-Residential Associated Building
938	OR01	Postal Box
856	CX	Emergency / Rescue Service
834	OI07	Hopper / Silo / Cistern / Tank
818	CC04	Public / Village Hall / Other Community Facility
802	CU01	Electricity Sub-Station
780	CL	Leisure - Applicable to recreational sites and enterprises
759	ZW	Place Of Worship
750	ZW99CH	Church
694	RI02	Communal Residence
684	CI01	Factory/Manufacturing
674	CR06	Public House / Bar / Nightclub
588	RH03	HMO Not Further Divided
587	RD10	Privately Owned Holiday Caravan / Chalet
528	CU11	Telephone Box
475	CL06	Indoor / Outdoor Leisure / Sporting Activity / Centre
473	RH	House In Multiple Occupation
440	CR01	Bank / Financial Service
438	P	Parent Shell
414	CT02	Bus Shelter
363	CR02	Retail Service Agent
326	CU04WC	Water Controlling / Pumping
320	CH01	Boarding / Guest House / Bed And Breakfast / Youth Hostel
306	CE03	Preparatory / First / Primary / Infant / Junior / Middle School
284	CR10	Fast Food Outlet / Takeaway (Hot / Cold)
283	CE02	Children's Nursery / Crèche
283	OG04	Slurry Bed / Pit
242	LC	Burial Ground
224	CU06	Telecommunication
212	CM01	Dentist
209	CH03	Hotel/Motel
202	ZW99CP	Chapel
196	CC10	Recycling Site
195	CC07	Church Hall / Religious Meeting Place / Hall
191	CE05	University

Table 2 shows a sample of the type of category information held by the OS for Wales, and the recorded totals of Unique Property Reference Numbers (UPRN) by Category. There are a number of UPRN which we would not expect to consume energy (examples highlighted in yellow), as well as a number of categories which are probably very similar in terms of their expected energy demands e.g. different categories of religious buildings or offices. We have interpreted and mapped electricity and heating energy profiles to these categories that we felt were the best likely fit, and used generic profiles where we did not have appropriate profiles. As noted previously industrial, transport and non-building commercial energy demands are not covered.

We can also look at the consumption demands by OA in a geographical format. Figure 3 shows the location of every domestic property in Wales with its OA average energy demand applied to it, separated into heating or electricity demands. The variation of demand around Wales can be clearly seen and helps reinforce the importance of considering the future energy supply system at a local as well as whole country basis. Figure 4 shows the same information but now for Non-Domestic Buildings.

These maps are available in high resolution in the ORCA database if greater detail is required.

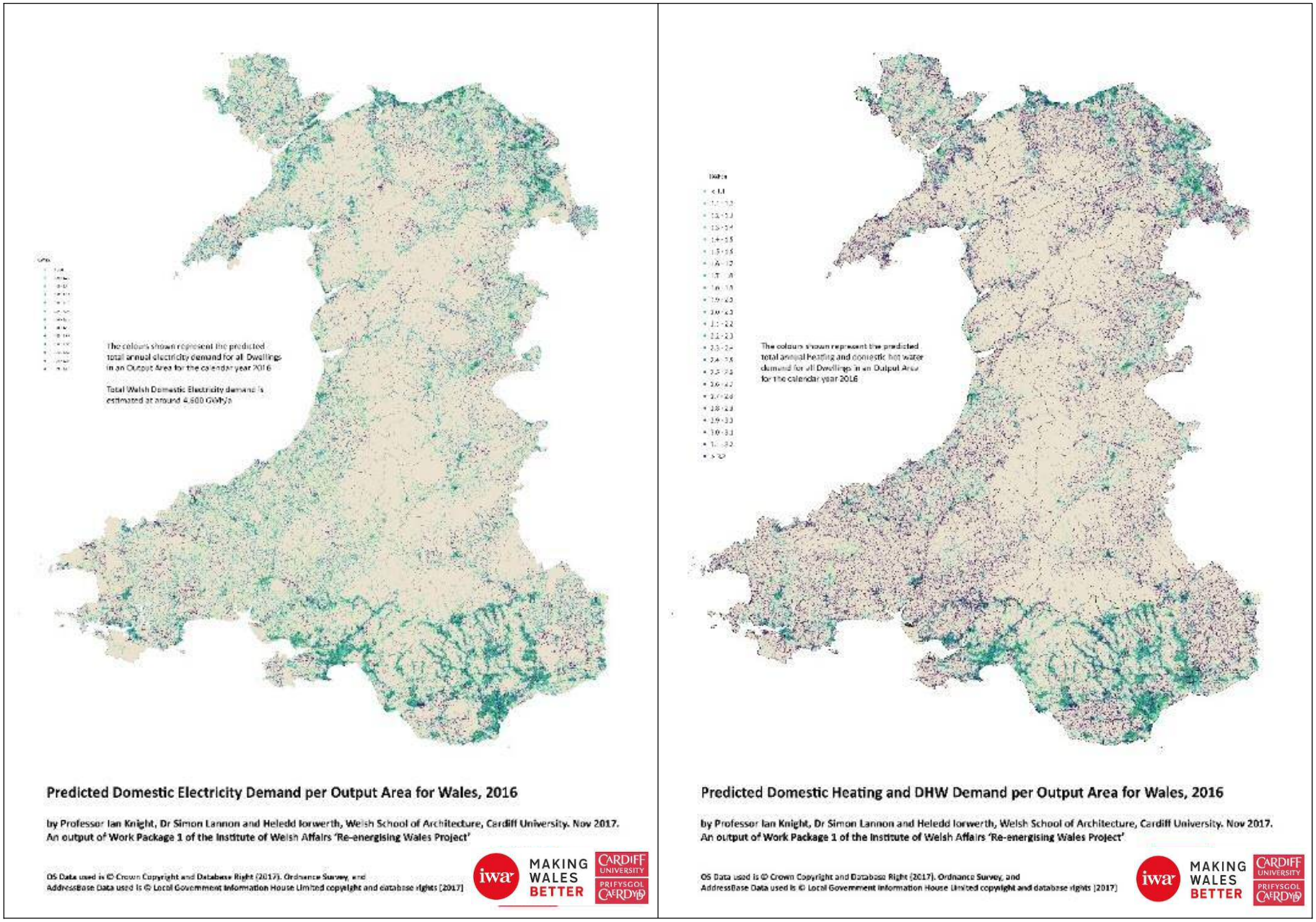


Figure 3: Estimated Annual Domestic Energy Demands by OA for Wales in 2016

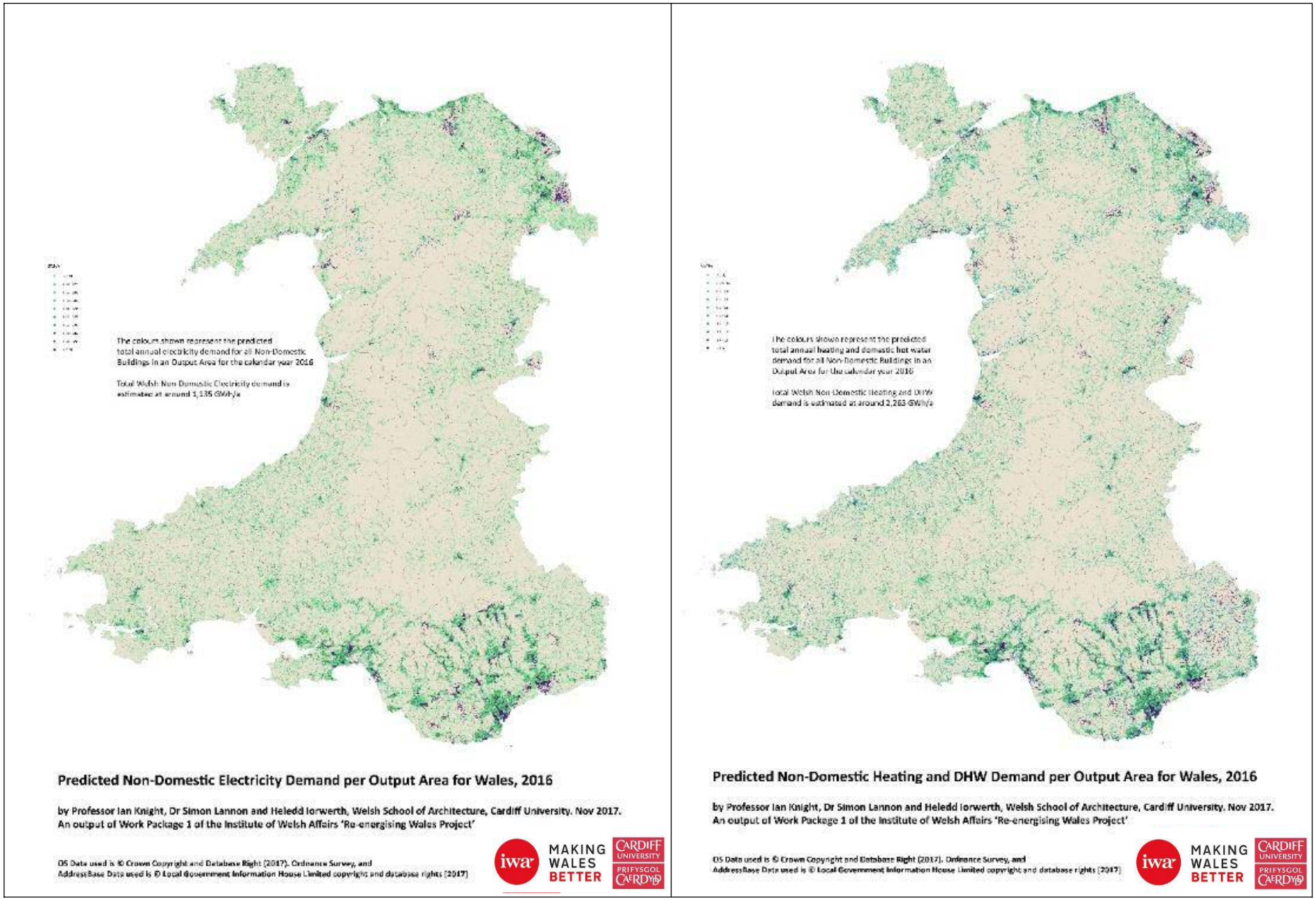


Figure 4: Estimated Annual Non-Domestic Energy Demands by OA for Wales in 2016

5.2 Findings and Observations by Local Authority

Table 3 and the accompanying graphs show the ranges of calculated total annual consumptions by domestic and non-domestic properties across all 22 Welsh LAs in both tabular and graphical formats. The domestic building demands are apparently significantly higher than the non-domestic building demands in all LA's. This does not seem unreasonable considering that the non-domestic figures do not include process, industrial or transport use e.g. no public realm energy use such as street lighting, traffic lights, etc., nor manufacturing demands. However, from the author's experience, these figures are lower than were expected and should be treated as 'for information only' at present. They represent less than 20% of the BEIS Commercial/Industrial annual energy use estimates per LA on average.

Table 3: Ranges of predicted building consumption per annum by Local Authority

Local Authority	Domestic Heating and DHW - Minimum (TWh/a)	Domestic Heating and DHW - Predicted (TWh/a)	Domestic Heating and DHW - Maximum (TWh/a)	Domestic Electricity - Minimum (TWh/a)	Domestic Electricity - Predicted (TWh/a)	Domestic Electricity - Maximum (TWh/a)	Non Domestic Heating and DHW - Minimum (TWh/a)	Non Domestic Heating and DHW - Average (TWh/a)	Non Domestic Heating and DHW - Maximum (TWh/a)	Non Domestic Electricity - Minimum (TWh/a)	Non Domestic Electricity - Average (TWh/a)	Non Domestic Electricity - Maximum (TWh/a)
Anglesey	0.203	0.455	1.180	0.067	0.115	0.192	0.024	0.049	0.092	0.010	0.023	0.041
Blaenau Gwent	0.249	0.429	0.804	0.063	0.107	0.164	0.037	0.091	0.181	0.016	0.045	0.078
Bridgend	0.464	0.809	1.570	0.127	0.215	0.327	0.039	0.069	0.116	0.013	0.036	0.066
Caerphilly	0.555	0.996	1.873	0.152	0.263	0.397	0.071	0.141	0.257	0.023	0.068	0.124
Cardiff	1.088	1.828	3.407	0.311	0.509	0.830	0.159	0.267	0.443	0.062	0.139	0.242
Carmarthenshire	0.500	1.638	3.008	0.157	0.263	0.494	0.005	0.009	0.015	0.002	0.004	0.007
Ceredigion	0.244	0.612	1.544	0.067	0.122	0.219	0.046	0.080	0.139	0.018	0.037	0.062
Conwy	0.416	0.843	1.747	0.112	0.192	0.321	0.040	0.066	0.109	0.015	0.033	0.055
Denbighshire	0.320	0.652	1.431	0.086	0.145	0.242	0.040	0.078	0.146	0.014	0.038	0.073
Flintshire	0.484	0.915	1.918	0.140	0.236	0.385	0.055	0.116	0.215	0.019	0.063	0.122
Gwynedd	0.460	0.997	2.609	0.114	0.205	0.363	0.090	0.201	0.415	0.059	0.100	0.164
Merthyr	0.199	0.366	0.718	0.053	0.094	0.145	0.019	0.047	0.093	0.008	0.024	0.044
Monmouthshire	0.312	0.680	1.411	0.086	0.154	0.272	0.061	0.096	0.144	0.012	0.037	0.066
Neath Port Talbot	0.496	0.867	1.789	0.137	0.223	0.359	0.041	0.073	0.127	0.014	0.032	0.058
Newport	0.493	0.813	1.526	0.137	0.228	0.354	0.069	0.135	0.239	0.023	0.075	0.137
Pembrokeshire	0.424	0.962	2.316	0.123	0.220	0.401	0.053	0.091	0.160	0.025	0.044	0.075
Powys	0.441	1.052	2.623	0.123	0.223	0.399	0.060	0.115	0.197	0.017	0.063	0.114
Rhondda Cynon Taf	0.828	1.385	2.551	0.227	0.374	0.607	0.075	0.131	0.223	0.030	0.067	0.111
Swansea	0.815	1.468	2.835	0.224	0.371	0.603	0.069	0.173	0.367	0.044	0.086	0.139
Torfaen	0.306	0.505	0.980	0.087	0.141	0.225	0.042	0.067	0.102	0.008	0.032	0.057
Vale of Glamorgan	0.458	0.804	1.539	0.122	0.206	0.333	0.045	0.105	0.201	0.019	0.057	0.104
Wrexham	0.450	0.788	1.774	0.122	0.210	0.358	0.089	0.157	0.269	0.026	0.074	0.133
WALES	**10.206**	**19.864**	**41.153**	**2.838**	**4.815**	**7.991**	**1.229**	**2.356**	**4.249**	**0.476**	**1.179**	**2.073**

Table 4 and the accompanying graphs show the ranges of calculated annual consumptions in Table 3 divided by the number of Unique Property Reference Numbers (UPRN) for domestic and non-domestic properties across all 22 Welsh LA's. Now the domestic building demands/UPRN are generally lower than the non-domestic building demands/UPRN in most LAs. The figures for Carmarthenshire non-domestic properties are too low, though we do not yet know why, and should be treated as incorrect.

The average predicted annual electricity demand for domestic properties across Wales of around 3,500 kWh/UPRN is in line with BEIS data and provides confidence in the calculation of this figure, and hence the average, minimum and maximum predictions of between 2,000 to 5,800 kWh/UPRN.a respectively.

The average minimum, predicted and maximum annual 'Heating and DHW demands' for domestic properties across Wales of 7,400, 14,400 and 29,800 kWh/UPRN respectively are believed to be new figures, as they are derived from calculations of the energy use required to maintain given conditions in each building rather than recorded consumption figures. Comparing these figures at OA level (from the detailed excel spreadsheets) with actual consumptions could help identify areas for action in the housing stock.

For non-domestic buildings the predicted average annual demands for heating and electricity use per UPRN seem possible considering that they do not include process or industrial use, will include many small offices and other relatively low energy consumers, and cover an average area of 257m². However, with non-domestic gas tariffs starting at >73,000 kWh/annum per UPRN, and noting that from a sample set of around 70 Schools the average annual demand was around 130,000 kWh/UPRN for electricity and around 190,000 kWh/UPRN for gas, then these figures do not remove the uncertainty surrounding the non-domestic energy demand calculations noted earlier when discussing Table 3.

Table 4: Ranges of predicted building consumption per UPRN per annum by Local Authority

Local Authority	Number of Domestic UPRN	Domestic Heating and DHW - Minimum (kWh/UPRN.a)	Domestic Heating and DHW - Predicted (kWh/UPRN.a)	Domestic Heating and DHW - Maximum (kWh/UPRN.a)	Domestic Electricity - Minimum (kWh/UPRN.a)	Domestic Electricity - Predicted (kWh/UPRN.a)	Domestic Electricity - Maximum (kWh/UPRN.a)	Number of Non-Domestic UPRN	Non Domestic Heating and DHW - Minimum (kWh/UPRN.a)	Non Domestic Heating and DHW - Average (kWh/UPRN.a)	Non Domestic Heating and DHW - Maximum (kWh/UPRN.a)	Non Domestic Electricity - Minimum (kWh/UPRN.a)	Non Domestic Electricity - Average (kWh/UPRN.a)	Non Domestic Electricity - Maximum (kWh/UPRN.a)
Anglesey	31,728	6,398	14,348	37,191	2,122	3,622	6,053	1,718	14,199	28,683	53,318	6,068	13,648	23,934
Blaenau Gwent	32,774	7,603	13,077	24,539	1,926	3,275	5,014	2,461	14,905	36,863	73,454	6,547	18,471	31,737
Bridgend	62,003	7,485	13,053	25,328	2,041	3,463	5,274	3,293	11,961	20,948	35,180	4,060	10,988	20,041
Caerphilly	77,547	7,152	12,843	24,152	1,957	3,389	5,122	3,802	18,791	37,118	67,708	6,160	17,879	32,600
Cardiff	150,148	7,245	12,173	22,690	2,069	3,389	5,525	20,040	7,936	13,320	22,100	3,086	6,952	12,084
Carmarthenshire	81,898	6,102	19,996	36,732	1,912	3,208	6,037	3,935	1,198	2,195	3,789	400	972	1,868
Ceredigion	32,670	7,475	18,739	47,247	2,057	3,738	6,694	3,984	11,497	20,063	34,952	4,546	9,312	15,651
Conwy	54,791	7,595	15,387	31,888	2,038	3,500	5,858	3,981	9,961	16,685	27,343	3,674	8,399	13,799
Denbighshire	41,025	7,803	15,900	34,880	2,098	3,546	5,899	5,498	7,280	14,174	26,575	2,549	6,982	13,253
Flintshire	67,015	7,229	13,657	28,614	2,092	3,529	5,746	5,339	10,224	21,740	40,278	3,481	11,800	22,765
Gwynedd	58,067	7,922	17,178	44,928	1,970	3,523	6,244	9,154	9,810	21,905	45,343	6,445	10,955	17,951
Merthyr	27,056	7,347	13,525	26,553	1,942	3,469	5,366	1,482	12,935	31,595	62,419	5,304	15,932	29,372
Monmouthshire	39,675	7,874	17,137	35,563	2,168	3,877	6,856	3,829	15,925	25,097	37,619	3,111	9,779	17,187
Neath Port Talbot	63,994	7,754	13,550	27,955	2,134	3,482	5,607	3,518	11,568	20,813	35,976	3,858	9,067	16,358
Newport	64,962	7,584	12,512	23,494	2,115	3,506	5,456	6,282	11,056	21,508	38,110	3,694	11,975	21,784
Pembrokeshire	59,190	7,172	16,259	39,126	2,070	3,711	6,780	6,254	8,437	14,514	25,523	4,016	7,047	12,013
Powys	59,841	7,366	17,585	43,831	2,057	3,733	6,673	6,393	9,375	18,060	30,782	2,665	9,800	17,888
Rhondda Cynon Taf	108,896	7,601	12,718	23,424	2,088	3,431	5,576	9,058	8,320	14,495	24,569	3,258	7,391	12,297
Swansea	108,991	7,479	13,465	26,008	2,059	3,400	5,533	8,707	7,890	19,855	42,184	5,092	9,880	15,935
Torfaen	41,029	7,470	12,296	23,894	2,127	3,435	5,478	3,262	12,887	20,417	31,313	2,313	9,737	17,625
Vale of Glamorgan	55,942	8,184	14,373	27,509	2,189	3,690	5,952	3,437	13,137	30,505	58,570	5,541	16,660	30,185
Wrexham	59,452	7,570	13,254	29,837	2,060	3,530	6,018	5,839	15,317	26,806	45,993	4,431	12,597	22,853
WALES	**1,378,694**	**7,403**	**14,408**	**29,849**	**2,058**	**3,492**	**5,796**	**121,266**	**10,137**	**19,430**	**35,035**	**3,926**	**9,721**	**17,092**

Finally, Table 5 and the accompanying graphs present the calculated demands for Wales and its LAs in terms of their energy demand per m². In this table the average annual demands for both heating and electricity per m² are in line with the author's expectations for domestic properties. For non-domestic properties the consumptions may be a little low per m² but a lower heating consumption per m² is not unexpected, compared to domestic properties, as often the non-domestic properties are intermittently heated and/or only heated during the warmer daylight hours. In addition, the envelope losses are also often lower per m² as the building surface to volume ratios can be lower than for domestic properties. Referring to the schools discussed earlier, their average annual heating demands are around 57 kWh/m2 and their average annual electricity demands around 34 kWh/m2, which supports the figures shown in Table 5. Figures from the EU Buildings Observatory for the UK (European Commission, 2018) for non-domestic buildings, which exclude industrial consumption, suggest heating demands of around 88 kWh/m².a, which are also in line with our calculations, but electricity demands of around 165 kWh/m².a, which are significantly higher than our average estimate of around 38 kWh/m².a

Table 5: Ranges of predicted building consumption per m2 per annum by Local Authority

Local Authority	Domestic Floor Area/m2	Domestic Heating and DHW - Minimum (kWh/m2.a)	Domestic Heating and DHW - Predicted (kWh/m2.a)	Domestic Heating and DHW - Maximum (kWh/m2.a)	Domestic Electricity - Minimum (kWh/m2.a)	Domestic Electricity - Predicted (kWh/m2.a)	Domestic Electricity - Maximum (kWh/m2.a)	Non - Domestic Floor Area/m2	Non Domestic Heating and DHW - Minimum (kWh/m2.a)	Non Domestic Heating and DHW - Average (kWh/m2.a)	Non Domestic Heating and DHW - Maximum (kWh/m2.a)	Non Domestic Electricity - Minimum (kWh/m2.a)	Non Domestic Electricity - Average (kWh/m2.a)	Non Domestic Electricity - Maximum (kWh/m2.a)
Anglesey	2,903,843	70	157	406	23	40	66	689,887	35	71	133	15	34	60
Blaenau Gwent	2,347,789	106	183	343	27	46	70	995,325	37	91	182	16	46	78
Bridgend	4,907,345	95	165	320	26	44	67	1,135,394	35	61	102	12	32	58
Caerphilly	5,731,507	97	174	327	26	46	69	1,567,115	46	90	164	15	43	79
Cardiff	11,451,744	95	160	297	27	44	72	3,351,884	47	80	132	18	42	72
Carmarthenshire	5,900,413	85	278	510	27	45	84	679,418	7	13	22	2	6	11
Ceredigion	3,259,459	75	188	474	21	37	67	780,489	59	102	178	23	48	80
Conwy	4,633,980	90	182	377	24	41	69	920,633	43	72	118	16	36	60
Denbighshire	3,492,242	92	187	410	25	42	69	937,619	43	83	156	15	41	78
Flintshire	5,419,116	89	169	354	26	44	71	2,044,476	27	57	105	9	31	59
Gwynedd	4,999,378	92	200	522	23	41	73	2,072,556	43	97	200	28	48	79
Merthyr	2,072,133	96	177	347	25	45	70	607,734	32	77	152	13	39	72
Monmouthshire	4,119,417	76	165	343	21	37	66	1,047,012	58	92	138	11	36	63
Neath Port Talbot	5,088,684	98	170	352	27	44	71	1,085,257	37	67	117	13	29	53
Newport	5,135,428	96	158	297	27	44	69	2,004,844	35	67	119	12	38	68
Pembrokeshire	5,581,845	76	172	415	22	39	72	1,139,207	46	80	140	22	39	66
Powys	5,791,710	76	182	453	21	39	69	1,673,632	36	69	118	10	37	68
Rhondda Cynon Taf	8,794,065	94	157	290	26	42	69	2,073,348	36	63	107	14	32	54
Swansea	8,536,396	95	172	332	26	43	71	2,148,363	32	80	171	21	40	65
Torfaen	3,075,775	100	164	319	28	46	73	1,023,643	41	65	100	7	31	56
Vale of Glamorgan	4,975,148	92	162	309	25	41	67	1,008,382	45	104	200	19	57	103
Wrexham	4,921,316	91	160	360	25	43	73	2,225,524	40	70	121	12	33	60
WALES	113,138,732	90	176	364	25	43	71	31,211,742	39	75	136	15	38	66

The above discussions form the author's main overview conclusions from this study. However, the full 32Gb of excel spreadsheets allow more detailed analyses at Output Area (OA) level to be conducted and some of these findings will be reported in future papers or reports.

5.3 Predicted Half Hourly Demands and Energy System Sizing

Figure 5 shows the size and timing of predicted half hourly domestic electricity peak demands for the whole of Wales. Similar figures can be produced by LA and OA for from the excel spreadsheets provided from this work. The data suggests that the electricity supply system for Wales needs to supply a minimum of 200 MW and a maximum of just under 2,000 MW to meet the electrical demands of the domestic sector at present. Electrifying transport across Wales could potentially be accommodated within this peak demand of 2,000 MW with controlled vehicle charging, but it is anticipated that if every house had an electric vehicle then average domestic electricity use could increase from around 10kWh per day to 15 - 20kWh per day.

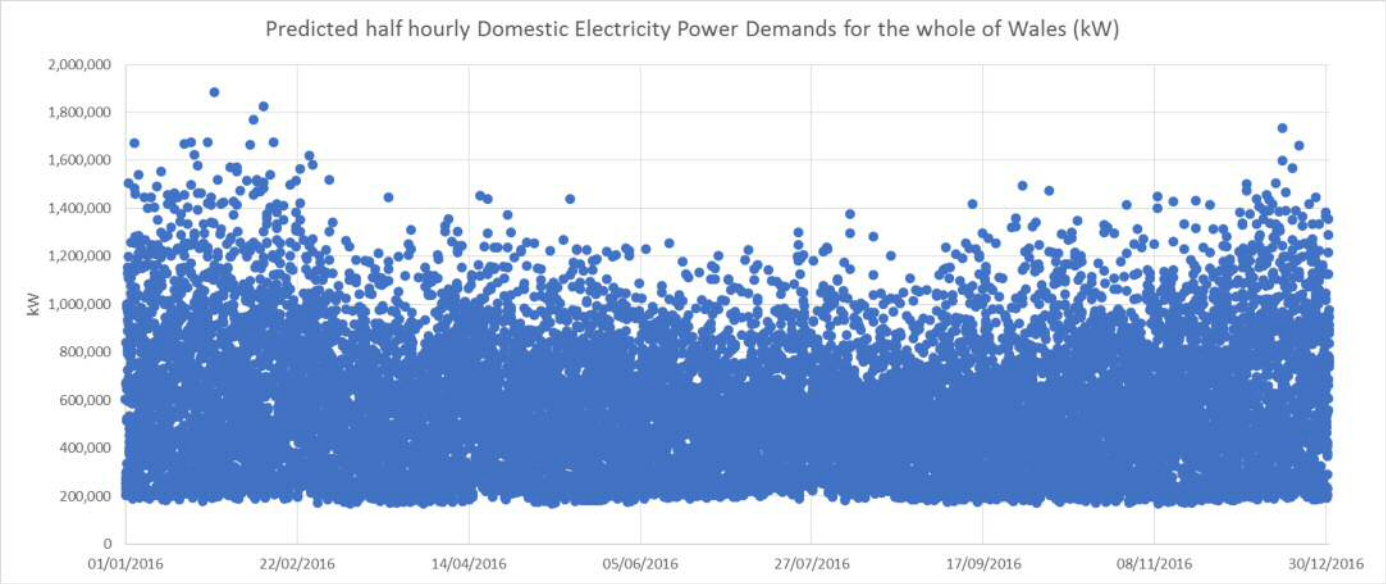


Figure 5: Predicted half hourly Domestic Electricity Power Demands for the whole of Wales

Figure 6 shows the size and timing of predicted half hourly domestic heating and DHW peak demands for the whole of Wales. Similar figures can be produced by LA and OA for from the excel spreadsheets provided from this work. The data suggests that the energy supply system for Wales needs to supply a maximum of about 25,000 MW to meet the heating and DHW demands of the domestic sector at present. However, these profiles are based on a very limited dataset and do not statistically represent the wider population sub-hourly profiles. This data should therefore be considered as overestimating these peak demands. In the author's opinion a peak demand of between 10,000 to 15,000 MW is a more accurate estimate of the domestic sector's likely heating and DHW requirements, based on normal installed heating capacity per m^2. However the shape of the demand profile in the figure does provide a reasonable insight into the variation of this supply requirement over the year.

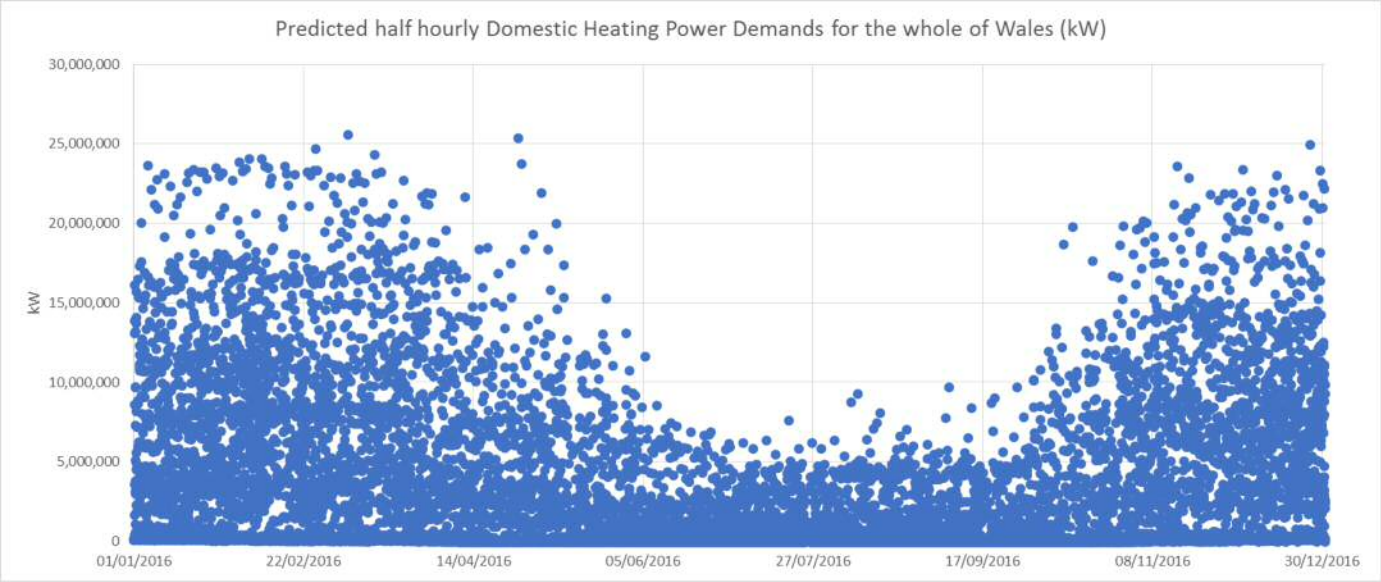


Figure 6: Predicted half hourly Domestic Heating and Domestic Hot Water Power Demands for the whole of Wales

Figure 7 presents the annual non-domestic buildings electricity demand profile for Wales. This suggests a peak power demand of between 300 to 450 MW could be expected from this sector – though as noted earlier it is felt the demand for this sector is underestimated so this figure could be higher in practice, perhaps around double the current figures shown.

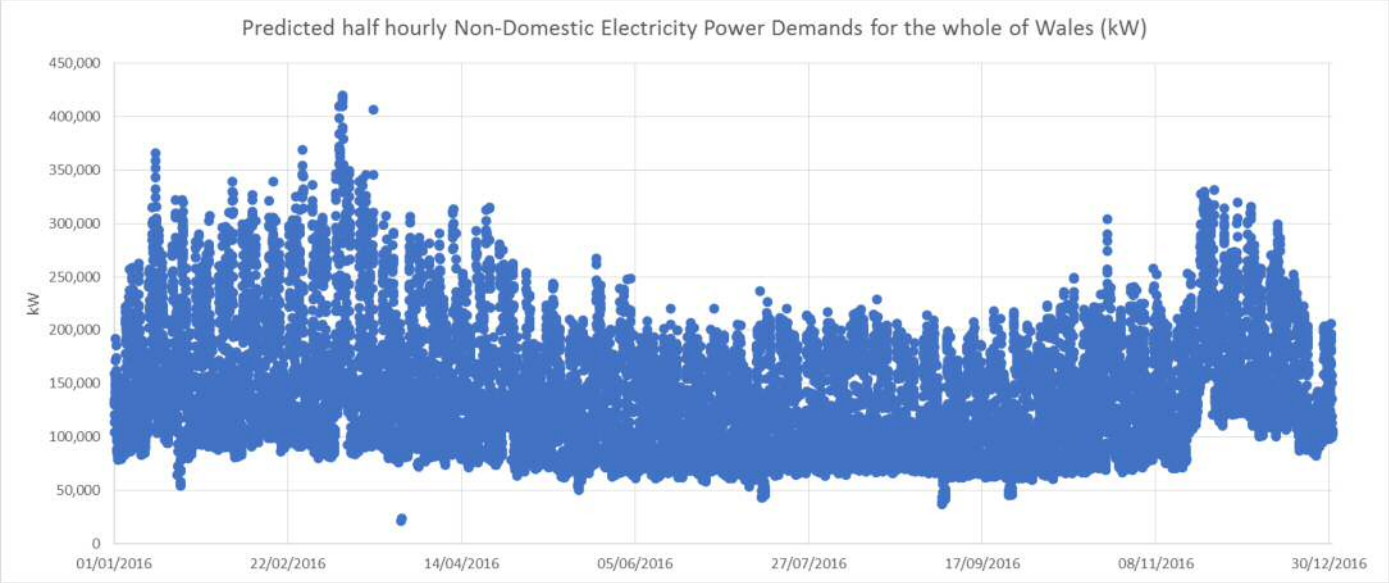


Figure 7: Predicted half hourly Non-Domestic Electricity Power Demands for the whole of Wales

Figure 8 shows the non-domestic heating demands follow a similar annual profile to the domestic heating demands but with a far lower predicted peak demand of around 1,500 MW. Even if this demand is also underestimated it is still significantly lower than the scale of the domestic demand shown earlier.

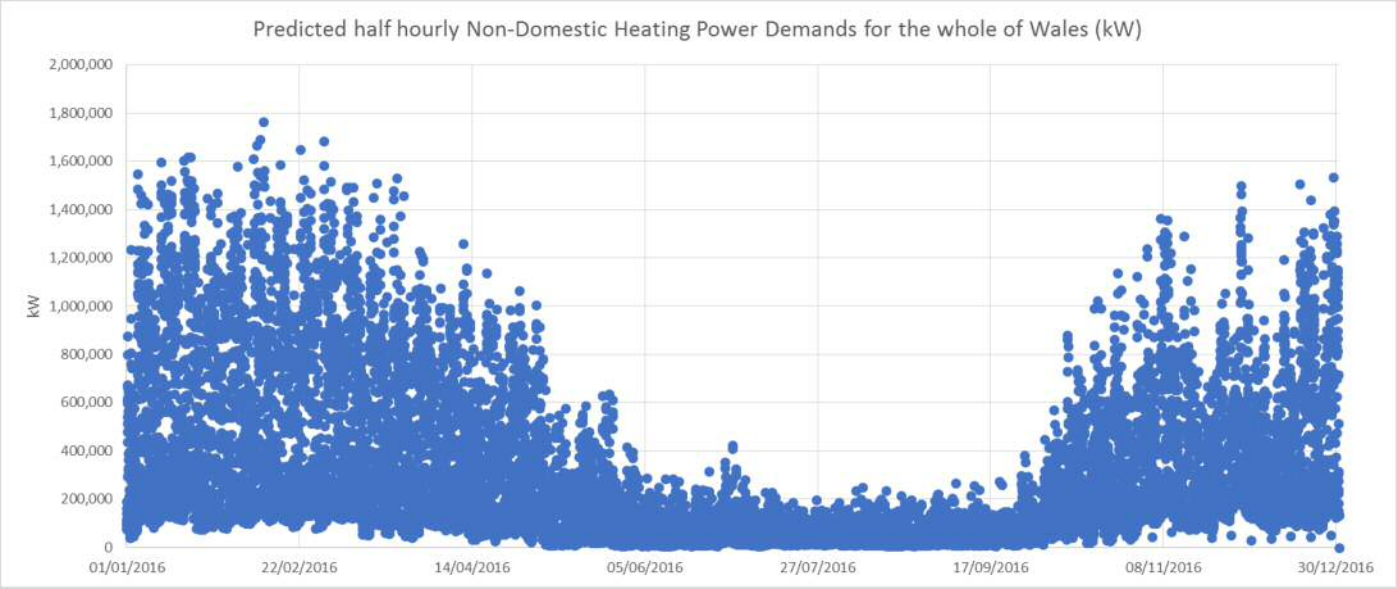


Figure 8: Predicted half hourly Non-Domestic Heating and Domestic Hot Water Power Demands for the whole of Wales

In summary, the outputs of this work package can be used to understand in more detail when and where energy is consumed in Wales, along with predictions of the impact of future development on power demands. This information can be used from local through to national scale to aid in the transition to a low carbon future.

The half-hourly energy demand profiles and all of Wales maps that accompany this report can be downloaded from the Cardiff University ORCA Repository at http://orca.cf.ac.uk/107222/ .

6 DATA CAVEATS AND DETAILS

It is important to note that, while the annual consumption estimates produced by the WP are shown to be comparable to BEIS data for many LAs, they are primarily intended for use in providing an insight into the potential peak size and timing of energy consumption and power demands across the year for buildings at a geographical level across Wales. They are not claimed to be the actual demands in 2016.

The domestic sub-hourly electricity demand profiles produced are derived from IEA ECBCS Annex 42 seasonal profiles and split the modelled annual electricity consumption into 4 seasons.

The sub-hourly domestic heating demand profiles are produced from a sample dataset which was too small to provide a statistically representative range of profiles. The half hourly OA demand profiles presented should therefore only be used as an indication of the potential peak power demands for each OA.

The profiles cannot be used for assessing the impact of past interventions on energy consumption, as they are not derived from the recorded consumption for each property. They can however be used as the Building Research Establishments Standard Assessment Procedure 2012 (BRE SAP) predictions for the potential annual performance for each domestic OA as a whole.

The non-domestic data profiles are experimental. They are derived from measured sub-hourly energy demand profiles per m^2 for various non-domestic building types. These profiles are then applied to the calculated floor areas for each building type in each OA as provided by the Ordnance Survey data. The main uncertainty with these profiles and predicted consumptions are the absence of any information on the activities and servicing arrangements in these buildings. They currently primarily reflect the expected consumption for naturally ventilated servicing and heating performance in these buildings. As such they almost certainly underestimate the actual consumption in these buildings in practice.

In addition, it should be noted that there are discrepancies between the non-domestic building numbers reported by building type, and those expected from knowledge of the building stock. Table 7, presented later, shows the number of buildings mapped from the OS data to each of the building types shown. There are a significant number of non-domestic buildings for which we have provided a generic profile as we do not have specific profiles for them. However, the same table also shows that there is only one airport reported for Wales, placed in Swansea, which is clearly wrong.

The main outcome of these issues is to create uncertainty about the non-domestic building demands predicted which would need further time invested to clarify, so the non-domestic profiles are best treated as for information at present.

Table 6 and Table 7 on the following pages show more detail of the characteristics and categorisations of the domestic and non-domestic buildings by LA which have been derived from the OS, DEC, EPC, and GIS data sources used in this work.

The data in Table 6 is derived from analysis of the OS Databases, OS GIS data, DEC's and EPC's for Wales, as detailed later in the report. The cells highlighted in yellow represent errors in transposing the data into this table that could not be rectified during the writing of this report. For RCT and Swansea it is not yet clear what has happened to cause this error.

Table 6: Domestic Building Metadata by Local Authority and Wales as a whole

Local Authority	Number of domestic properties	Total floor area of domestic properties (m2)	Average floor area of domestic properties (m2)	Detached - number of domestic properties	Semi Detached - number of domestic properties	Mid Terraced - number of domestic properties	End Terraced - number of domestic properties	Flats - number of domestic properties	pre 1919 - number of domestic properties	1919-1983 - number of domestic properties	post 1983 - number of domestic properties	1 occupant - number of domestic properties	2 occupants - number of domestic properties	3 occupants - number of domestic properties	4+ occupants - number of domestic properties	Mains gas - number of domestic properties	Solid fuel - number of domestic properties	Oil - number of domestic properties	biomass - number of domestic properties	electric - number of domestic properties	wood - number of domestic properties	LPG - number of domestic properties	no system - number of domestic properties
Anglesey	31,728	2,903,843	92	14,863	5,249	5,183	4,308	2,125	9,596	20,967	1,165	9,228	12,514	4,662	5,321	15,285	128	8,033	57	5,501	212	2,416	96
Blaenau Gwent	32,774	2,347,789	72	3,116	6,906	12,537	6,098	4,117	15,924	15,524	1,326	8,223	13,325	5,495	5,731	32,044	102	86	136	258	41	54	53
Bridgend	62,003	4,907,345	79	14,266	19,214	13,066	9,300	6,157	15,995	40,073	5,935	13,838	26,052	10,481	11,632	59,622	135	498	368	956	76	280	68
Caerphilly	77,547	5,731,507	74	11,862	24,589	21,820	12,522	6,754	26,049	44,380	7,118	16,861	31,304	13,520	15,862	75,198	319	536	182	696	108	433	75
Cardiff	150,148	11,451,744	76	18,165	30,872	38,715	19,848	42,548	39,984	100,332	9,832	41,407	52,069	23,426	33,246	136,766	43	109	810	12,025	28	215	152
Carmarthenshire	81,898	5,900,413	72	30,958	22,779	12,327	8,298	7,536	65,075	13,969	2,854	14,490	48,769	7,826	10,813	49,720	1,029	24,304	374	3,637	763	1,957	114
Ceredigion	32,670	3,259,459	100	15,881	5,439	3,430	3,138	4,782	14,507	16,286	1,877	10,204	12,702	4,334	5,430	8,873	406	14,130	195	7,121	599	1,273	73
Conwy	54,791	4,633,980	85	-	-	-	-	-	-	-	-	15,104	22,030	7,387	10,270	44,497	172	3,639	157	4,297	297	1,636	96
Denbighshire	41,025	3,492,242	85	17,333	11,743	3,362	4,337	4,250	13,263	26,083	1,679	10,761	16,142	6,016	8,106	31,536	184	5,067	130	2,758	307	945	98
Flintshire	67,015	5,419,116	81	23,738	24,469	5,614	7,856	5,338	13,550	49,982	3,483	15,105	26,331	11,103	14,476	54,259	164	7,947	684	2,418	259	1,189	95
Gwynedd	58,067	4,999,378	86	18,838	10,162	11,958	9,492	7,617	30,749	26,043	1,275	17,706	21,337	7,717	11,307	29,810	547	10,553	207	12,013	961	3,761	214
Merthyr	27,056	2,072,133	77	3,745	5,781	10,156	5,261	2,113	12,321	13,226	1,509	5,713	10,107	5,102	6,134	26,007	220	288	133	194	23	145	46
Monmouthshire	39,675	4,119,417	104	16,641	7,790	4,882	5,430	4,932	9,476	27,052	3,147	8,923	16,351	6,015	8,386	30,154	200	5,999	167	1,846	256	1,011	42
Neath Port Talbot	63,994	5,088,684	80	12,348	22,409	12,538	8,501	8,198	21,525	38,257	4,212	15,394	23,942	11,218	13,440	60,067	597	1,898	222	835	68	196	111
Newport	64,962	5,135,428	79	11,498	15,283	16,700	10,131	11,350	9,128	49,972	5,862	14,669	24,919	10,043	15,331	60,642	90	565	1,276	1,978	32	327	52
Pembrokeshire	59,190	5,581,845	94	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Powys	59,841	5,791,710	97	27,864	11,365	7,011	7,439	6,162	21,413	34,314	4,114	15,497	26,069	7,570	10,705	27,607	732	21,194	155	6,752	1,037	2,222	141
Rhondda Cynon Taf	108,896	8,794,065	81	15,561	-	44,278	37,629	11,428	57,169	44,517	7,210	12,066	76,656	9,414	10,760	105,943	505	412	526	896	104	313	197
Swansea	108,991	8,536,396	78	-	50,996	-	38,480	19,515	32,121	70,781	6,089	30,302	40,033	17,357	21,299	100,235	371	2,567	674	4,124	135	786	99
Torfaen	41,029	3,075,775	75	6,934	8,587	12,318	7,820	5,370	6,954	32,379	1,696	8,993	15,843	7,114	9,079	39,635	57	225	491	463	47	82	29
Vale of Glamorgan	55,942	4,975,148	89	13,995	13,448	11,835	7,613	9,051	14,197	37,838	3,907	13,081	21,726	9,131	12,004	50,955	54	2,304	34	1,928	75	522	70
Wrexham	59,452	4,921,316	83	17,163	18,413	7,543	9,070	7,263	13,221	41,308	4,923	14,022	22,428	9,892	13,110	50,764	88	4,684	111	3,116	132	516	41
WALES	**1,378,694**	**113,138,732**	**82.1**	**294,769**	**315,494**	**255,273**	**222,571**	**176,606**	**442,217**	**743,283**	**79,213**	**311,587**	**560,649**	**194,823**	**252,442**	**1,089,619**	**6,143**	**115,038**	**7,089**	**73,812**	**5,560**	**20,279**	**1,962**

Table 7: Non-Domestic Building Energy Use Categories mapped from the OS data, by Local Authority and Wales as a whole

Local Authority	Airport	Barrage	Castle	Changing Room	Community Building	Crematorium	Dwelling	Dwelling-Max	External Sports with Floodlights	Farm	Greenhouse	Gypsy Site	Hospital	Hotel	Ice Rink	Laboratory	Library	Library Store	Light Industry	Market-Indoor	Mortuary	Museum	No profile	Nursery	Office	Phonemast	Place of Worship	Primary School	Prison	Pub/Restaurant	Residential	Residential-Camping	Residential-Care	Retail	Secondary School	Sports Centre Dry	Sports Centre Leisure Pool	Station	Street and traffic lights	Swimming Pool	Telephone exchange	Theatre	Warehouse	White Water Centre	Workshop	No classification
	-	-	-	-	17	-	52	-	1	11	-	-	1	84	-	-	3	-	44	-	-	2	211	4	189	5	14	14	-	40	67	20	23	208	7	-	1	1	-	-	-	2	12	3	-	682
Blaenau Gwent	-	-	-	-	29	1	-	-	-	32	-	-	6	3	-	-	1	-	23	-	-	1	474	1	534	-	49	15	-	49	5	-	24	327	4	-	4	-	-	-	-	6	6	-	-	867
Bridgend	-	-	-	-	18	-	-	-	1	5	-	-	1	20	-	-	4	-	209	-	-	1	668	4	307	1	30	18	1	105	429	1	42	323	6	-	-	-	-	3	-	-	37	-	-	1,059
Caerphilly	-	-	-	-	71	2	-	-	1	1	-	-	2	5	-	-	10	-	349	-	-	3	697	22	432	8	73	37	-	163	207	-	58	613	33	-	7	2	2	-	2	1	116	-	-	885
Cardiff	-	-	-	-	56	-	-	-	-	3	-	-	16	36	-	9	8	-	355	-	-	1	2,638	16	2,479	12	179	44	-	175	425	-	8,365	749	10	-	2	1	1	-	-	8	52	-	-	4,400
Carmarthenshire	-	-	-	-	20	-	-	-	-	22	-	-	2	44	-	1	7	-	35	-	-	4	1,093	8	347	7	35	36	-	62	110	3	110	338	8	-	3	1	-	-	-	2	7	-	-	1,630
Ceredigion	-	-	-	-	33	-	-	-	1	123	-	-	1	283	-	2	4	-	147	-	-	5	610	8	345	13	38	37	-	122	651	13	422	449	5	-	2	2	-	2	3	9	37	-	1	616
Conwy	-	-	-	-	27	-	-	-	-	2	-	-	2	146	-	-	2	-	75	-	-	1	881	8	460	3	66	15	-	55	279	4	112	281	9	-	-	3	-	-	1	2	16	1	-	1,530
Denbighshire	-	-	-	-	44	4	-	-	1	7	-	-	3	86	-	-	3	-	225	-	-	4	609	15	478	6	56	12	-	75	2,214	-	-	362	10	-	-	1	-	-	1	1	104	-	-	1,177
Flintshire	-	-	-	-	54	-	-	-	-	16	-	-	3	25	-	2	10	-	328	-	-	1	662	9	859	24	41	26	-	63	497	1	37	398	13	-	2	6	-	-	4	2	39	-	-	2,217
Gwynedd	-	-	-	-	216	1	-	-	-	98	-	-	2	566	-	-	12	-	278	-	-	11	864	12	856	10	251	13	-	214	1,705	23	281	973	14	-	4	4	2	-	-	4	110	1	-	2,629
Merthyr	-	-	-	-	15	-	-	-	1	1	-	-	2	4	-	-	2	-	9	-	-	1	322	4	371	-	28	23	-	16	16	-	49	148	11	-	1	1	-	-	1	5	4	-	-	447
Monmouthshire	-	-	-	-	40	3	-	-	1	390	-	-	6	115	-	4	1	-	85	-	-	4	722	11	624	6	126	11	1	86	197	2	73	375	26	-	2	1	1	-	2	4	40	-	-	870
Neath Port Talbot	-	-	-	-	35	-	-	-	1	249	-	-	2	31	-	1	13	-	156	-	-	2	566	10	381	-	37	36	-	112	79	1	85	331	11	-	2	1	1	1	2	12	63	-	1	1,296
Newport	-	-	-	-	23	1	-	-	-	7	-	-	13	14	-	2	3	-	237	-	-	-	631	12	771	2	44	11	-	70	1,378	-	1,068	413	9	-	-	1	1	-	-	1	77	1	-	1,492
Pembrokeshire	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Powys	-	-	-	-	44	-	-	-	1	20	-	-	4	257	-	-	2	-	164	-	-	7	1,031	12	795	7	76	9	-	81	257	14	46	386	16	-	1	2	1	1	2	10	60	1	-	3,086
Rhondda Cynon Taf	-	-	-	-	101	1	-	-	1	11	-	-	6	39	-	4	8	-	269	-	-	4	1,432	49	1,602	2	73	53	-	307	148	5	1,519	868	77	-	3	12	-	-	-	21	425	-	-	2,018
Swansea	1	-	-	-	75	2	-	-	1	21	-	-	12	140	-	-	13	-	175	-	-	5	1,051	26	1,246	16	72	33	1	176	1,257	3	568	795	11	-	7	4	1	-	1	11	42	-	-	2,941
Torfaen	-	-	-	-	20	-	-	-	-	2	-	-	14	6	-	-	2	-	186	-	-	1	903	4	252	3	48	3	-	55	103	-	92	171	10	-	2	-	-	-	1	1	51	-	-	1,332
Vale of Glamorgan	-	-	-	-	29	1	-	-	2	30	-	-	4	37	-	-	3	-	247	-	-	3	597	11	617	20	30	29	-	162	258	-	57	658	13	-	3	3	-	-	2	8	56	1	-	556
Wrexham	-	-	-	-	61	1	-	-	-	59	-	-	8	66	-	-	2	-	122	-	-	3	895	20	802	26	139	15	-	64	148	10	693	505	9	-	2	6	-	-	8	4	41	-	-	2,130
WALES	**1**	**-**	**-**	**-**	**1,028**	**17**	**52**	**-**	**13**	**1,110**	**-**	**-**	**110**	**2,007**	**-**	**25**	**113**	**-**	**3,718**	**-**	**-**	**64**	**17,557**	**266**	**14,747**	**171**	**1,505**	**490**	**3**	**2,252**	**10,430**	**100**	**13,724**	**9,671**	**312**	**-**	**48**	**52**	**10**	**7**	**30**	**114**	**1,395**	**8**	**2**	**33,860**

The data in Table 7 is derived from the Ordnance Survey (OS) Addressbase database. Where we do not have specific energy use profiles for a building type then these are counted under the 'No profile' category, and a generic profile used as a 'best guess'. 'No classification' covers all UPRN for which there is either no energy consumption or which fall into the industrial or non-building energy use categories.

Figure 9 orders this information from largest numbers of UPRN to smallest. The non-domestic buildings in Wales are dominated by UPRN which do not have an energy classification or for which we have had to provide a generic energy use profile. This partly helps to explain the lower than expected consumption for this sector. The next 4 largest categories of non-domestic UPRN are then Offices, Residential Care Homes, Commercial Residential Homes, and Retail Units. In the author's experience, none of these categories are particularly high-energy consumers per m² on average, which further supports the data presented earlier for the relatively low consumption in the non-domestic sector.

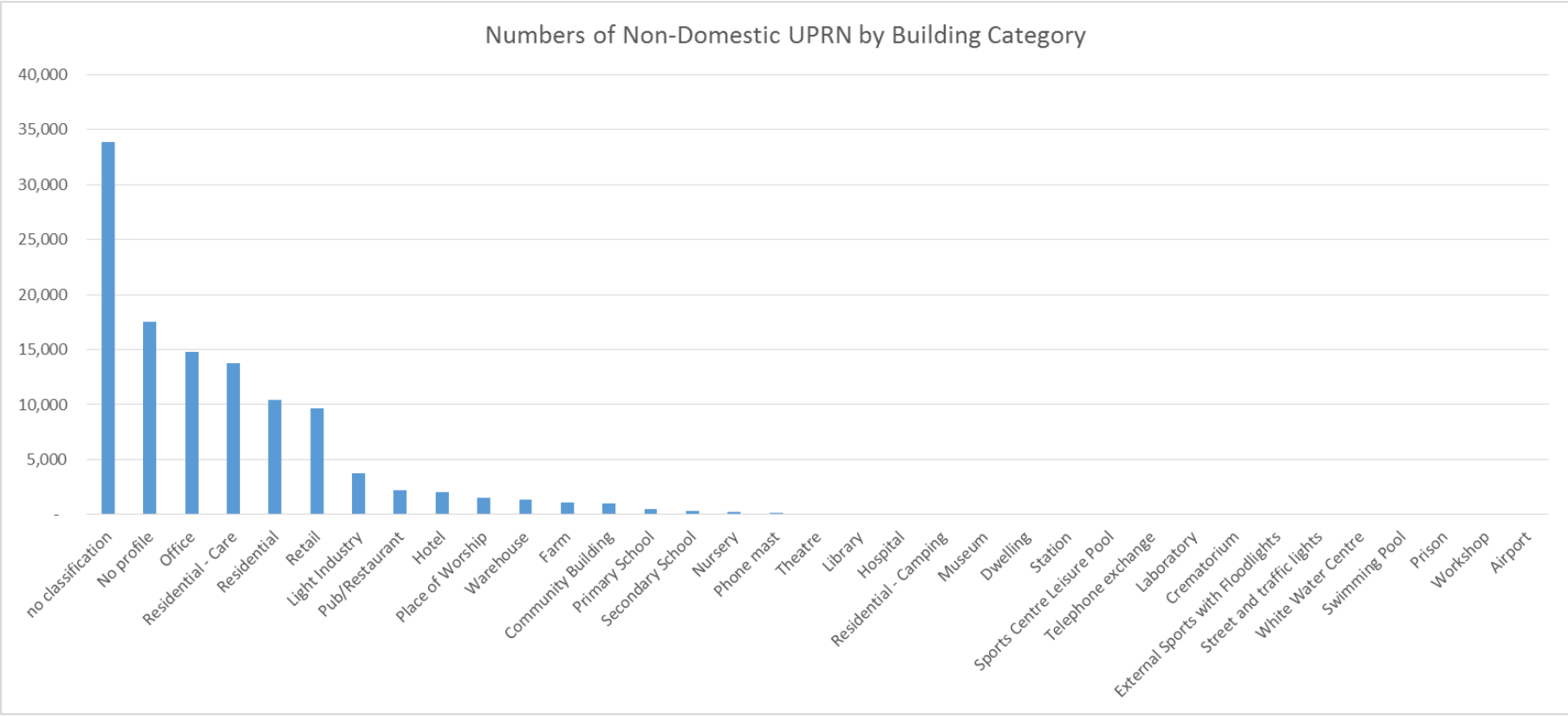


Figure 9: Numbers of Non-Domestic UPRN by Category for Wales

6.1 Comparison with Business, Energy and Industrial Strategy (BEIS) Data

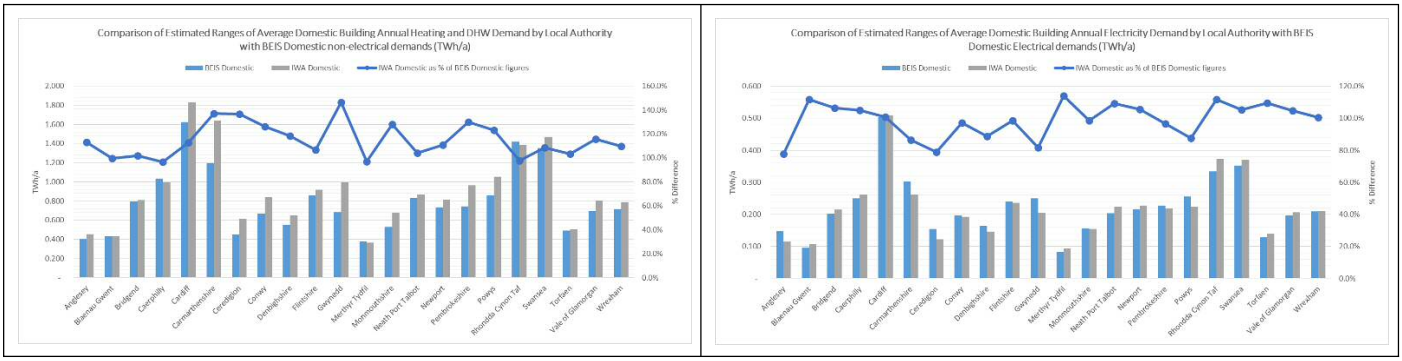


Figure 10: Comparison of Estimates for Annual Domestic Heating and Electricity Demands by Local Authority (LA) with BEIS 2015 data

Figure 10 shows a generally strong correlation between the IWA domestic energy demand estimates and the BEIS LA data. The main discrepancies appear to arise in those LAs with a lot of off-gas network heating, though BEIS own figures do provide domestic non-gas consumptions so these should be considered.

The BEIS calculation methodology uses data collected from MPANs and MPRNs as part of the process, so this may indicate significant variations between modelling and reality. However, BEIS also define domestic use as all gas consumption less than 73,200 kWh/a. Our calculation has identified the type of building at each UPRN so this will have introduced a variation in the calculated values for each sector as the data shows that a significant number of non-domestic buildings appear to consume less gas than 73,200 kWh/a. The final confounding factor is that BEIS figures are weather corrected to allow comparison across years and the IWA figures are not. It is not possible for this project to demonstrate whether the IWA figures are better or worse than the BEIS data – they are just different in some areas.

The IWA predicted annual domestic electricity demands were between 78% and 114% of the BEIS predicted figures by LA, with an all Wales average of 99%, i.e. nearly identical overall, but with some significant variations by LA.

The IWA predicted domestic heating and DHW demand profiles were generally higher than the BEIS figures, this time 97 to 146% of the combined non-electric domestic fuels consumption by BEIS by LA, with an all Wales average of 114%. It is important to note that the IWA figures represent the predicted heating and DHW power demands, which can be met from any energy source. This removes the need to understand the fuel used for the heating and DHW for each building, and allows for inclusion of the demand from off-grid properties. Clearly some electrical energy demand will be for heating in practice, so it is anticipated this will reduce the differences found.

The variation in heating demands between IWA and BEIS is in line with observations from Wales and West Utilities at some Re-energising Wales project meetings that the BEIS figures seem to underestimate gas use. These observations have not been tested in any detail.

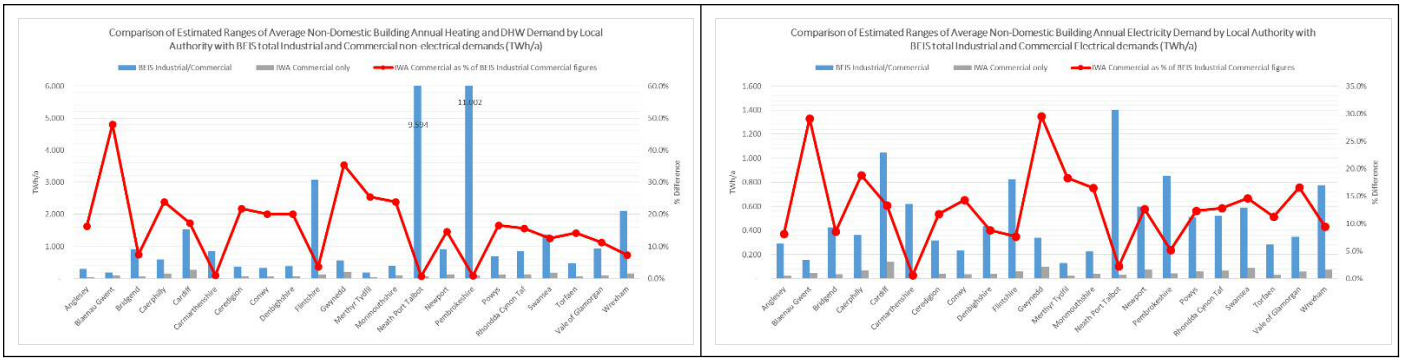


Figure 11: Comparison of Estimates for Annual Non-Domestic IWA Predicted Heating and Electricity Consumption by Local Authority (LA) with BEIS 2015 data for the total Industrial and Commercial Sectors

For the IWA non-domestic building energy demand predictions we can only compare them with the combined industrial/commercial BEIS figures for 2015, and place the IWA Estimates as a % of this combined consumption. The graphs in Figure 11 show a wide range of % variations by LA for both electricity and all other fuels.

Overall the IWA predicted non-domestic building heating and DHW demands represent a median 16% of the total non-electrical energy use predicted by BEIS for the combined industrial and commercial sector (the median was used to remove the major bias introduced by the Pembrokeshire, Neath Port Talbot and Flintshire heavy industry use). For electrical only demands, the IWA estimates represent a median figure of 12.5% of the total industrial and commercial electrical energy use estimated by BEIS.

Overall, these comparisons generally provide confidence in the methodology used in this WP for assessing the energy consumption of the domestic sector in Wales. For the non-domestic sector the lack of equivalent published figures from BEIS for the non-Domestic buildings sector means we can have less certainty in the IWA estimates produced, so they should be used as indicative figures only at present.

For both the IWA and BEIS estimates there are anomalous figures, which would benefit from further study to establish the reason for the variations.

7 RATIONALE AND METHODOLOGY UNDERPINNING THE DERIVATION OF THE IWA PROFILES

The profiles derivation is based around the IWA Re-energising Wales projects need to produce annual half-hourly energy demand profiles at as fine-grained a geographical level as possible, without compromising the privacy requirements of individual consumers.

A half-hourly energy demand profile enables comparison of potential generation profiles from renewable energy sources in a geographical area with the likely concurrent demand in that area over a full year. This then enables initial estimates of over or under-generation capacity from renewables at each time of day along with the amount and type of energy storage that might be required to maximise the use of specific renewable generation technologies.

The profiles presented represent only buildings demand in each OA i.e. they do not represent industrial process or transport energy demands as these were not available at the time of producing these profiles.

The geographical area used to aggregate the estimated demand from each Unique Property Reference Number (UPRN) was a choice between 2011 Census Output Areas (OA's) or Postcodes. The OA's were chosen as they have been shown to meet the requirements for data privacy and could also be aggregated into Lower Layer Super Output Areas (LSOA) and Middle Layer Super Output Areas (MSOA) for larger scale energy demand and supply analysis (Office for National Statistics, 2011).

For the non-Domestic profiles the calculation assumes that existing measured half-hourly energy demand/m^2 profiles for electricity and heating, that are generated and held by K2n Ltd (Knight) for a variety of building types across the UK, can be used to predict the percentage of the annual energy consumption that will be used in any half hour period for buildings of a similar typology across Wales.

The approach used to derive domestic annual heating (and electricity) consumption figures was to combine GIS, EPC and Addressbase data per UPRN to produce data for use in BRE's SAP 2012 calculation procedure. These annual consumption figures were then apportioned across the year using the sub-hourly domestic gas and electricity profiles available to the project. The detail of how this data was derived is provided in the following sections of this report.

It was anticipated that the actual annual energy consumption of individual MPAN's and MPRN's in some buildings would be available to the project to enable the modelled estimates to be assessed against actual consumptions but this actual data was not available at the time of writing this report.

7.1 Format of the Half-Hourly Data Files

The data files produced by the process followed in this WP are structured as follows:

- Each Welsh council has its own ZIP file containing the OA's most closely associated with its boundaries.
- The ZIP file structure for each council separates the 'kW demands per HH by OA' into 'Heating & DHW' demands and 'Electricity' demands. It further separates the profiles into domestic and non-domestic building typologies.
- The domestic profiles contain separate spreadsheets for the 'Maximum', 'Minimum', 'Average' and 'Predicted' kW per HH interval. The 'Maximum' and 'Minimum' spreadsheets are intended for use in helping size generation needs to meet these demands and are derived from measured data showing annual consumption and its distribution.
- The 'Average' and 'Predicted' spreadsheets for domestic buildings show how the 'Average' profile generated from measured data (the 'Average' spreadsheet) differs from those generated from the SAP Calculations (the 'Predicted' spreadsheet). The profiles for the 'Predicted' spreadsheet use the

measured 'Average' apportionment of data profile to distribute the predicted annual consumption for the year.

- The non-domestic building profiles contain separate spreadsheets for the 'Maximum', 'Minimum' and 'Average' profiles only i.e. all predictions are drawn ONLY from measured energy consumption profiles gathered from various non-domestic building typologies. The typologies used are presented later in this report.

An example of the data contained in the spreadsheets is shown below. This is the common format for all the data presented. For each Output Area (OA) within the Council (the OA name appears on the row labelled 'Area', e.g W00003947) the data covers:

- The number of UPRN in that OA (shown on the row labelled 'Count')
- The calculated 'Total Floor Area' covered by the UPRN's in that OA (shown on the row labelled Total Floor Area)
- The total demand in kW (electricity here) for each OA for the half hour period shown in the date and time column
- The sums of all the OA's for Count, Total Floor Area and kW/HH are shown in the column under the council name – Swansea is shown here. This spreadsheet shows a total domestic UPRN Count of 108,991 properties, with a 'Total Floor Area' of 8,536,396 m², and a total domestic electrical demand of 50.009 MW (5.9 W/m²) at 00:30 on the 1st of Jan 2016.

	A	B	C	D	E	F	G	H	I
1	Predicted Domestic Electricity Demand per interval by OA - buildings only (kW)								
2		Area	Swansea	W00003947	W00003948	W00003949	W00003950	W00003951	W00003952
3		Count	108,991.00	107.00	130.00	114.00	116.00	119.00	119.00
4	Date and Time	Total Floor Area	8,536,396.26	11,385.80	12,333.51	11,227.82	11,738.07	11,384.29	10,973.42
5	01/01/2016 00:30		50,009.39	49.99	58.80	55.58	51.87	51.91	50.74
6	01/01/2016 01:00		62,269.09	47.30	60.78	67.71	49.97	47.86	48.85
7	01/01/2016 01:30		51,036.57	42.86	54.21	58.01	44.77	43.57	44.12
8	01/01/2016 02:00		24,129.70	35.51	37.60	27.42	36.21	37.90	35.36
9	01/01/2016 02:30		21,952.66	32.38	34.26	24.93	33.02	34.57	32.24
10	01/01/2016 03:00		20,515.32	29.05	31.05	23.25	29.67	30.94	28.98
11	01/01/2016 03:30		20,588.44	29.83	31.66	23.28	30.45	31.82	29.72
12	01/01/2016 04:00		21,817.22	28.09	30.02	23.05	28.93	29.91	28.01
13	01/01/2016 04:30		19,417.39	27.13	28.89	21.58	27.76	28.91	27.04
14	01/01/2016 05:00		18,458.58	25.85	27.68	20.86	26.41	27.51	25.79
15	01/01/2016 05:30		16,966.51	25.75	26.99	19.16	26.24	27.54	25.60
16	01/01/2016 06:00		16,510.03	24.72	26.00	18.62	25.21	26.43	24.59
17	01/01/2016 06:30		17,352.81	26.45	27.69	19.57	26.96	28.31	26.29
18	01/01/2016 07:00		19,381.54	26.26	27.56	20.18	27.02	28.09	26.11
19	01/01/2016 07:30		19,970.90	31.04	32.21	22.26	31.64	33.29	30.80
20	01/01/2016 08:00		23,765.88	36.72	38.02	26.20	37.46	39.40	36.43
21	01/01/2016 08:30		25,106.52	40.87	42.27	28.66	41.54	43.87	40.54
22	01/01/2016 09:00		27,130.95	44.47	45.92	30.98	45.19	47.75	44.10

Analysis of the domestic sector spreadsheets presented will show some differences between the demands shown in the SAP 'Predicted' model spreadsheet and the Demands shown in the 'Average' profile spreadsheets. These arise from the predicted data further weighting the average, minimum and maximum data predictions by factors such as age.

The 'shape' of the measured profiles presented for both domestic and non-domestic sectors are derived from measured sub-hourly demands in operational buildings, so should encompass the actual operation of buildings in practice in each sector, though there are relatively small sample sets for some sectors.

The accuracy of the data can be viewed at two time intervals – the overall annual energy demand and the validity of the demands at any particular interval. The overall annual energy demands predicted have been tested against BEIS (Department for Business, Energy & Industrial Strategy, 2017) published experimental data for OA's, and are discussed further in section 8.6.2.

The method of aggregating measured UPRN HH demand profiles by typology and area has not been able to be validated yet, as at the time of writing this report no accessible datasets showing actual sub-hourly demand at the OA level had been found. Efforts will continue over the project to obtain such sample datasets to verify the method used to produce these profiles, and to clarify the likely accuracy of the non-domestic data, which has been derived from measured data.

In the interim users should treat the spreadsheet profiles as the estimates that they are.

7.2 Model Structure

Figure 12 is a schematic outlining the processes and data involved in estimating the **annual consumption of each building** within Wales. The large grey squares are the main data sources used, the light blue squares are the intermediate data created within the modelling process and the dark blue the final annual consumption of buildings data sets. The white ovals show the modelling processes involved. The box labels show which section of this report contains further descriptions of the process.

Figure 13 follows on from Figure 12 by outlining the process for using the outputs from Figure 12 to estimate the **half hour consumption of each building** throughout a year and then aggregate these profiles by OA. These aggregated estimated half-hourly electricity and heating demand profiles by OA are the data available in the spreadsheets provided by this work package.

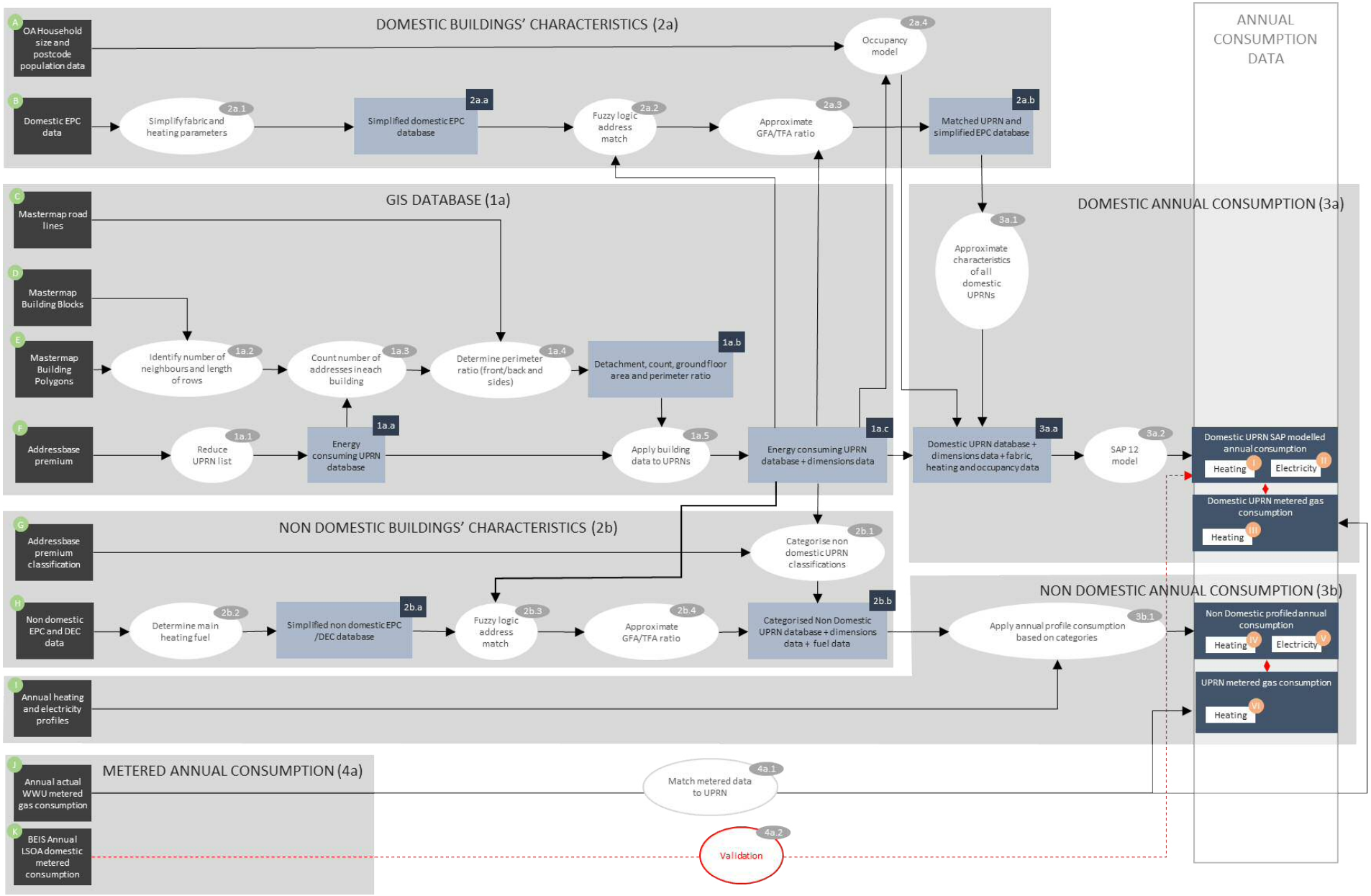


Figure 12: Model structure outline for estimating annual electricity and heating demands per UPRN

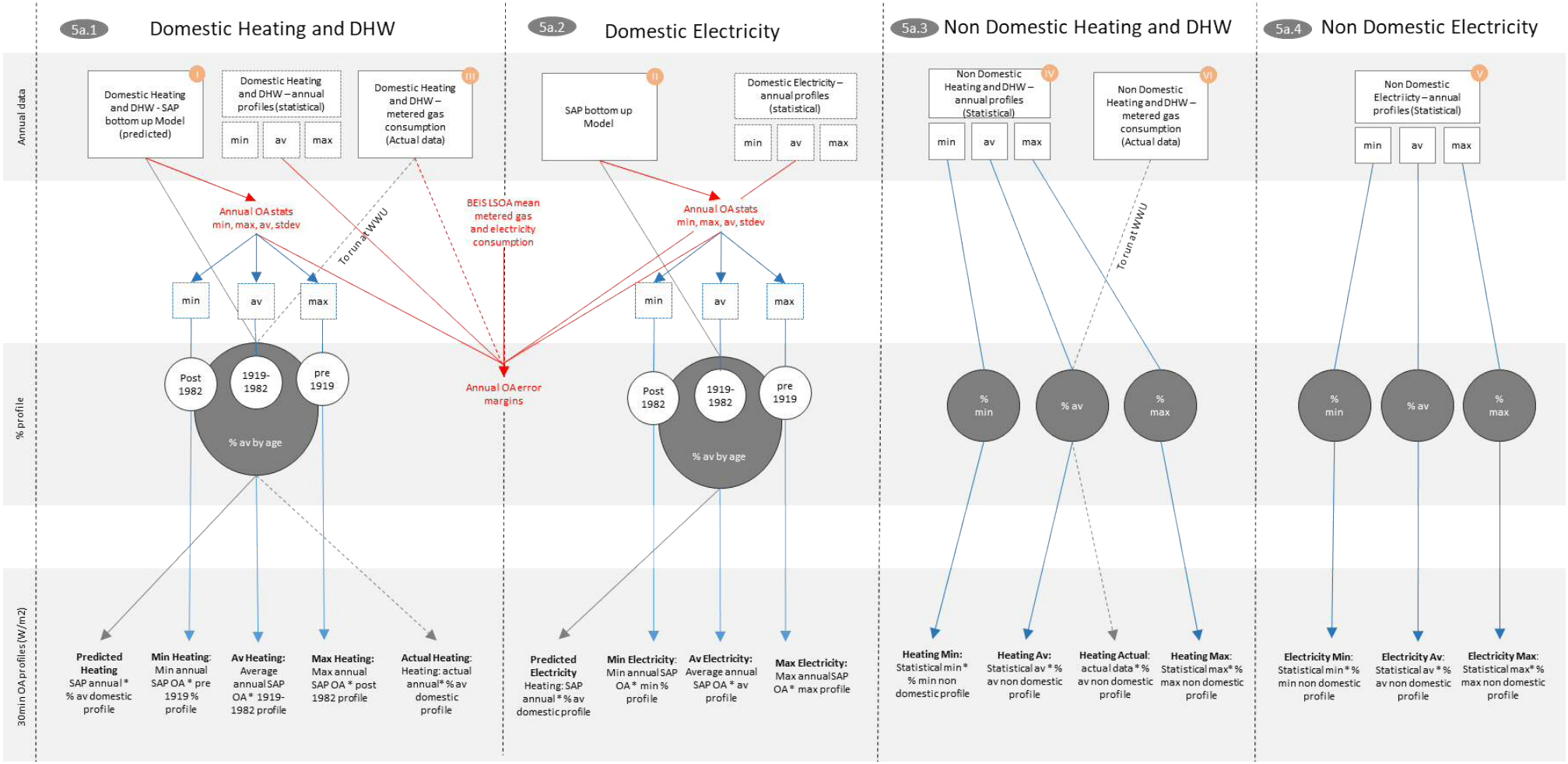


Figure 13: Model structure outline for converting Annual Demands by UPRN into half-hourly profiles by Output Area

8 MODELLING PROCESS

8.1 GIS Database

Two main data sources were used to geographically identify energy consuming buildings: Addressbase Premium (Ordnance Survey, 2017) and Mastermap Typography Layer (Ordnance Survey, 2017). Figure 14 shows the data sources and their relationship within a geographical information system (GIS). A simplified 'building blocks' version of the Mastermap Topography layer and a Mastermap road lines layer were further used to determine the typological and dimensional details of each address point.

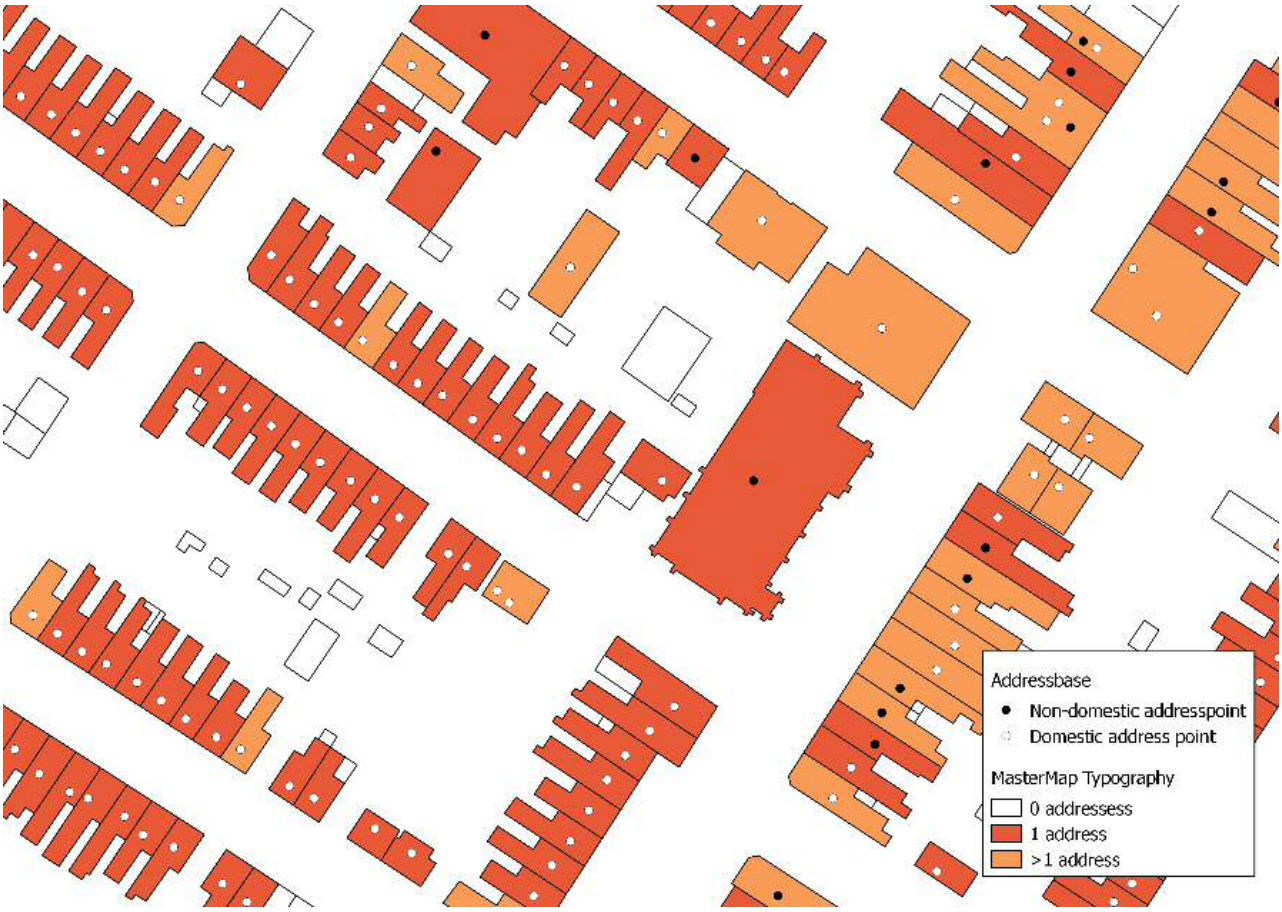


Figure 14: GIS database formation (addressbase premium and mastermap topography layer)

Figure 15 outlines the data sources and processes used to create a combined GIS database of address points (UPRNs) of unique energy consumption with detailed dimensions data.

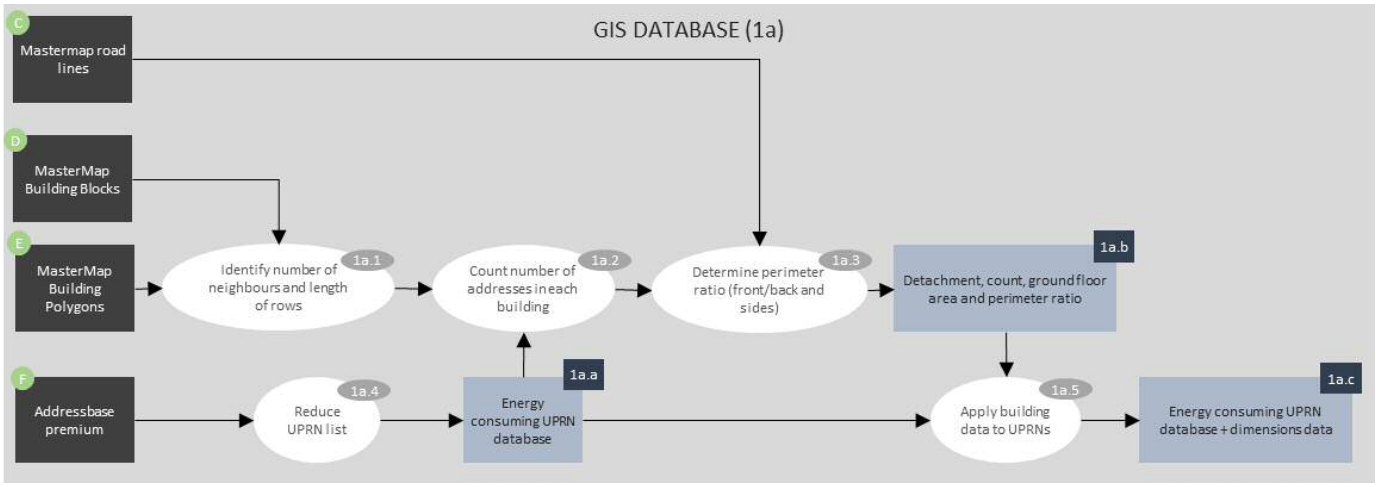


Figure 15: GIS Database processes (1a)

8.1.1 Reducing the address database

The Addressbase premium (Ordnance Survey, 2017) geographical database was processed and reduced to contain only currently used address points of unique energy usage. Address points or Unique Property Reference Numbers (UPRNs) which were provisional or historic records (Logical status ≠1), not in use (BLPU state ≠2), not a postal address (Addressbase Postal Code = N) or parent UPRNs with child UPRNs were removed. Addressbase premium codes and definitions are defined in (Ordnance Survey, 2017).

8.1.2 Identifying number of neighbours and length of building rows

A python script (Gandhi, 2017) for use within the geographical information system QGIS was applied to derive the number of neighbours/adjacent polygons for each individual building. A simplified Mastermap typography database which groups buildings in blocks was used to calculate the number of buildings within each 'block' and therefore allowed the distinction between end-terrace and semi-detached properties.

8.1.3 Counting the number of addresses in each building

Mastermap typography polygons were matched to the reduced database of energy consuming UPRNs giving the count of addresses within each building. This was used to identify flats (residential addresses in buildings with more than 1 address) and to split the building's dimensions equally between the addresses. Figure 16 describes the resultant detachment groups from section 8.1.2 and 8.1.3.

Detachment	Condition
Flat	More than 1 UPRN matched to polygon
Detached	No neighbours/adjacent buildings
Mid Terraced	2 or more neighbours/adjacent buildings
End Terraced	1 neighbour/adjacent building and more than 2 buildings in building block
Semi Detached	1 neighbour/adjacent building and 2 buildings in building block

Figure 16: Derivation of building detachments

8.1.4 Determining the perimeter ratio (front/back and sides)

Each mastermap polygon's equivalent bounding box (the best fit rectangle covering the polygon) was created using GIS, see Figure 17. The distance of each of the bounding box's sides to the nearest road was calculated. The nearest and furthest sides were assumed to be the front and back of buildings (width) with the other two sides assumed to be the sides of buildings (length). The length/width ratio was calculated for each polygon.

The side (length) of the UPRN was calculated as the square root of ((approx. TFA/floors) /perimeter ratio) and the front back (width) of the UPRN was calculated as (approx. TFA/floors)/UPRN length. See sections 8.2.3 and 8.3.4 for further explanations of dimension fields.

Figure 17: Determining buildings' perimeter ratio using GIS

8.1.5 Applying building data to address points

Each Mastermap polygon's data was applied to all address points within or touching its boundary as can be seen in Figure 18. The resultant 'Energy consuming UPRN database + dimensions data' included the fields listed in Figure 19.

Figure 18: Applying building data to UPRNs in GIS

UPRN Address	Concatenate of address from the Addressbase database
UPRN	Addressbase UPRN
Postcode	Postcode
OAcode	Output Area Code – Matching UPRNs to Output area by location using GIS
Classification	Addressbase classification code
Detachment	Detachment - calculated using Addressbase and Mastermap GIS files
UPRN GFA	Ground floor area of UPRN based on GIS calculation
side (m)	Approximate length of property
front back (m)	Approximate width of property

Figure 19: Fields included in the resultant energy consuming UPRN database

8.2 Approximating the characteristics of domestic buildings

Figure 20 outlines the process of determining the characteristics of domestic buildings. This included the use of EPC data (Department For Communities and Local Government, 2017), which was matched to the UPRN database as well as an occupancy model for approximating the number of occupants in dwellings.

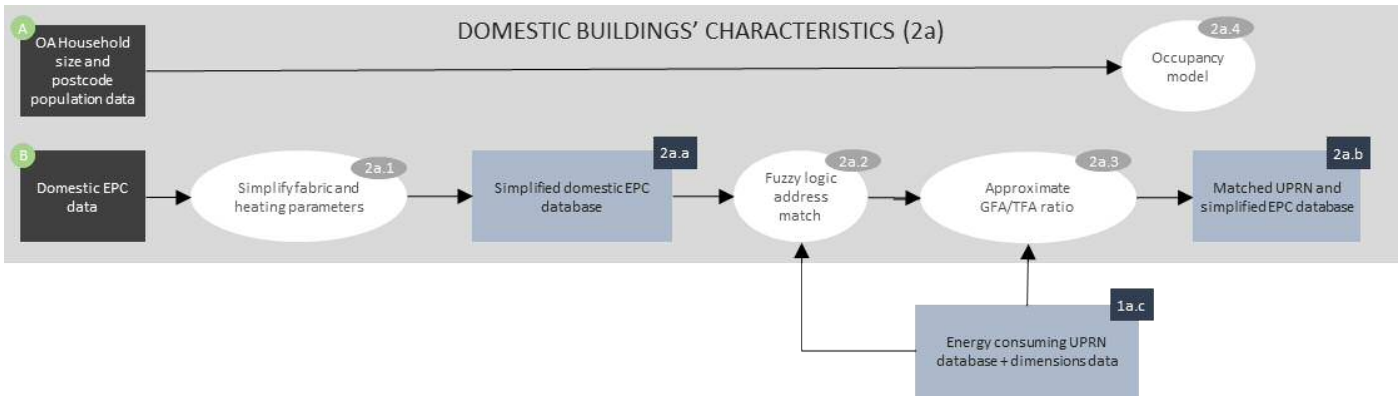


Figure 20: Domestic building's characteristics processes (2a)

8.2.1 Simplifying fabric and heating parameters

Data from the energy performance certificates were simplified and grouped (e.g. wall types grouped into solid uninsulated, solid insulated, cavity insulated, cavity uninsulated). The derived characteristics were inputted into the Standard Assessment Procedure (SAP) model for those UPRNs matched to EPCs. This data was also used to determine the most common characteristic for dwellings of a specific type within an area (see section 8.4.1). Figure 21 describes the derivation of SAP 2012 input fields from the EPC data for domestic properties.

FABRIC

<table>
<tr><th>Characteristics</th><th>Description</th></tr>
<tr><td>Property Age</td><td>Derived age of domestic EPC based on fabric characteristics
The age of each domestic EPC was approximated based on the following fabric characteristics:
<table><tr><th>Pre 1919</th><th>1919-1983</th><th>Post 1983</th></tr><tr><td>• If the primary wall type was solid (single brick or stone)</td><td>• If single glazing windows are present
• Or if roof's energy efficiency was rated as very poor or poor
• Or if wall's energy efficiency was rated as very poor or poor
• Or if there is no floor insulation</td><td>• All other certificates</td></tr></table></td></tr>
<tr><td>Window U Value</td><td>Simplified window U value of EPCs
EPC windows description and energy efficiency rating simplified to 5 U value groups
<table><tr><td>U value (W/m²K)</td><td>2</td><td>2.2</td><td>3</td><td>3.1</td><td>4.8</td></tr></table></td></tr>
</table>

Wall U value

Simplified wall type of EPCs

EPC wall descriptions grouped into five wall types

wall type	U value (W/m²K)
Solid uninsulated	1.7
Solid insulated	0.45
Cavity insulated	0.45
Cavity uninsulated	1.6
Cavity partly	1

Roof U value

Simplified roof insulation levels of EPCs

EPC roof descriptions grouped into eight roof insulations

U value (W/m²K)	N/A *	0.4	1.5	0.16	0.12	0.6	1	2

* another dwelling above

HEATING SYSTEM

Characteristics	Description
Main fuel type	**Simplified main fuel of EPCs** EPC main heat descriptions and main fuel types were grouped into eight groups of main heating fuels Fuel | electric | mains gas | oil | solid | LPG | wood | biomass | No system
Heating system type	**Simplified heating system type of EPCs** EPC main heat descriptions and main fuel types were grouped further into 11 groups of heating system types Heating system types Air source heat pump | Storage heaters | Heat pump Boiler | Ground source heat pump | Community heat pump Community | No system | Micro-cogeneration Community CHP | Water source heat pump
Heating system emitter type	**Simplified heating system emitter of EPCs** EPC main heat descriptions and main fuel types were grouped further into 8 heat emitter types Heating system emitter radiators | No system | underfloor & radiators underfloor | Portable heaters | Ceiling heating warm air | Room heaters
Heating control	**Simplified heating system control of EPCs** EPCs are attributed with the corresponding control group based on the heating control description (see SAP 12 document table 4e for control group descriptions (BRE, 2014)). Control group | 0 | 1 | 2 | 3

Heating system temperature adjustment

Heating system temperature adjustment of EPCs

EPCs were attributed with the corresponding temperature adjustment based on the heating control description (see SAP 12 document table 4e for control group descriptions (BRE, 2014)).

Temperature adjustments	-0.15	0	0.3	0.4	0.6	0.7

Heating system responsiveness

Heating system responsiveness of EPCs

Table 4d in SAP2012 document (BRE, 2014)was used to identify the responsiveness of the simplified heating system description (fuel, system, emitter)

Responsiveness	1	0.75	0.25	0.4	0.5	0

Heating system efficiency

Heating system efficiency of EPCs

Table 4b in SAP2012 document (BRE, 2014) was used to identify the approximate efficiency of the simplified heating system description (fuel, system, emitter)

Heating system efficiency (%)	0	0.35	0.4	0.52	0.64	0.73	0.77	0.8	0.85	1	1.7	2.3	3

Figure 21: Derivation of SAP 2012 input fields from the EPC data for domestic properties

8.2.2 Matching addresses (EPCs and address points)

A fuzzy matching technique was used to match EPCs to Addressbase UPRNs. This allowed records to be matched without being identical. The VBA code from (mr excel, n.d.) was applied to the Addressbase database and EPC/DEC address database by postcode.

8.2.3 Approximating ground floor area/total floor area ratio

The property's total floor area according to its EPC was used to calculate the ratio of the EPC total floor area to the address point calculated ground floor area.

8.2.4 Modelling Occupancy

It is well documented that occupants have a significant effect on the amount of energy used and usage patterns in dwellings. Household size, a key variable associated with occupants and energy use is represented within the model. Data on the counts of occupants and households on postcode level and OA level counts of household sizes (Nomis, 2017) was used to approximate the distribution of households of various sizes within each postcode. The actual household/dwelling count per postcode from the GIS address database was used to approximate the number of various household sizes in each postcode.

Household sizes were applied to modelled 'dwelling' UPRNs according to the approx. TFA i.e. if there were 2*4+ person households, 5*3-person households etc. in a postcode then it would be assumed that the 2 households with the largest floor area would have 4+ occupants and the next 5 would have 3 occupants etc.

8.3 Approximating the characteristics of Non-domestic buildings

Figure 22 outlines the data sources and processes used to determine the characteristics of non-domestic buildings.

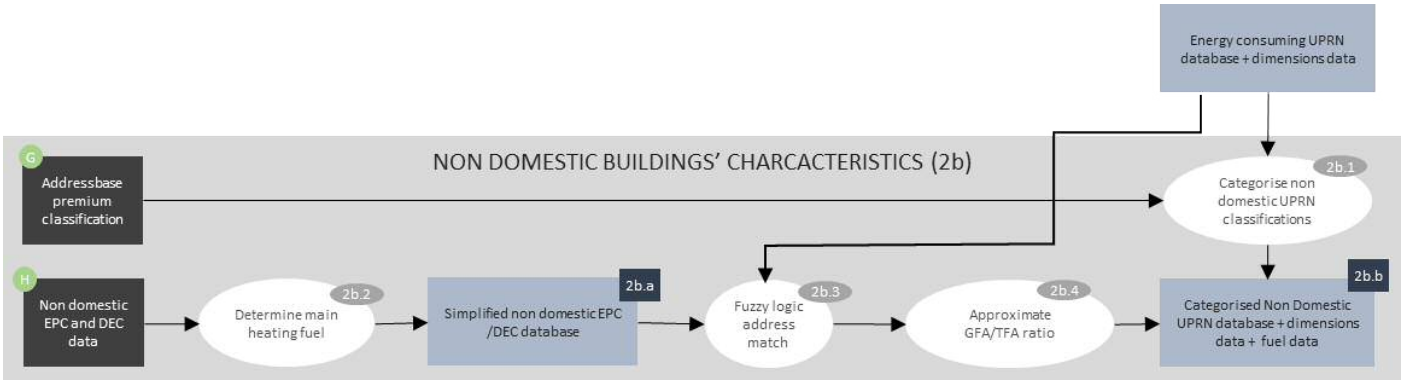


Figure 22: Non-domestic buildings' characteristics processes (2b)

8.3.1 Categorising non-domestic UPRN classifications

Addressbase premium assigns a classification code to each UPRN. These profile codes are split into 4 levels, primary, secondary, tertiary, and quaternary, see (Survey, 2013) for full list of Addressbase premium codes. These codes were used to group non-domestic properties into 'sectors', which are assigned with typical energy consumption values per m2 (W/m²). Figure 23 lists the 45 non-domestic building sectors applied to UPRNs based on their classification codes.

Non–domestic Building Sectors		
Airport	Laboratory	Residential
Barrage	Library	Residential - Camping
Castle	Library Store	Residential - Care
Changing Room	Light Industry	Retail
Community Building	Market - Indoor	Secondary School
Crematorium	Mortuary	Sports Centre Dry
Dwelling	Museum	Sports Centre Leisure Pool
Dwelling-Max	No profile	Station
External Sports with Floodlights	Nursery	Street and traffic lights
Farm	Office	Swimming Pool
Greenhouse	Phone mast	Telephone exchange
Gypsy Site	Place of Worship	Theatre
Hospital	Primary School	Warehouse
Hotel	Prison	White Water Centre
Ice Rink	Pub/Restaurant	Workshop

Figure 23: List of the 45 non-domestic building sectors applied to UPRNs

8.3.2 Determining the main heating fuel of non-domestic properties

Data on main heating fuels from the energy performance certificates and 'Display Energy Certificates' (DECs) were simplified and grouped into seven groups of main heating fuels. Data on the main heating fuel for these properties were used to approximate the main fuel used for heating in all non-domestic buildings within the same area.

Fuel	Electric	Mains gas	Oil	Solid	LPG	Wood	Biomass	No system

Figure 24: Non-domestic main heating fuel groups

8.3.3 Matching addresses (EPCs/DECs and address points)

As for domestic properties, a fuzzy matching technique was used to match EPCs and DECs to Addressbase UPRNs. This allowed some records to be matched without being identical. The VBA code from (mr excel, n.d.) was applied to the Addressbase database and EPC/DEC address database by postcode.

8.3.4 Approximating ground floor area/total floor area ratio

A property's total floor area according to an EPC or DEC was used to calculate the ratio of the EPC/DEC total floor area to the address point calculated ground floor area.

8.4 Calculating domestic annual consumption

Figure 25 outlines the processes used to approximate the annual consumption of all domestic addresses.

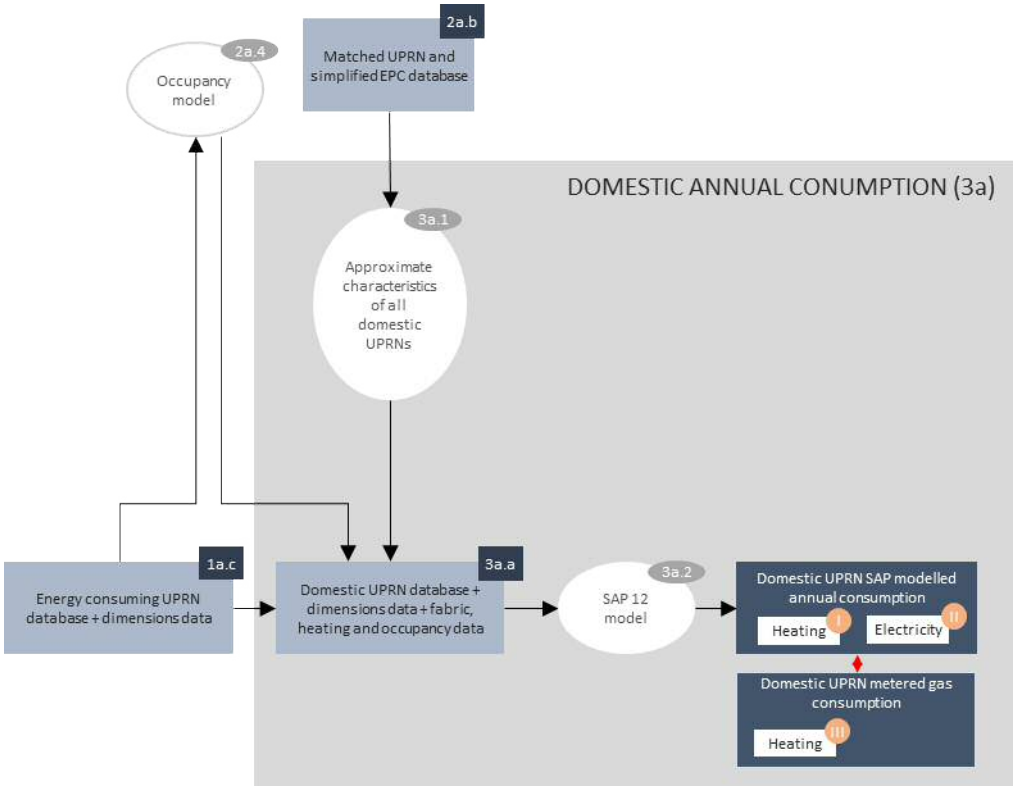


Figure 25: Domestic annual consumption processes (3a0

8.4.1 Approximating the characteristics of all domestic UPRNs

8.4.1.1 Fabric and Heating Characteristics based On EPC Data

A VBA code is applied to all domestic UPRNs to approximate their fabric and heating system characteristics. The mode value is calculated for each dwelling detachment/age group within each postcode, output area and the whole LA. If an EPC has been attributed to the UPRN then the UPRN's characteristics is equal to the EPC characteristics.

Otherwise, if a mode value is available on postcode level for the UPRN's detachment/age group then this is applied to the UPRN, otherwise the output area mode value for the detachment/age group is applied etc. Figure 26 lists and gives an outline of the derivation of all characteristics used in the SAP 2012 model approximated from EPC data.

Characteristic	Description
Age group	**Approximate age of dwellings based on 'EPC age' of dwellings of same detachment within postcode or OA** The mode EPC age group is calculated for each dwelling detachment within each postcode, output area and the whole Local Authority. If an EPC has been attributed to the UPRN then the UPRN's 'approx. age group' is equal to the 'EPC age'. Otherwise, if a mode 'EPC age' is available on postcode level for the UPRN's detachment then this is applied to the UPRN, otherwise the output area mode 'EPC age' for the detachment is applied etc.
Windows U value	**Approximate window U value based on mode U value of EPC of same detachment within postcode or OA** The mode EPC window U value group is calculated for each dwelling detachment/age group within each postcode, output area and the whole Local Authority. If an EPC has been attributed to the UPRN then the UPRN's 'window U value' is equal to the 'EPC window U value'. Otherwise, if a mode window U value is available on postcode level for the UPRN's detachment/age group then this is applied to the UPRN, otherwise the output area mode window U value for the detachment is applied etc.
Wall U value	**Approximate wall U value based on mode U value of EPC of same detachment within postcode or OA** The mode EPC wall U value group is calculated for each dwelling detachment/age group within each postcode, output area and the whole Local Authority. If an EPC has been attributed to the UPRN then the UPRN's 'wall U value' is equal to the 'EPC wall U value'. Otherwise, if a mode wall U value is available on postcode level for the UPRN's detachment/age group then this is applied to the UPRN, otherwise the output area mode wall U value for the detachment is applied etc.
Roof U Value	**Approximate roof U value based on mode U value of EPCs of same detachment within postcode or OA** The mode EPC roof U value group is calculated for each dwelling detachment/age group within each postcode, output area and the whole Local Authority. If an EPC has been attributed to the UPRN then the UPRN's 'roof U value' is equal to the 'EPC roof U value'. Otherwise, if a mode roof U value is available on postcode level for the UPRN's detachment/age group then this is applied to the UPRN, otherwise the output area mode roof U value for the detachment is applied etc.

Characteristic	Description
Main Fuel	**Assumed main fuel based on mode main fuel of EPCs within postcode or OA** The mode EPC main fuel group is calculated for each postcode and output area. If an EPC has been attributed to the UPRN then the UPRN's main fuel is equal to the EPC's main fuel. Otherwise, if a mode main fuel is available on postcode level then this is applied to the UPRN, otherwise the output area main fuel is applied.
Heating system type	**Assumed heating system type based on mode of EPCs of same main fuel within postcode or OA** The mode EPC heating system type is calculated for each main fuel within each postcode and output area. If an EPC has been attributed to the UPRN then the UPRN's heating system type is equal to the EPC's heating system description (p1). Otherwise, if a mode heating system type is available for the main fuel on postcode level then this is applied to the UPRN, otherwise the output area mode heating system type is applied.
Heating system emitter type	**Assumed heating system emitter based on mode of EPCs of same main fuel and system type within postcode or OA** The mode EPC heating system emitter is calculated for each main fuel/heating system type within each postcode and output area. If an EPC has been attributed to the UPRN then the UPRN's heating system type is equal to the EPC's heating system emitter. Otherwise, if a mode heating system emitter is available for the main fuel/heating system type on postcode level then this is applied to the UPRN, otherwise the output area mode heating system emitter for that main fuel/heating system type is applied.
Heating system control	**Assumed heating system control based on mode of EPCs of same heating system (fuel, system and emitter)** The mode EPC heating system control is calculated for each heating system type (fuel, system and emitter) If an EPC has been attributed to the UPRN then the UPRN's heating system control is equal to the EPC's heating system control. Otherwise, the mode heating system control for the heating system (fuel, system and type) is applied to the UPRN.
Heating system temperature adj	**Assumed heating system temperature adjustment based on mode of EPCs of same heating system (fuel, system and emitter)** The mode EPC heating system temperature adjustment is calculated for each heating system type (fuel, system and emitter) If an EPC has been attributed to the UPRN then the UPRN's heating system temperature adjustment is equal to the EPC's heating system's temperature adjustment. Otherwise, the mode heating system temperature adjustment for the heating system (fuel, system and type) is applied to the UPRN.
Heating system responsiveness	**Assumed heating system responsiveness based on mode of EPCs of same heating system (fuel, system and emitter)** The mode EPC heating system responsiveness is calculated for each heating system type (fuel, system and emitter)

	If an EPC has been attributed to the UPRN then the UPRN's heating system responsiveness is equal to the EPC's heating system's responsiveness. Otherwise, the mode heating system responsiveness for the heating system (fuel, system and type) is applied to the UPRN.
Heating system efficiency	**Assumed heating system efficiency based on mode of EPCs of same heating system (fuel, system and emitter)** The mode EPC heating system efficiency is calculated for each heating system type (fuel, system and emitter) If an EPC has been attributed to the UPRN then the UPRN's heating system efficiency is equal to the EPC's heating system's efficiency. Otherwise, the mode heating system efficiency for the heating system (fuel, system and type) is applied to the UPRN.

Other Characteristics

Column header	Description	
Approx occupants	**As described in section 8.2.4.**	
No floors	**Number of floors assumed in property** Round up of 'approx. TFA' divided by 'UPRN GFA'	
Side (m)	**Approximate length of property**	**As described in section 8.1.4.**
Front back (m)	**Approximate width of property**	
Sheltered sides	**Number of sides shared with other properties** Detached – 0 sheltered sides Semi Detached and End Terraced – 1 sheltered side Mid Terraced and Flat – 2 sheltered sides	
Solid door area	**The surface area of solid external doors** Flats – assumed no external doors (0m2) All other UPRNs – assumed 4m2	
Windows net area	**The net surface area of UPRN's windows** Perimeter of UPRN's external wall: (2) *front back + (2-sheltered sides) *side Gross external wall area of UPRN: the floor height (assumed 2.5m) *external wall perimeter*number of floors Net window area of UPRN: 25% of the external wall area	
Ground floor net area	**The net ground floor area of the UPRN** Approx. TFA/ no floors	
External wall net area	**The net external wall area of the UPRN** Gross external wall area-net windows area- solid door area	
Roof net area	**The net roof floor area of the UPRN** Flats = 0m2 Else = Ground floor net area	
Windows North	**Split of windows net area on building sides** All assumed west facing	0% for all dwellings
Windows East		Detached = 42%, Semi Detached or End Terraced = 45%, Mid Terraced = 45%, Flats = 0%

<table>
<tr><td>Windows South</td><td></td><td>Detached = 10%, Semi Detached or End Terraced = 5%, Mid Terraced = 0%, Flats = 0%</td></tr>
<tr><td>Windows West</td><td></td><td>Detached = 48%, Semi Detached or End Terraced = 50%, Mid Terraced = 55%, Flats = 100%</td></tr>
<tr><td>Air Permeability</td><td colspan="2">Assumed infiltration rate based on approx. age
<table>
<tr><th>Approx age</th><th>Infiltration rate (air changes per hour)</th></tr>
<tr><td>Pre 1919</td><td>1.3</td></tr>
<tr><td>1919-1983</td><td>1.1</td></tr>
<tr><td>Post 1983</td><td>0.6</td></tr>
</table></td></tr>
<tr><td>Living area fraction</td><td colspan="2">
<table>
<tr><th colspan="2">Terraced</th><th colspan="2">Semi Detached</th><th colspan="2">Detached</th><th colspan="2">Flat</th></tr>
<tr><td>TFA > than</td><td>L.A.F</td><td>TFA > than</td><td>L.A.F</td><td>TFA > than</td><td>L.A.F</td><td>TFA > than</td><td>L.A.F</td></tr>
<tr><td>0</td><td>0.5</td><td>0</td><td>0.25</td><td>0</td><td>0.25</td><td>0</td><td>0.5</td></tr>
<tr><td>60.65</td><td>0.25</td><td>76.9</td><td>0.21</td><td>102.3</td><td>0.21</td><td>54.45</td><td>0.25</td></tr>
<tr><td>76</td><td>0.21</td><td>107.4</td><td>0.16</td><td>125.35</td><td>0.16</td><td>74.1</td><td>0.21</td></tr>
<tr><td>99.8</td><td>0.16</td><td>152.05</td><td>0.12</td><td>171.95</td><td>0.12</td><td></td><td></td></tr>
<tr><td>137</td><td>0.12</td><td></td><td></td><td>248.55</td><td>0.12</td><td></td><td></td></tr>
</table>
</td></tr>
<tr><td>Thermal mass parameter</td><td colspan="2">Assumed thermal mass based on approx. age
<table>
<tr><th>Approx age</th><th>Thermal mass (kJ/m2K)</th></tr>
<tr><td>Pre 1919</td><td>450</td></tr>
<tr><td>1919-1983</td><td>200</td></tr>
<tr><td>Post 1983</td><td>200</td></tr>
</table></td></tr>
</table>

Figure 26: Derivation of all characteristics used in the SAP 2012 model approximated from EPC data

8.4.2 SAP 2012 model calculation

In the UK, the National Calculation Method (NCM) for dwellings is the Standard Assessment Procedure (SAP) which plays a significant role in monitoring and evaluating the UK's housing stock as well as the development of energy efficiency policies and schemes. SAP 2012 is a worksheet based on a steady state model, and equations are calculated monthly. A VBA code ran the SAP model for each domestic UPRN based on the approximated characteristics. Figure 27 lists the additional assumptions applied to all domestic UPRNs whilst Figure 28 lists the outputs recorded for each UPRN from the SAP model.

Additional SAP model assumptions	• Temperature during heating periods in the living area = 18° • Water heating is assumed to be from main heating system • Efficiency of heating system assumed constant throughout year • Assumed 0 kWh/m2 space cooling and electricity for pumps, fans and electric keep-hot • Assumed no electricity generation • Severn or Wales region used for monthly external temperature, wind speed and solar gain values dependent on the Local Authority's location

Figure 27: Additional SAP 2012 assumptions applied to all domestic UPRNs

Column header	Description	Annual domestic consumption values
Space heating main	Main space heating consumption (kWh/year) for UPRN	I Domestic UPRN annual heating and hot water (DHW) consumption - SAP modelled (predicted) - kWh/year
Water heating	Water heating consumption (kWh/year) for UPRN	
Electricity pumps etc	Electricity for pumps, fans and electric keep-hot consumption (kWh/year) for UPRN Currently 0kWh/year for all dwellings	II Domestic UPRN annual electricity consumption - SAP modelled (predicted) - kWh/year
Electricity Lighting	Lighting electricity consumption (kWh/year) for UPRN	
Electricity Appliances	Appliances electricity consumption (kWh/year) for UPRN	
Total Dom	Total consumption (kWh/year) for UPRN Space heating, water heating, electricity for pumps etc. and electricity for lighting	

Figure 28: Outputs recorded for each UPRN from the SAP model

8.5 Calculating non domestic annual consumption

Figure 29 outlines the processes used to approximate the annual consumption of all non-domestic addresses.

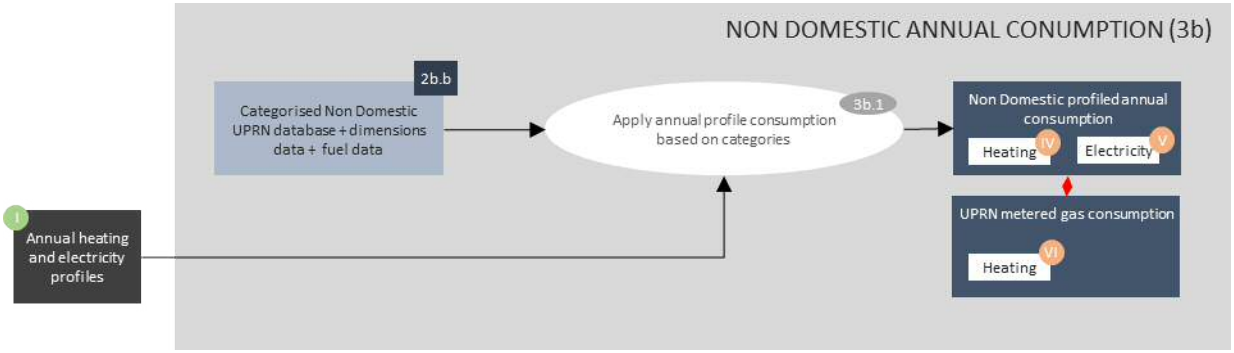


Figure 29: Non domestic annual consumption processes (3b)

8.5.1 Applying annual profile consumption based on building categories

Average annual heating and DHW and electricity consumptions (kWh/m2) are applied to each non-domestic UPRN based on their sector categories as described in 8.3.1. These consumptions are presented as measured minimum, average and maximum consumptions/m² for the sector.

The building sector consumptions used have been obtained from measured data gathered by K2n Ltd (Knight) from samples per building sector that are too small to be statistically validated but were considered the best estimates available to the project.

Where specific sector data is not available, some sectors use data from other sectors where this is considered to be a better fit than applying the no profile generic average data, which has been calculated from across all sectors. Sectors with no measured data that are considered unsuitable to use the generic no profile figures have no consumption applied where these building typologies are encountered in Addressbase. Table 7 shows these sectors in Yellow.

The measured annual consumption values chosen for each non-domestic sector are multiplied with the approximated floor area of each UPRN, giving an annual minimum, average and maximum heating and DHW consumption (kWh) and electricity consumption (kWh) for each UPRN.

8.6 Applying Metered Annual Consumption

Figure 30 describes how BEIS's aggregated metered data (Department for Business, Energy & Industrial Strategy, 2017) was used to validate the domestic annual consumption values and the potential to match actual metered data to UPRNs for use within the model. The Wales and West Utilities (WWU) actual annual consumption data referred to has not yet been obtained to provide further validation of the datasets produced. It is hoped both this and Western Power Distribution (WPD) actual annual consumption electricity data may be available before the end of the project.

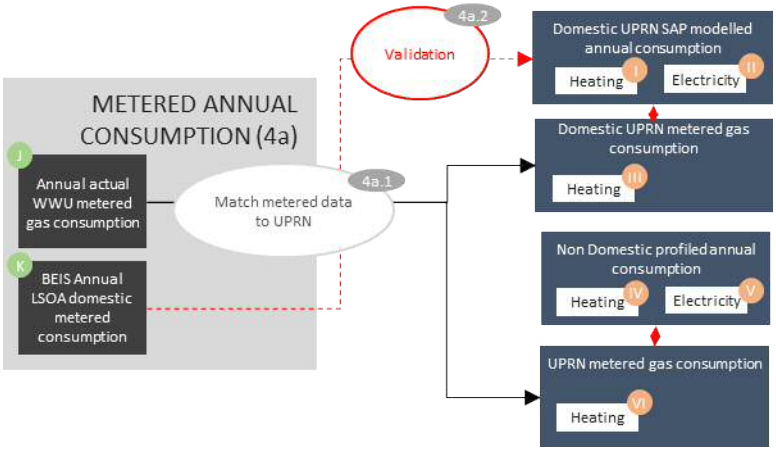


Figure 30: Metered annual consumption processes

8.6.1 Matching metered data to UPRNs

A similar technique to those in section 8.2.2 and 8.3.3 would be used to match the addresses of Meter Point Reference Numbers (MPRNs) to UPRNs if available. These matched annual consumption values could then be used to help estimate the half hourly profiles of buildings as explained in section 8.7.

8.6.2 Model validation

Lower Super Output Area (LSOA) level metered gas and electricity consumption data for Swansea was used to validate the domestic annual consumption model (Figure 31 and Figure 32). All modelled domestic heating and DHW consumption demands were compared to the metered gas consumption, which could help explain why the model generally slightly over-predicts when compared to the metered gas consumption as often this heating and DHW demand could be satisfied by electricity or other fuels.

Further analysis using BEIS' experimental postcode level metered data (Department for Business, Energy & Industrial Strategy, 2017) could be made as well as the use of UPRN level metered data, if available, to refine the annual estimates. Access to sufficient UPRN level data would allow the accuracy of the non-domestic model to also be assessed.

It is important to note that the model does not allow for transport, process or large industrial energy use in a postcode, as this data was not available to the project team.

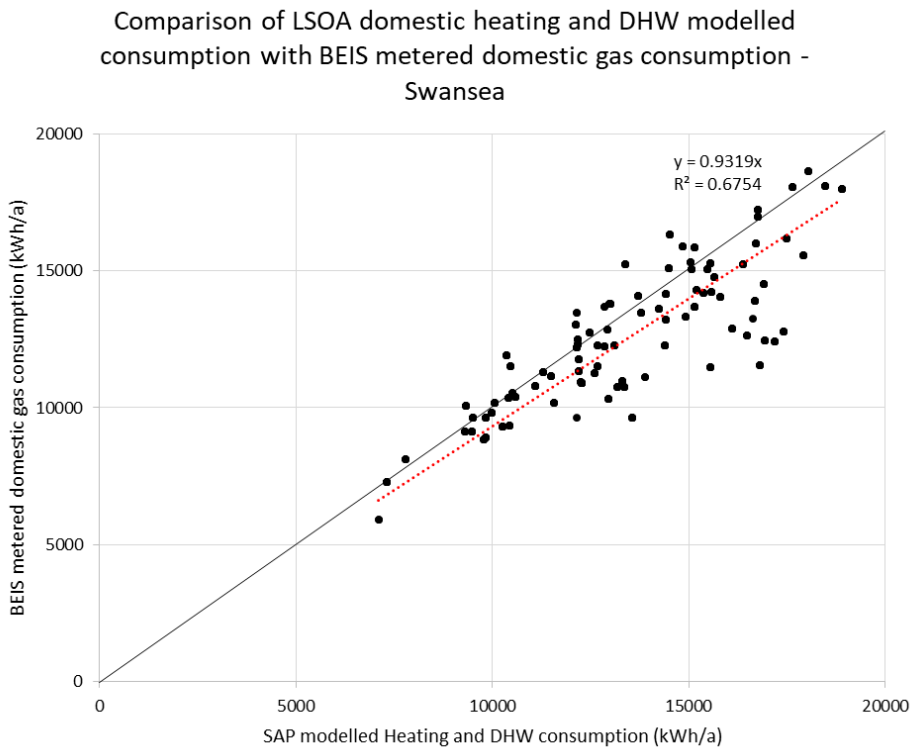


Figure 31: Comparison of LSOA domestic heating and DHW modelled consumption with BEIS metered domestic gas consumption - Swansea

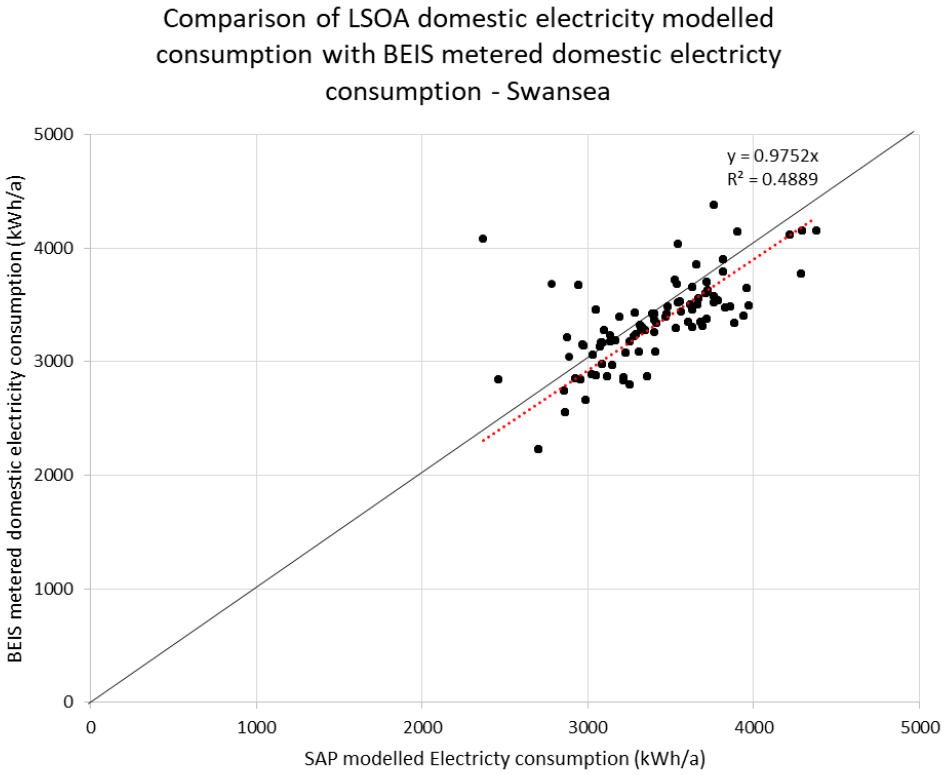


Figure 32: Comparison of LSOA domestic electricity modelled consumption with BEIS metered domestic electricity consumption - Swansea

8.7 Calculating Half Hourly Consumption per Output Area

In this section, the estimation of half hourly consumption per output area as outlined in Figure 33 is described. The calculation is split into 4 sections; 'Domestic Heating and DHW', 'Domestic Electricity', 'Non-Domestic Heating and DHW' and 'Non Domestic Electricity'. Half hourly results are aggregated to OA level due to privacy issues.

8.7.1 Half Hourly Domestic Heating and DHW Calculation

Three profiles were used for estimating the half hourly domestic heating and DHW consumption; one for properties built before 1919, one for properties built between 1919 and 1982 and another for those built after 1982 as this information was available for each UPRN in the Addressbase data. For each half hour in the year, the three profiles used specify the percentage of the total annual energy consumption used. See Figure 33. The process was undertaken in the following order:

1. **SAP model's domestic heating and DHW - half hourly per OA** - The average percentage use half hourly profile applied to the UPRNs' SAP model domestic heating and DHW annual consumption value was based on the UPRNs age group.
2. **Minimum, average and maximum domestic heating and DHW – half hourly per OA** - The post 1982 percentage use half hourly profile was applied to all UPRNs' based on the minimum SAP model domestic heating and DHW annual consumption per OA. Similarly, the 1919-1982 profile was applied to the average SAP consumption values whilst the pre-1919 profile was applied to the maximum consumption values.
3. **Domestic heating and DHW metered gas consumption – half hourly per OA –** If available, the average percentage use profiles will be applied to the UPRNs' actual metered gas consumption value based on the UPRNs age group.

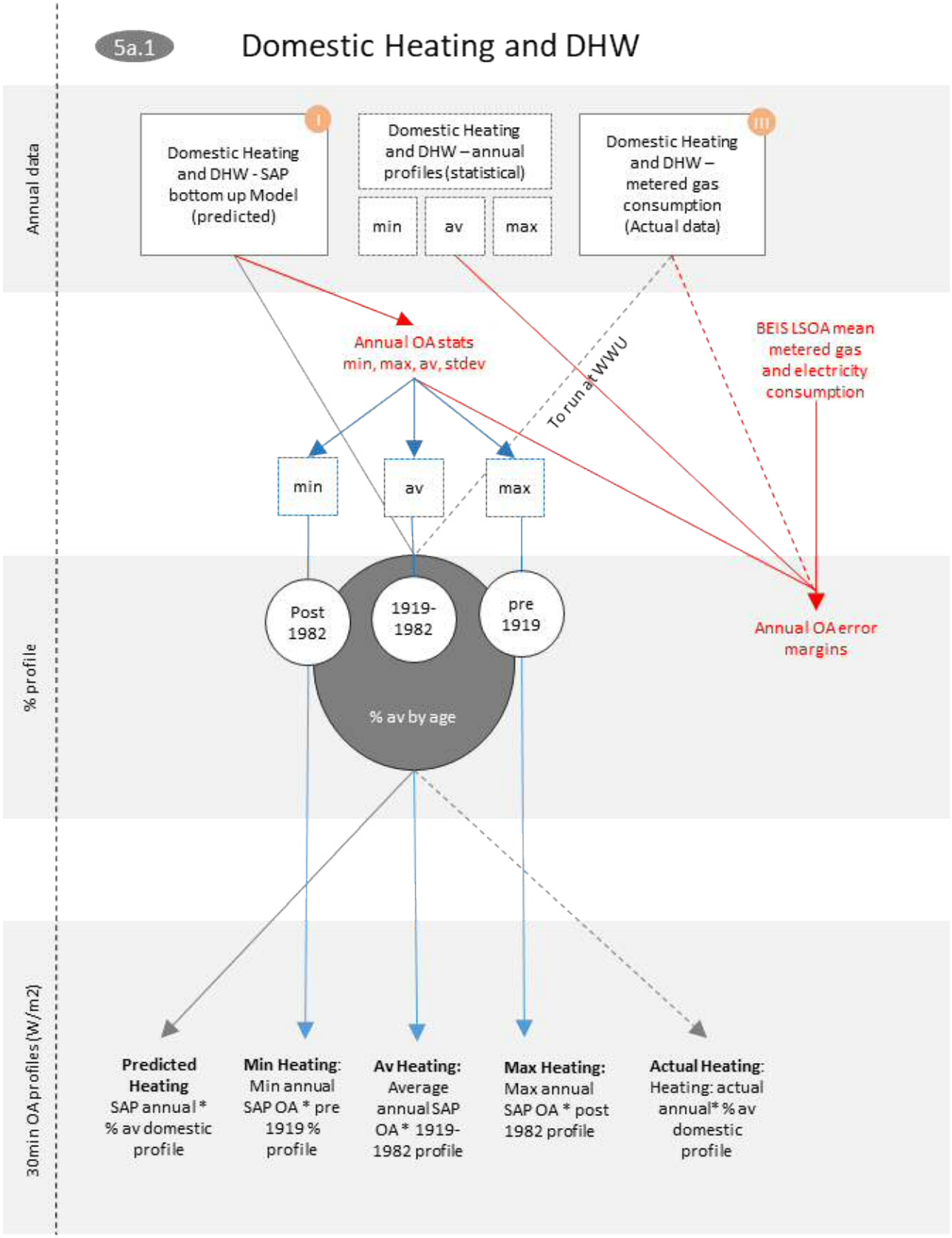


Figure 33: Calculation of domestic heating and DHW half hourly consumption values per OA

8.7.2 Half Hourly Electricity Calculation

Three profiles were used for calculating the half hourly domestic electricity consumption; one for properties built before 1919, one for properties built between 1919 and 1982 and another for those built after 1982. As with the heating profiles in the previous section, for each half hour of the year these profiles specify the percentage of the total annual energy consumption used. See Figure 34.

1. **SAP model's domestic electricity - half hourly per OA** - Half hourly percentage use profiles were applied to the UPRNs' SAP model domestic electricity annual consumption value based on the UPRNs age group.
2. **Minimum, average and maximum domestic electricity – half hourly per OA** - The post 1982 percentage use half hourly profile was applied to all UPRNs' based on the minimum SAP model domestic electricity annual consumption per OA. Similarly, the 1919-1982 half hourly profile was applied to the average consumption values whilst the pre-1919 half hourly profile was applied to the maximum consumption values.

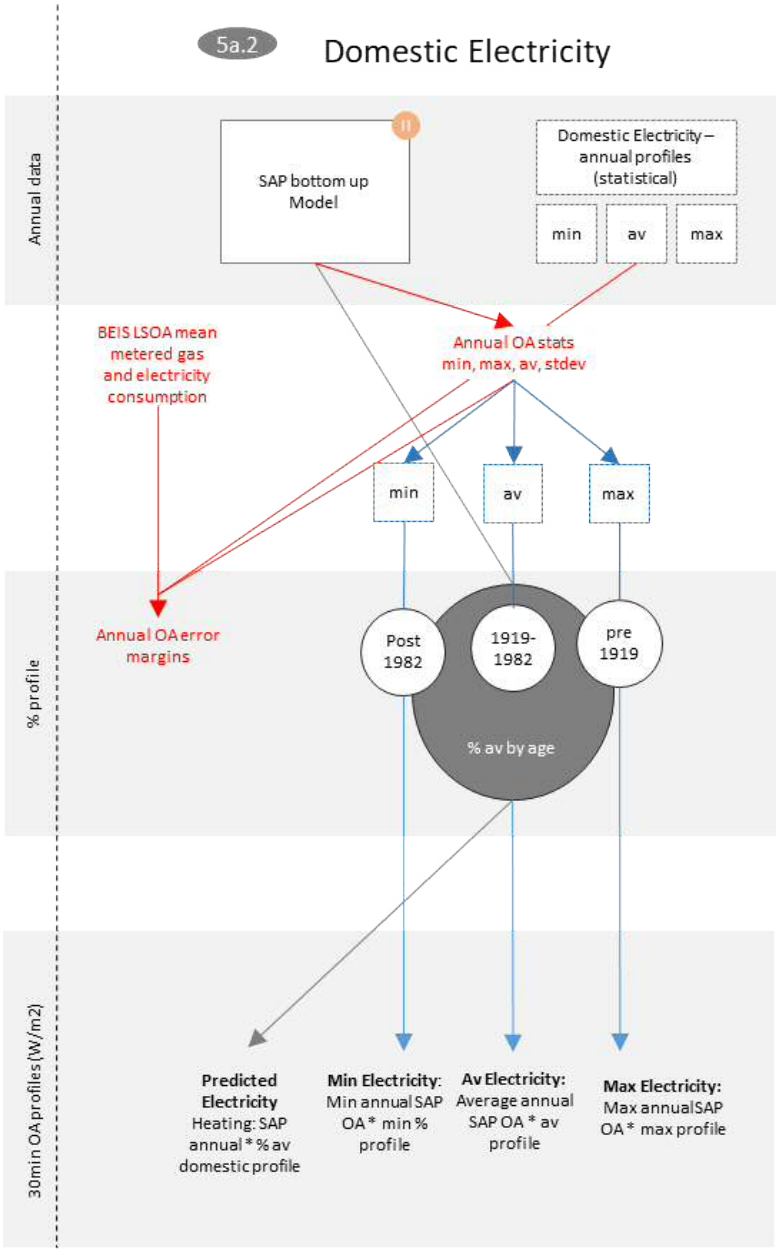


Figure 34: Calculation of domestic electricity half hourly consumption values per OA

8.7.3 Half Hourly Non-Domestic Heating and DHW Calculation

Three profiles were used for calculating the half hourly non-domestic heating and DHW consumption; one minimum consumption pattern, one average consumption pattern and a maximum consumption pattern. For each half hour of the year, these profiles specify the percentage of the total annual energy consumption used. See Figure 35.

1. **Minimum, average and maximum non-domestic heating and DHW set values – half hourly per OA** - The minimum percentage use half hourly profile was applied to all UPRNs' based on the minimum set value of that sector. Similarly, the average half hourly profile was applied to the average consumption values whilst the maximum half hourly profile was applied to the maximum consumption values.
2. **Non-Domestic heating and DHW metered gas consumption – half hourly per OA –** If available, the percentage use profiles will be applied to the UPRNs' actual metered gas consumption value based on the UPRNs profile sector.

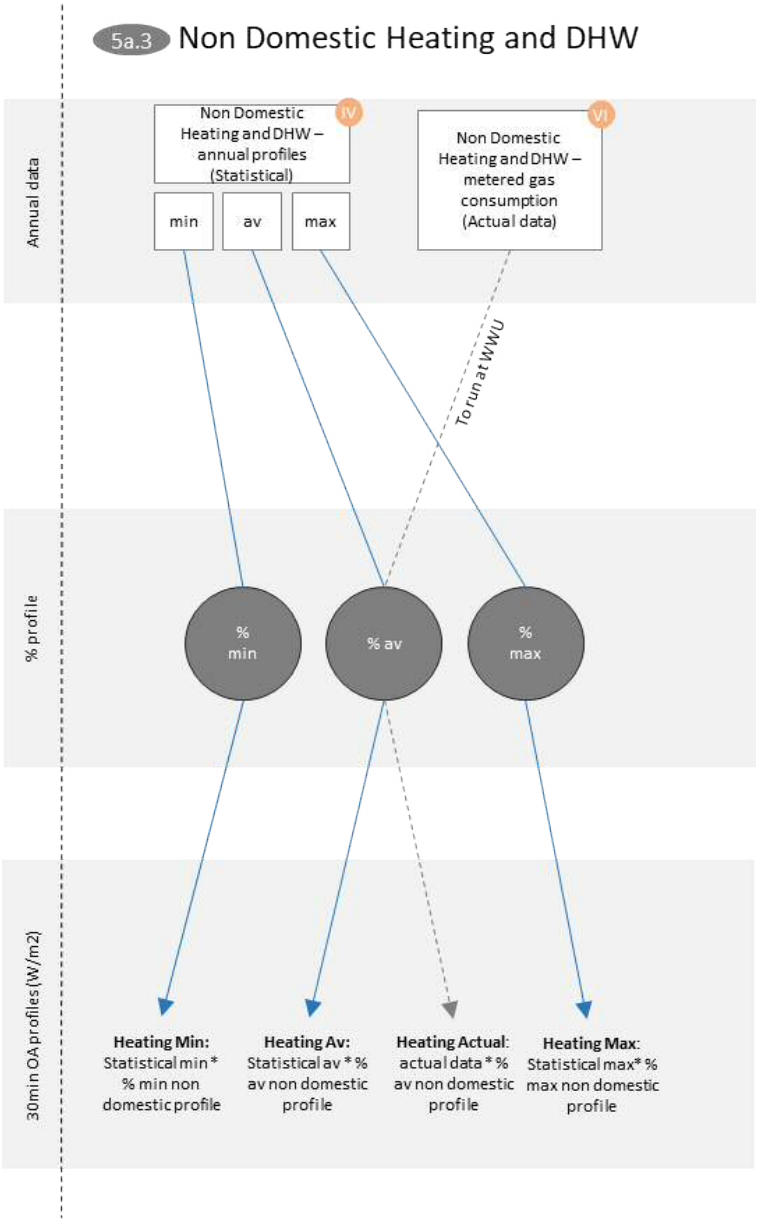


Figure 35: Calculation of non-domestic heating and DHW half hourly consumption values per OA

8.7.4 Half Hourly Non-Domestic Electricity Calculation

Three profiles were used for calculating the half hourly non-domestic electricity consumption; one minimum consumption pattern, one average consumption pattern and a maximum consumption pattern. For each half hour of the year, these profiles specify the percentage of the total annual energy consumption used. See Figure 36.

1. **Minimum, average and maximum non-domestic electricity set values – half hourly per OA** - The minimum percentage use half hourly profile was applied to all UPRNs' based on the minimum set value of that sector. Similarly, the average half hourly profile was applied to the average consumption values whilst the maximum half hourly profile was applied to the maximum consumption values.

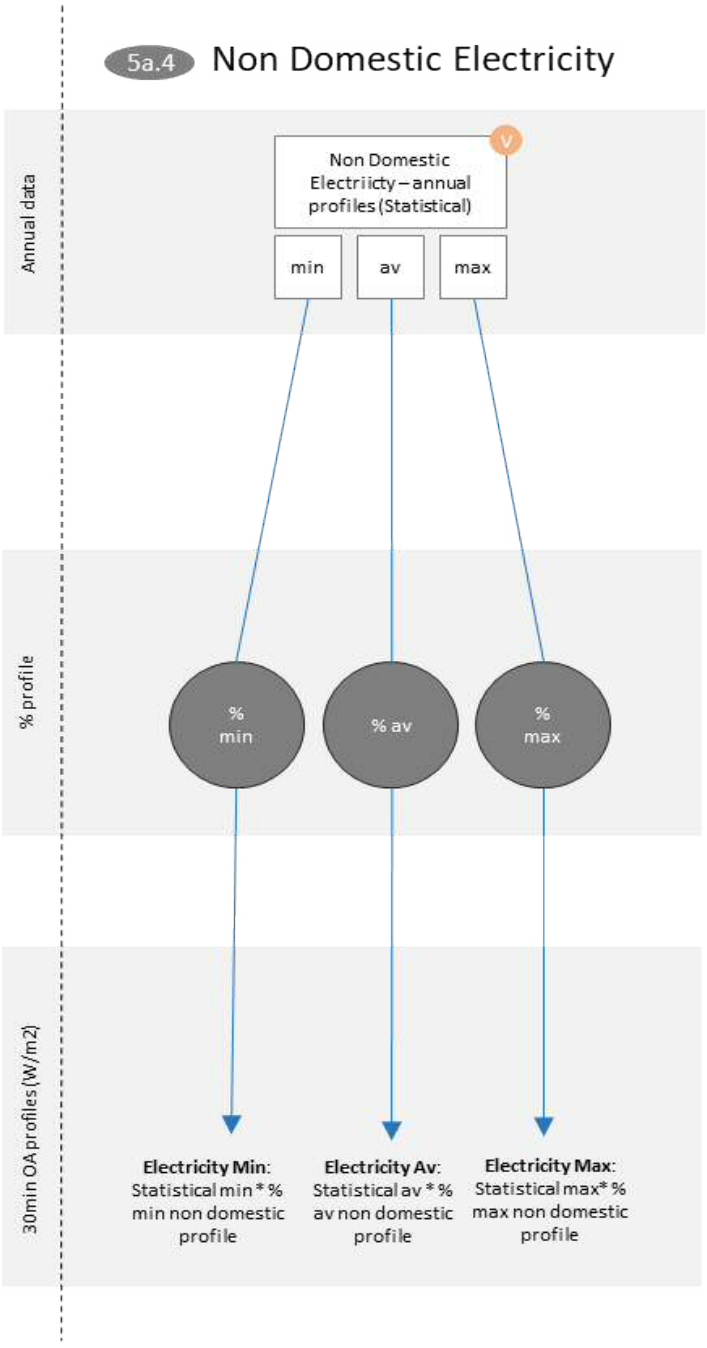


Figure 36: Calculation of non-domestic electricity half hourly consumption values per OA

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