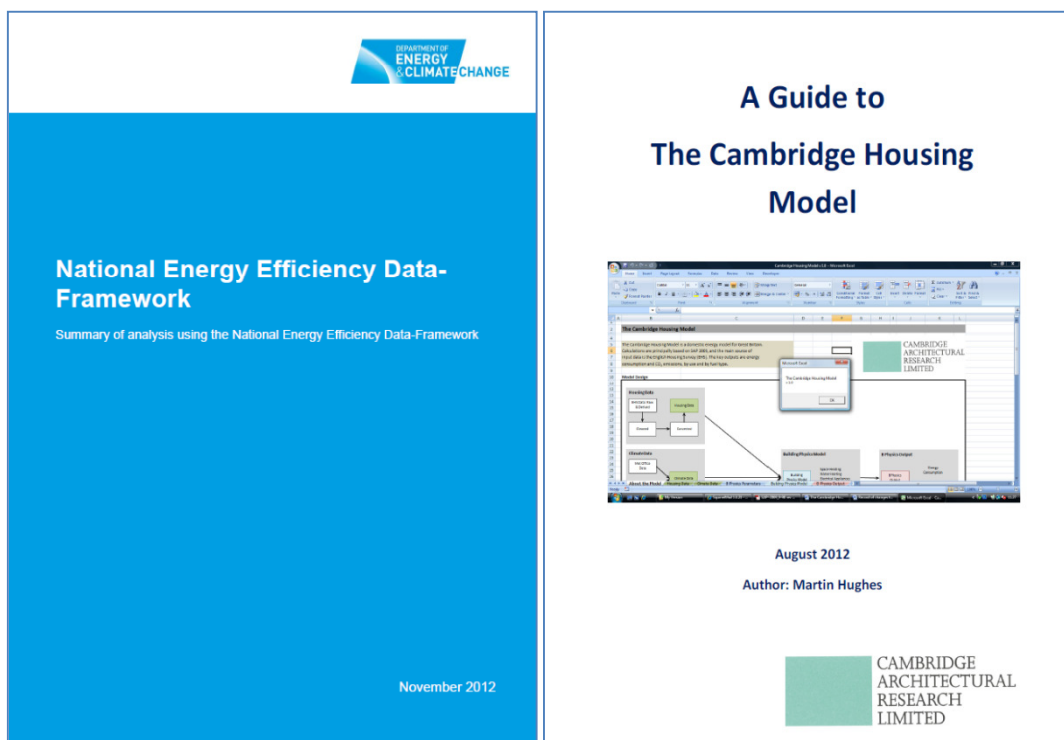# Comparing the Cambridge Housing Model against the National Energy Efficiency Data-Framework and Meter Readings

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Comparing the Cambridge Housing Model against the National Energy Efficiency Data-Framework

Executive Summary

This report compares modelled estimates of household energy use from the Cambridge Housing Model against actual energy use data published through the National Energy Efficiency Data (NEED) framework, and utility meter data provided by DECC for 2010. The NEED data is banded in different ways – by dwelling size, by number of bedrooms, by building type (detached, semi-detached, terrace etc.) by tenure, by region, and by income. We have generated equivalent bands using the Cambridge Housing Model (CHM), based on property data from the English Housing Survey, and building physics algorithms based on SAP09 and BREDEM.

In each section of the report we have shown the published NEED data at the top, unadjusted CHM estimates second, and CHM estimates adjusted so that the totals match data published in the Digest of UK Energy Statistics (DUKES). Then we show a comparison carried out by DECC of the unadjusted CHM estimates against metered gas and electricity use, where available. We have followed the convention of reporting median values in the report where possible.

The adjusted CHM figure for electricity is 4% over the NEED median, and the modelled figure for gas is 5% below the NEED median. This may suggest that the NEED sample of homes does not exactly match total UK energy use as reported in DUKES, or it may reflect the difference between the *mean* values used for the DUKES adjustment and the *medians* reported in NEED.

Comparing data specifically for electrically heated homes found that the CHM estimates of electricity use for heating were consistently higher than measured.

Findings

Floor Area

- CHM appears to under-estimate gas use compared to NEED overall, although it over-estimates for large dwellings, even after the modelling adjustment.

- CHM appears to over-estimate electricity use for large dwellings compared to NEED, even after the modelling adjustment.

- The CHM estimates also appear to over-estimate consumption for larger dwellings and under-estimate for smaller dwellings, when compared with the meter data.

Dwelling Types

- CHM appears to under-estimate gas use for detached dwellings and purpose-built flats compared to NEED, and over-estimate for terraces and converted flats, even after the modelling adjustment.

- The CHM electrical use estimate was fairly close to the meter data for semi-detached, detached and terraced houses, but over-estimated for flats, and particularly converted flats.

Dwelling Age

- The gas estimates are too high for pre-1919 homes, and too low for homes built since 1983. There may be a case for adjusting demand temperature or heating regimes in the model to achieve a better match for gas use in different age bands. Or, if estimates of gas use for specific ages of dwellings are important, we may need to re-examine the method of adjusting to match DUKES.

- The difference between the CHM gas use estimates and the metered data increase as dwellings get older. While the electricity use in the CHM estimates is consistently high, it is generally quite close to the meter data (apart from electrically heated dwellings – see note below).

Tenure

- The adjusted CHM appears to over-estimate gas use for owner-occupied and privately-rented properties, but under-estimate for social housing. This may suggest that owner-occupied and private rented homes are actually heated to a lower temperature and/or for shorter periods than assumed in the CHM. We should consider revising demand temperatures and heating regimes based on tenure.

Region

- NEED data shows remarkably even gas consumption between regions, while the CHM estimates a much bigger effect of climate – suggesting that the space heating algorithms may put too much weight on external temperature.

- Conversely, NEED shows a comparatively large range of electricity use between regions, which is not reflected in CHM estimates. This may suggest that we currently under-estimate the effect of climate and latitude on electricity use.

- Both of these findings were supported by comparing the CHM data with the meter data, highlighting in particular the disproportionate effect of region on *modelled* gas consumption.

Income

- The CHM appears to model income effects better for electricity than for gas use. Gas use estimates tend to overestimate consumption for higher income dwellings, and underestimate for lower income dwellings, while estimates for electricity appear to get better for higher incomes.

- The income effects are likely to be linked to the floor area, due to a correlation between income and dwelling size.

Dwellings with Electric Heating

- One of the key findings from comparing meter data with the CHM was that CHM estimates for electricity use in electrically heated dwellings were consistently higher. In some cases, such as dwellings built pre-1850, converted flats, and dwellings above 110m^2, the estimated electricity was around double the metered average.

However, some of the discrepancies between NEED and the CHM are linked to different sampling – because we do not have all the parameters for all dwellings (i.e. some are 'unknown' for some dwellings). For example, we do not have income data for all homes.

How do NEED and the Cambridge Housing Model differ?

The Department asked us to clarify the significant differences between data from the National Energy Efficiency Data framework and the data used in the Cambridge Housing Model. This is an important precursor to understanding some of the root causes of differences in modelled outputs: the comparisons are relatively complex, with drivers of energy use that can vary from year to year. (Energy prices, external temperature, and even one-off events like the Olympics may all affect the use of energy in the home.)

There are four significant differences between NEED and the CHM:

1. NEED gas consumption data is weather-corrected by the Energy Companies before they submit annual data to DECC. Their method of correcting is not transparent, and even DECC is uncertain about how this adjustment takes place. It is not possible to remove the corrections retrospectively, which makes it harder to draw direct comparisons.

2. The Cambridge Housing Model uses regional and monthly weather data as part of the energy use calculations. Outputs are also adjusted to match DUKES data for gas and electricity use each year. This means that effectively it also includes a weather-adjustment. However, the form of adjustment is almost certain to be different from the 'black box' adjustment used for the data that goes into NEED, and is bound to lead to some discrepancies, which probably vary somewhat from year to year.

3. The DUKES adjustments applied to CHM outputs have the effect of adjusting for aggregate, average behaviour across all UK homes. However, this simple but crude adjustment cannot possibly reflect behavioural differences between different individual dwellings or households. Conversely, NEED data incorporates these individual behavioural effects, but they may not be perfectly representative for the whole housing stock. (Especially because NEED homes are all in England, and may be skewed towards more energy-efficient homes.

4. Initial CHM modelling does not include price effects on energy use (i.e. it does not reflect how some households may use more energy when prices fall, and less when prices rise). However, this is incorporated in DUKES so the modelling adjustments do help address this. Again, this is reasonable for aggregate figures across all homes, but not for sub-groups of homes. NEED does include price determinants (among other variables affecting actual energy use), and these are almost certain to be more accurate for sub-groups, which undoubtedly affects the income comparisons below.

We return to these differences below on page 21, and show two charts comparing NEED, DUKES and sub-national statistics on energy consumption in homes. These charts make year-by-year comparisons between the total figures easier, and they show how the gap between DUKES and NEED was much greater in the exceptionally cold year of 2010 than in other years.
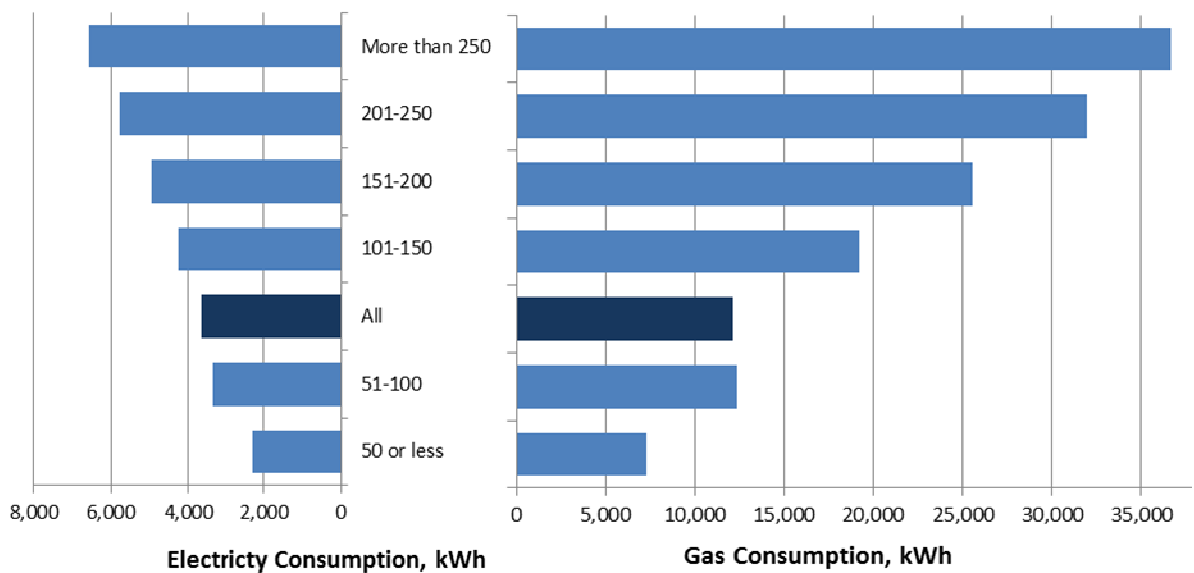
Floor Area

NEED Energy Use by Floor Area, m^2
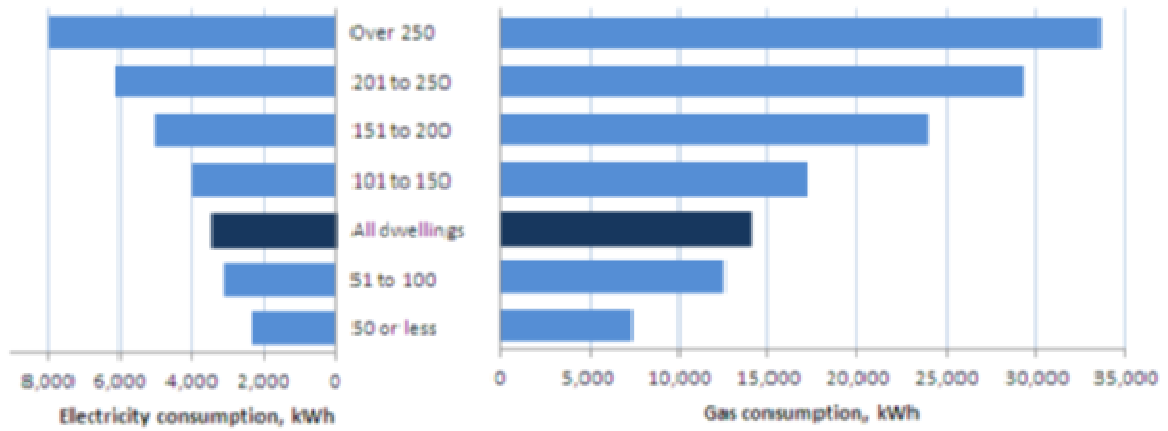
CHM Unadjusted Energy Use by Floor Area
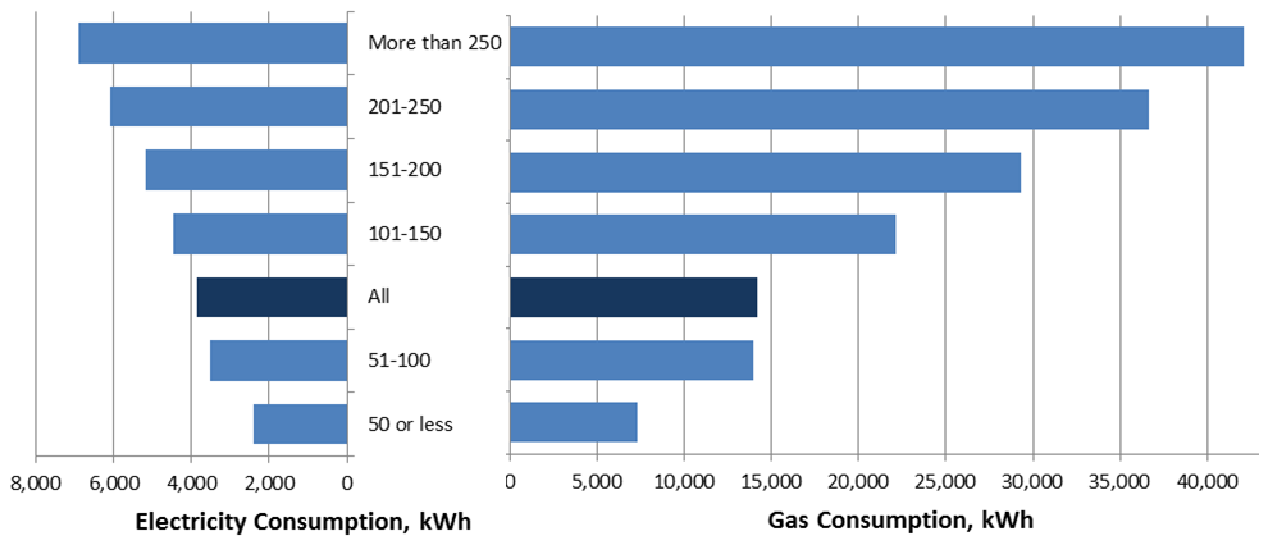
CHM Adjusted Energy Use by Floor Area

Floor area

When the CHM estimates are broken down into the same floor area bands as those reported in NEED[1], the match for electricity is quite close. The unadjusted estimate across all dwellings is a little higher than the NEED value, but the adjusted estimate is very similar (only 4% over). CHM estimates are also very close for small dwellings, although the estimates appear to be less accurate for large dwellings.

However, the gas estimates do not match quite so well against NEED. The unadjusted estimate for all dwellings is a little high, and surprisingly, the adjusted figure for all dwellings is around 5% too low. Both gas estimates are close to the measured values for small dwellings, but both look to be too high for large dwellings.

(NEED gas data is weather-adjusted, and the Energy Companies do not publish details of the adjustment, so it is not clear how the adjustment relates to modelled estimates from the CHM, which themselves take account of the actual weather for each reporting year. It is not possible to remove the weather adjustment in NEED gas data – or in the metered data reported in the next section.))

Implication: CHM appears to under-estimate gas use compared to NEED overall, although it over-estimates for large dwellings, even after the modelling adjustment.

Floor Area (m^2)	Gas Use			Electricity Use		
	CHM (Adjusted)	NEED	Difference	CHM (Adjusted)	NEED	Difference
50 or less	7,297	7,400	103	2,285	2,300	15
51-100	12,317	12,600	283	3,356	3,200	-156
101-150	19,217	17,300	-1,917	4,250	4,000	-250
151-200	25,526	23,900	-1,626	4,927	5,000	73
201-250	31,923	29,300	-2,623	5,788	6,100	312
More than 250	36,658	33,600	-3,058	6,556	8,000	1,444

(CHM values are shown to 3 or 4 significant figures not because we believe they are this accurate, but to show directly figures reported from the model.)

[1] *DECC (2012) National Energy Efficiency Data-Framework: Summary of analysis using the National Energy Efficiency Data-Framework. London: DECC.*

Floor area: Metered Data vs. CHM

A comparison of the unadjusted CHM electricity and gas consumption against metered data carried out by DECC (right) showed that electricity use is relatively close for all but the smallest dwellings. For gas use however, while there is a general over-estimate for the stock (on average 21%), the percentage discrepancy increases from 12% to 27%, from the smallest to the largest dwelling floor area.

In the electrically heated homes, we found that the modelled estimate was significantly higher than the metered value for all dwelling sizes. However, the discrepancy is similar to that seen between the gas meter data and the CHM estimate.

Implication: the over-estimate of electricity use for electrically heated dwellings is likely to be from the same source as the overestimation in gas heating demand. Therefore, the issue is likely to be linked to the heating demand algorithm, rather than any specific issues with how the model deals with electrical heating.
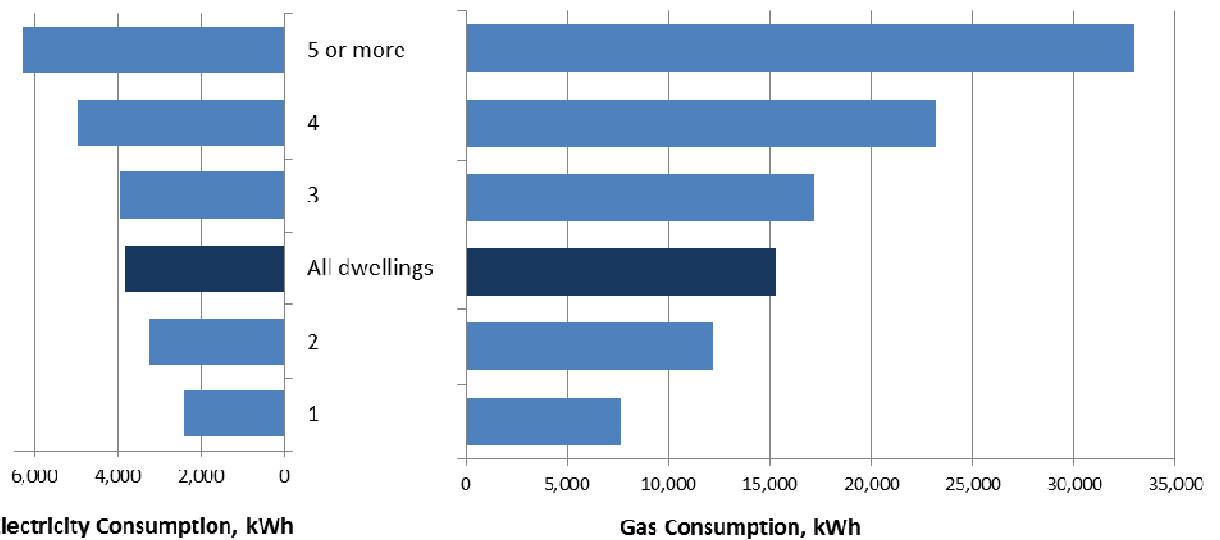

Annual Electricity Use (all homes)

Annual Gas Use (all homes)

Annual Electricity Use (electrically heated homes)
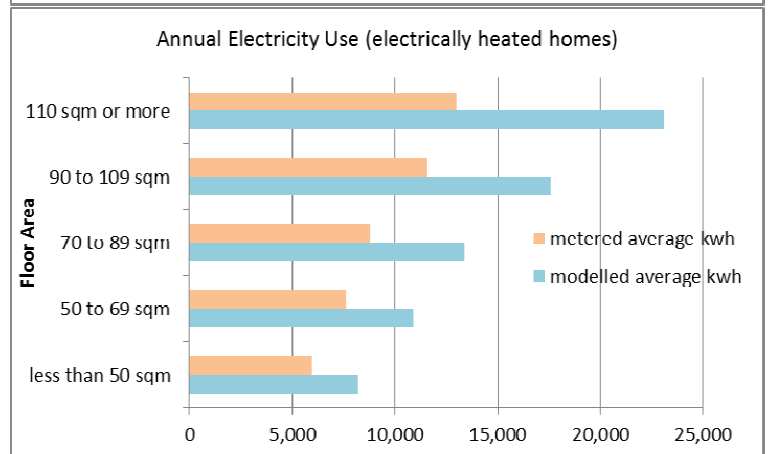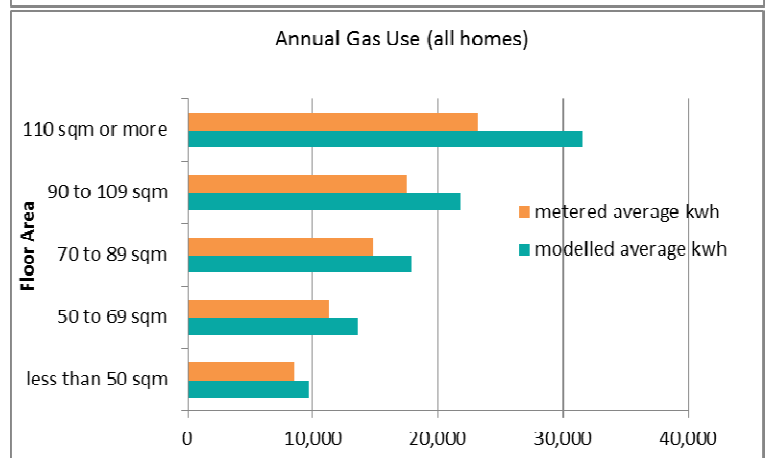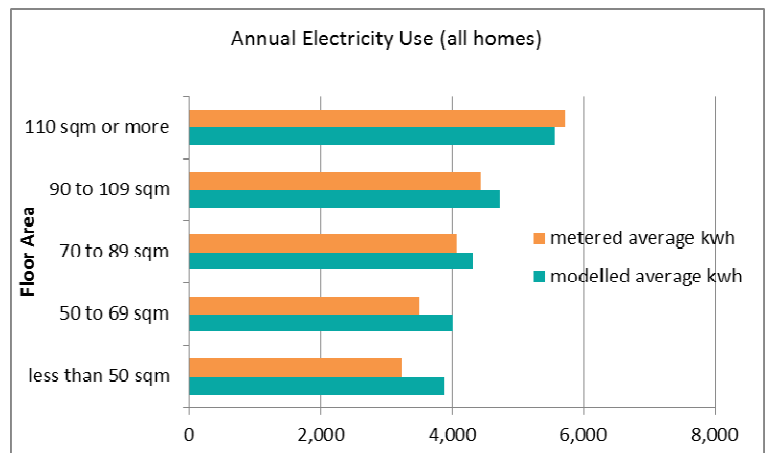
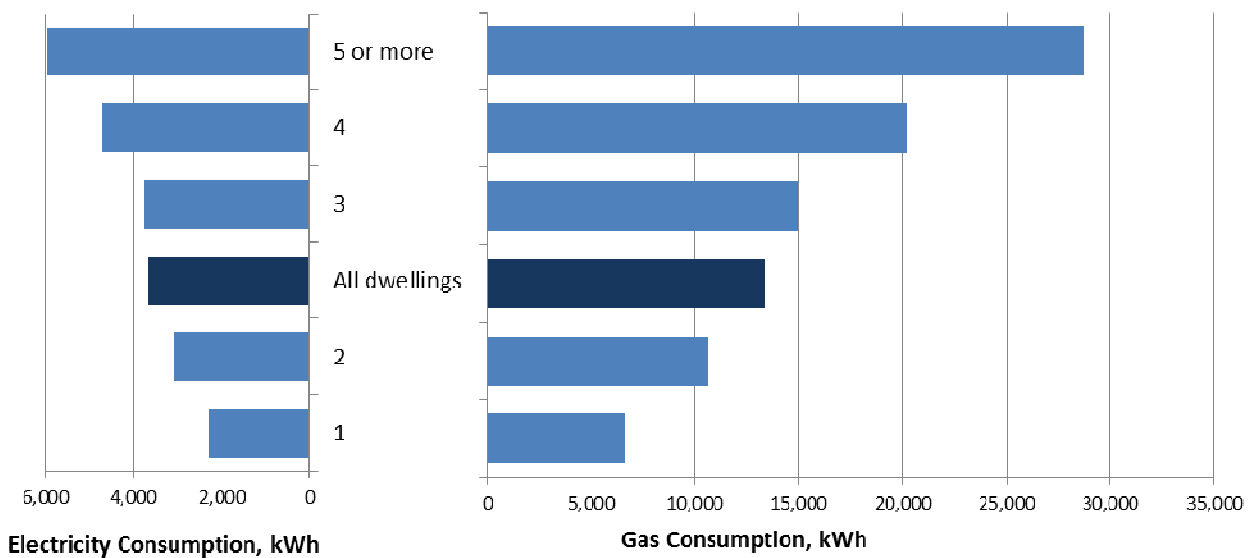## Number of Bedrooms

NEED Energy Use by Number of Bedrooms
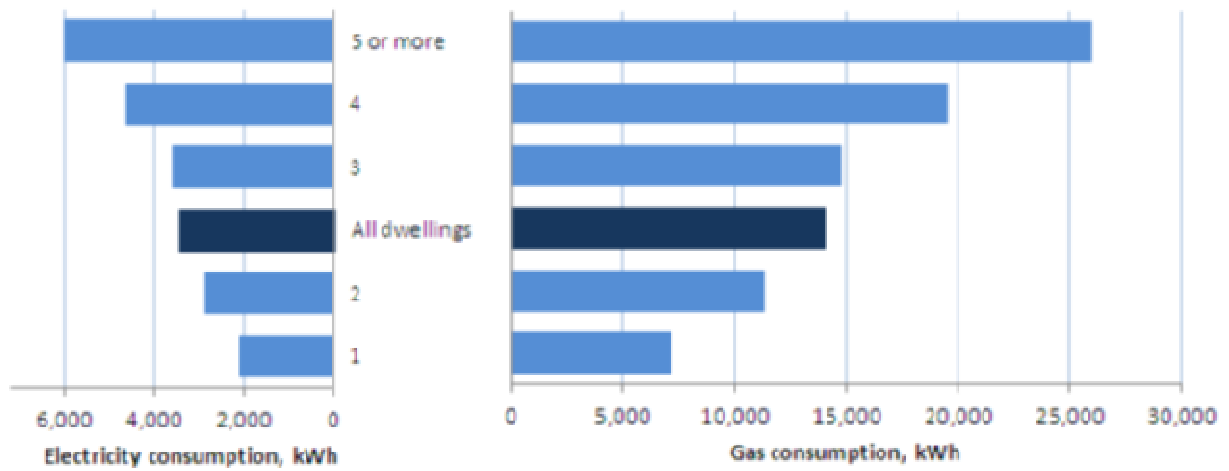
CHM Unadjusted Energy Use by Number of Bedrooms

CHM Adjusted Energy Use by Number of Bedrooms

Number of bedrooms

When the CHM estimates are broken down into bedroom bands like those reported in NEED, the match for electricity is quite close. The unadjusted estimate across all dwellings is a little higher than the NEED value, but the adjusted estimate is very similar (again, only 4% over). CHM estimates are also very close for small dwellings, although the estimates appear to be less accurate for large dwellings.

However, the gas estimates do not match quite so well against NEED. The unadjusted estimate for all dwellings is a little high, and surprisingly, the adjusted figure for all dwellings is around 5% too low. Both gas estimates are close to the measured values for small dwellings, but both look to be too high for large dwellings.

Implication: CHM appears to over-estimate gas use for large dwellings, even after the modelling adjustment.
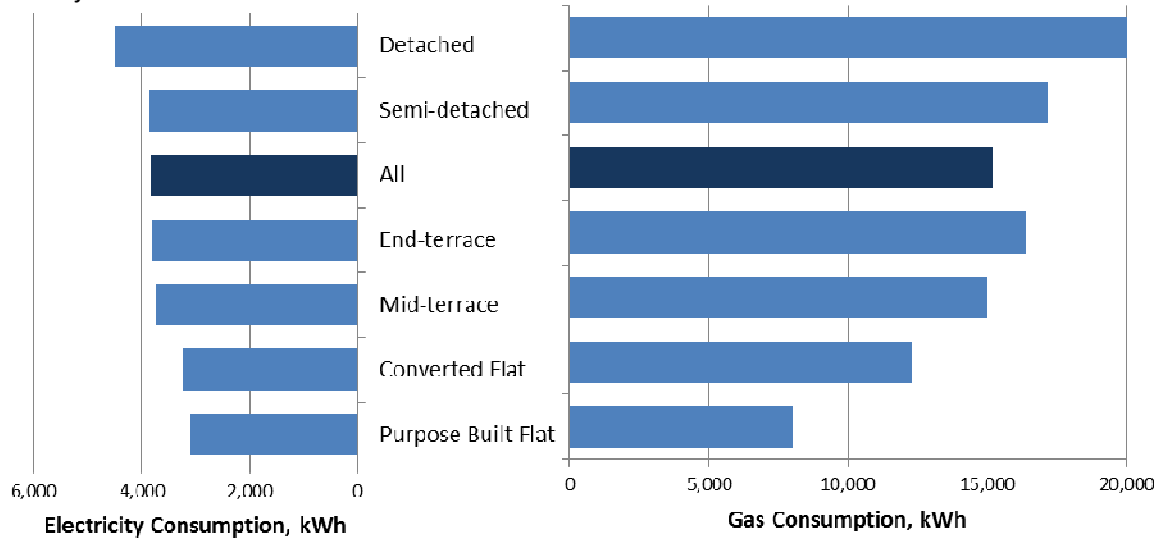
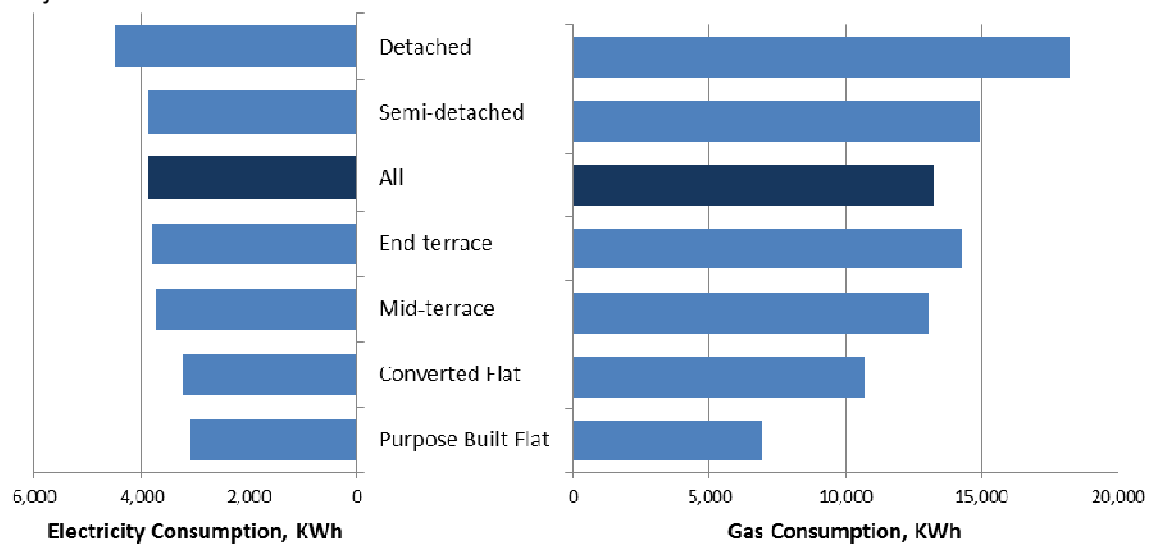|	Gas Use			Electricity Use		
Bedrooms	CHM (Adjusted)	NEED	Difference	CHM (Adjusted)	NEED	Difference
1	6,618	7,200	582	2,287	2,100	-187
2	10,636	11,300	664	3,069	2,900	-169
3	14,964	14,800	-164	3,761	3,600	-161
4	20,173	19,500	-673	4,706	4,600	-106
5+	28,708	26,000	-2,708	5,978	6,000	22

Dwelling Type

NEED
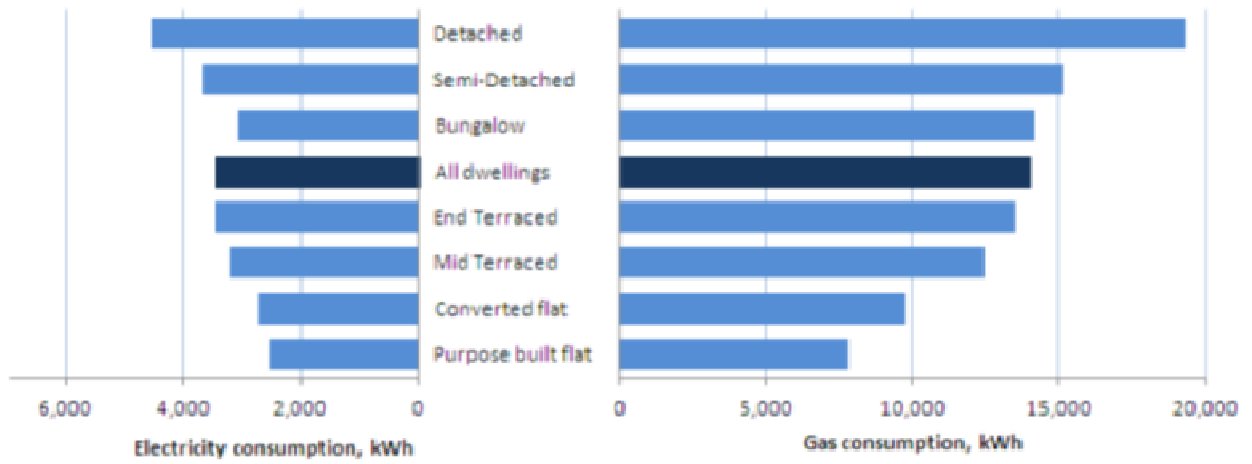
CHM Unadjusted

CHM Adjusted

Dwelling type

When the CHM estimates are broken down into similar house types to those reported in NEED, the match for electricity is once again better for electricity than for gas. (Bungalows are not specifically identified in the EHS, so we have not been able to compare bungalow data directly. Bungalows are included mainly as 'detached' dwellings, and some are also counted as semi-Ds or terrace houses.)

Both adjusted and unadjusted electricity use estimates from the CHM are very close for detached and semi-detached homes, but less accurate for terraces and flats (over-estimating by 8-16%).

The gas use estimates appear to be good for semi-Ds (only 1% off, as an average across the band). However, the gas estimates for detached homes are do not match quite so well against NEED. The unadjusted estimate for detached homes is a little high, and surprisingly, the adjusted figure for all dwellings is around 6% too low. The estimates for gas use in flats are also a weak match against NEED, with converted flats estimated at 9% over the measured value, and purpose-built flats estimated at 11% lower.

Implication: CHM appears to under-estimate gas use for detached dwellings and purpose-built flats, and over-estimate for terraces and converted flats, even after the modelling adjustment.

	Gas Use			Electricity Use		
Type	CHM (Adjusted)	NEED	Difference	CHM (Adjusted)	NEED	Difference
Detached	18,213	19,300	1,087	4,494	4,600	106
Semi-Detached	14,917	15,100	183	3,859	3,700	-159
End Terraced	14,242	13,500	-742	3,800	3,500	-300
Mid Terraced	13,071	12,400	-671	3,722	3,200	-522
Converted flat	10,708	9,800	-908	3,219	2,700	-519
Purpose built flat	6,968	7,800	832	3,089	2,500	-589

Dwelling Type: Metered Data vs. CHM

Comparing the metered data against the unadjusted CHM outputs showed that metered electricity consumption for semi-detached, detached and terraced houses was typically close to the CHM prediction. However the modelled energy use in flats, particularly converted flats, was much higher than the metered consumption.

In homes that were electrically heated, it was found that the CHM outputs overestimated electricity consumption across all of the house types.

Implication: the data indicates that SAP based algorithms used for estimating electricity use may need to be reassessed for converted flats.
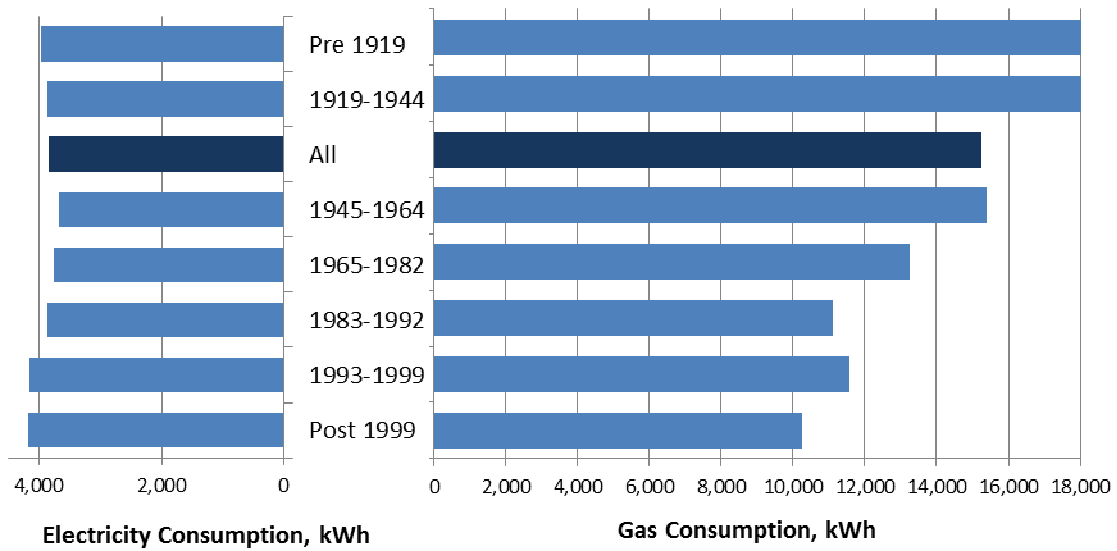
Annual Electricity Use (all homes)

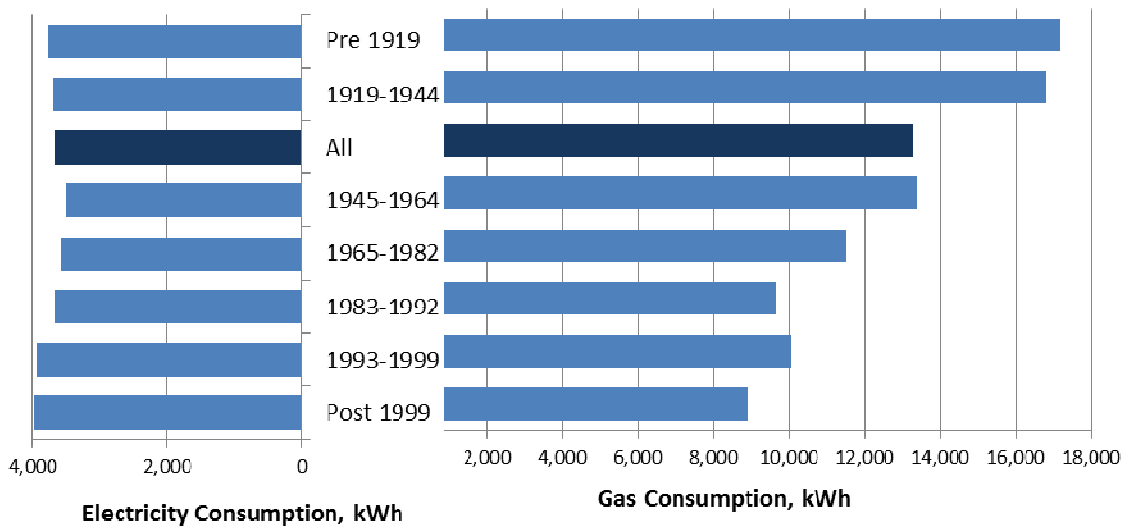**Annual Electricity Use (electrically heated homes)**
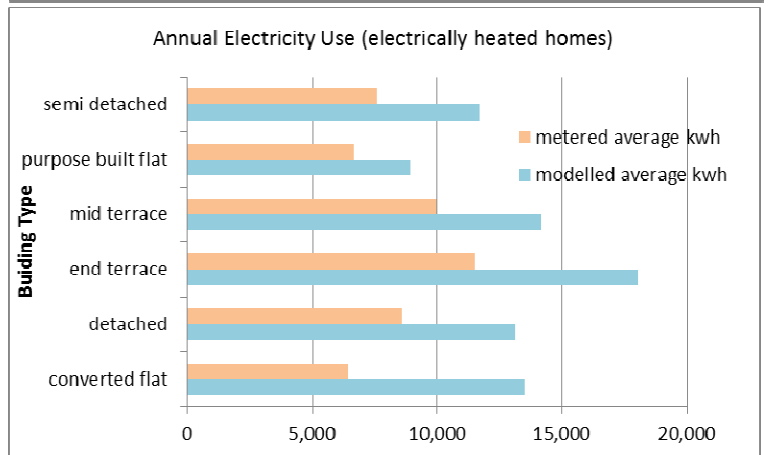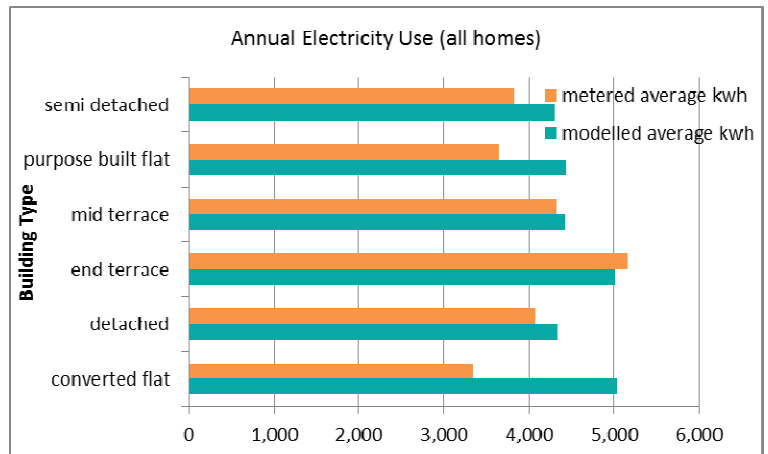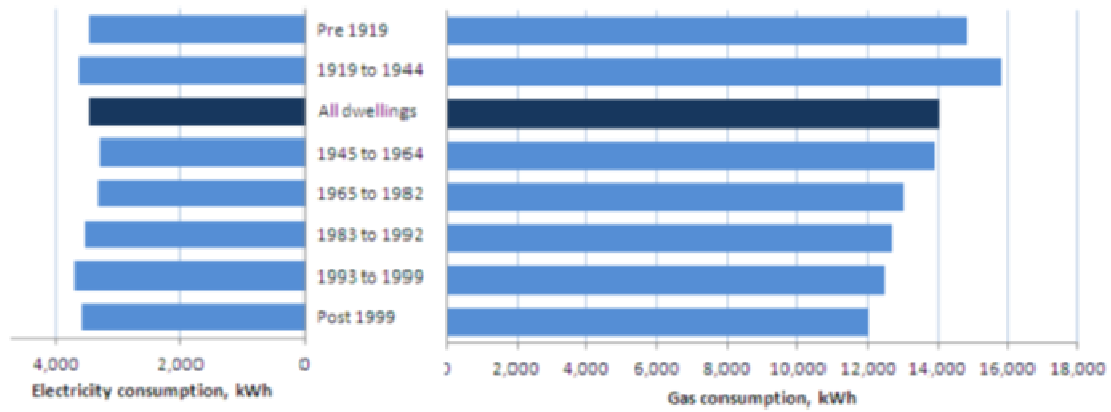
Dwelling Age

NEED

CHM Unadjusted

CHM Adjusted

Dwelling Age

When the CHM estimates are broken down into the same age bands as NEED, adjusted electricity estimates are quite close – typically within 8% of the NEED measurement. Surprisingly, the CHM estimates are all slightly higher than the NEED values. The CHM estimate for homes built since 1999 is 10% higher than the NEED measurement

However, the gas estimates do not match quite so well against NEED. The adjusted estimate for all dwellings is a little high, and surprisingly, the adjusted figure for all dwellings is around 6% too low. The gas estimates are close to the measured values for dwellings built between 1945 and 1964, but too high for pre-1919 homes, and too low for homes built since 1983. This suggests that the rather crude method of adjusting to match DUKES may be flawed when it comes to estimating gas use for specific ages of dwellings.

Implication: We may need to re-examine the method of adjusting to match DUKES, if estimates of gas use for specific ages of dwellings are important. Alternatively, there may be a case for adjusting demand temperature or heating regimes to achieve a better match for gas use in different age bands.

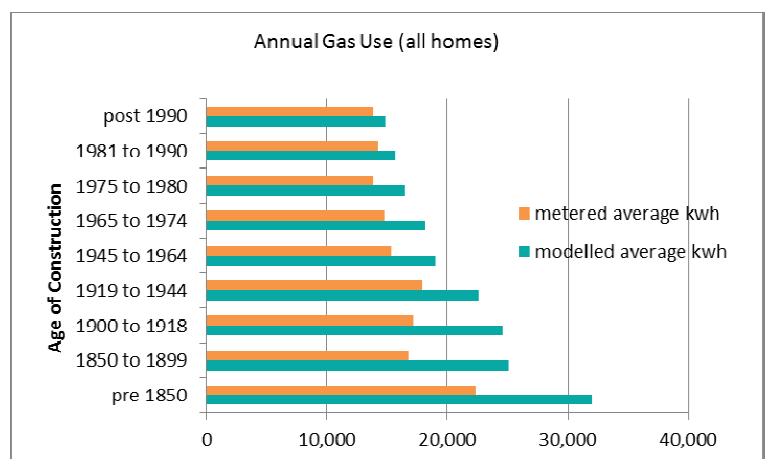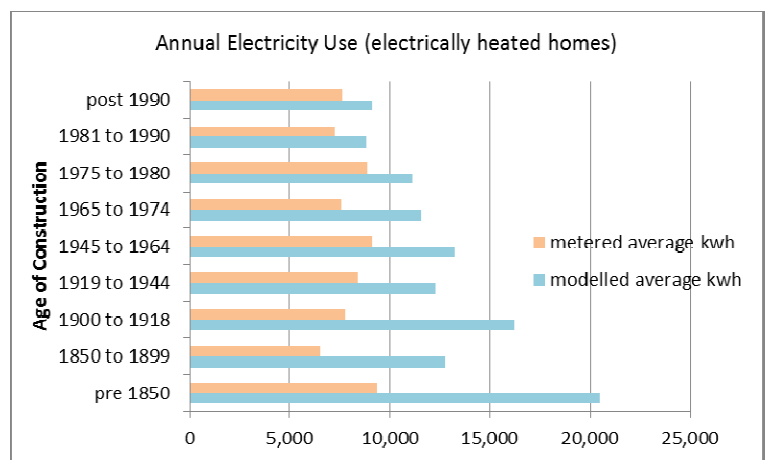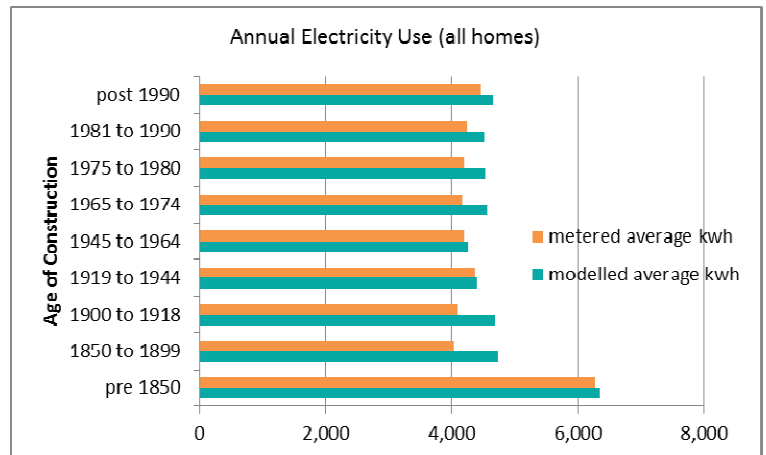|	Gas Use			Electricity Use		
Age	CHM (Adjusted)	NEED	Difference	CHM (Adjusted)	NEED	Difference
Pre 1919	17,179	14,800	-2,379	3,763	3,500	-263
1919 to 1944	16,833	15,800	-1,033	3,672	3,600	-72
1945 to 1964	13,380	13,900	520	3,480	3,300	-180
1965 to 1982	11,540	13,100	1,560	3,566	3,300	-266
1983 to 1992	9,656	12,500	2,844	3,662	3,500	-162
1993 to 1999	10,059	12,700	2,641	3,939	3,700	-239
Post 1999	8,922	12,000	3,078	3,969	3,600	-369

Dwelling Age: Metered Data vs. CHM

A comparison of the metered electricity use against the unadjusted CHM electricity use shows that the CHM output is consistently high, in particular for homes built between 1850-1899, which have the highest percentage difference.

The differences all rise for homes which are electrically heated, with the highest difference found in the oldest homes,
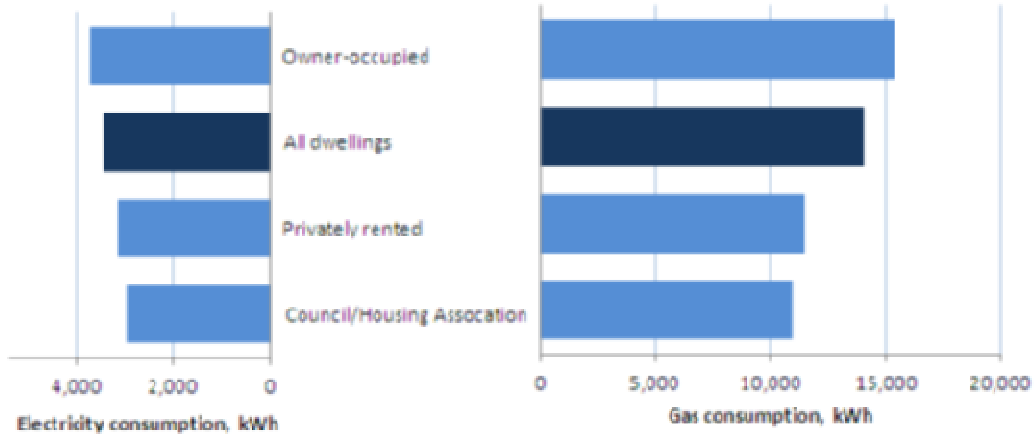
built pre-1850.

While the unadjusted CHM gas consumption is higher than the metered data for all years, the trend shows an increasing discrepancy as homes get older, going from a 7% difference post-1990, to a 30% difference for homes built pre-1850.

Implication: The gas consumption trend indicates that the method for assessing dwellings built in different periods, based on RdSAP, may need to be re-examined. One avenue of research could be to consider recent suggestions that U-values for solid walls, found in older dwellings, are better than typically assumed, leading to over-estimates of energy use.
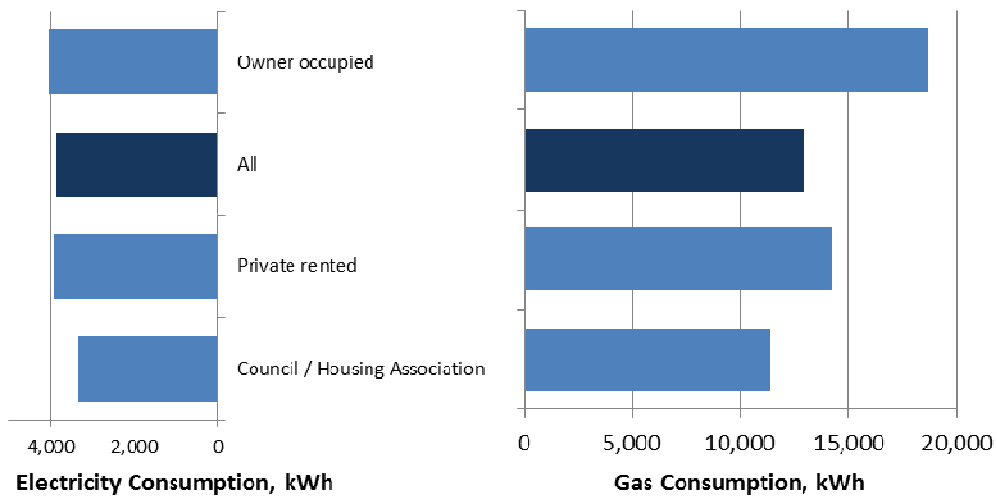

Annual Electricity Use (all homes)

Annual Electricity Use (electrically heated homes)

Annual Gas Use (all homes)

Tenure

NEED

Electricity consumption, kWh

Gas consumption, kWh

CHM Unadjusted

Electricity Consumption, kWh

Gas Consumption, kWh

CHM Adjusted

Electricity Consumption, kWh

Gas Consumption, kWh
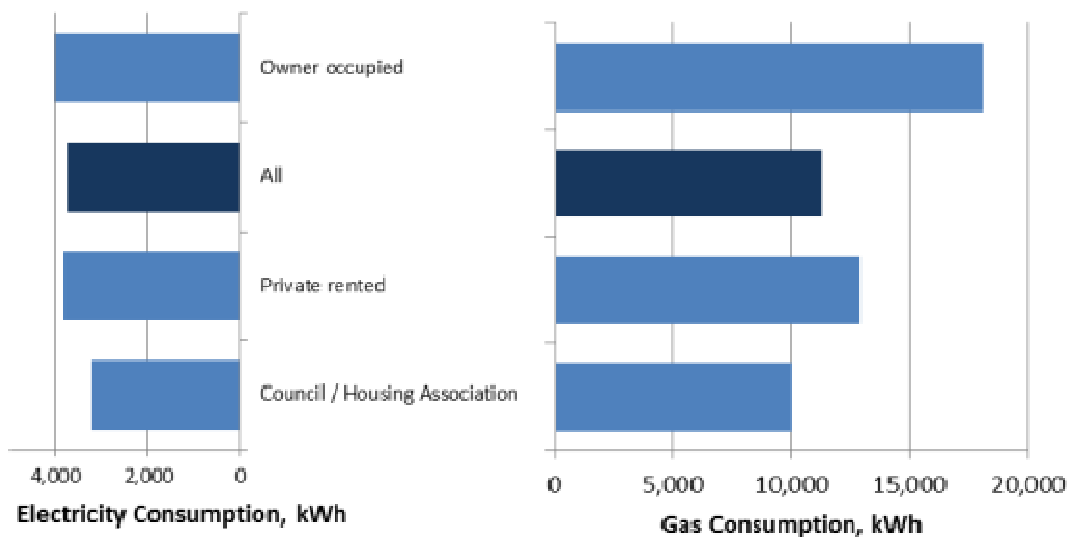
Tenure

When the CHM estimates are broken down into the same tenures as those used in NEED, there appear to be significant discrepancies between modelled estimates and measurements. The adjusted estimates for electricity use in owner-occupied and social housing privately-rented properties look a little too high (6-8%), and the electricity estimate for privately-rented homes looks significantly too high (22% over NEED).

On the gas side of the equation, the adjusted CHM appears to over-estimate for owner-occupied and privately-rented properties, but under-estimate for social housing. It is possible that this points to mistaken assumptions about demand temperatures and heating regimes in homes of different tenures. We currently assume that demand temperature and hours of heating are standardised across all homes. This finding may suggest that owner-occupied and private rented homes are actually heated to a lower temperature and/or for shorter periods than assumed in the CHM. Social housing, meanwhile, appears to use more energy for heating than the modelled estimates, suggesting that they may be heated to a higher temperature and/or for longer periods.

Implication: Consider revising demand temperatures and heating regimes based on tenure. And examine why the CHM's electricity use estimate is so much higher than the NEED measurement.
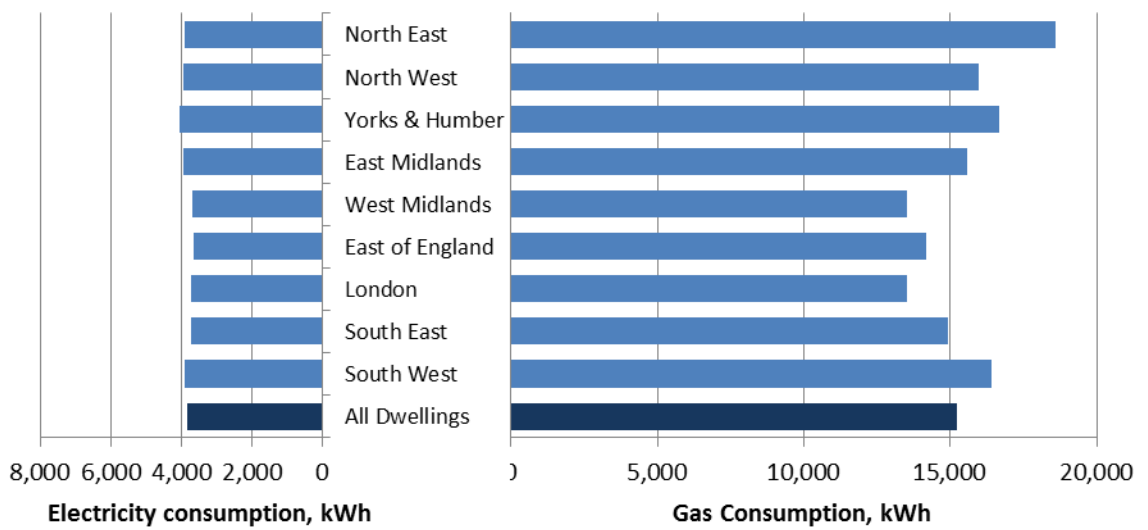
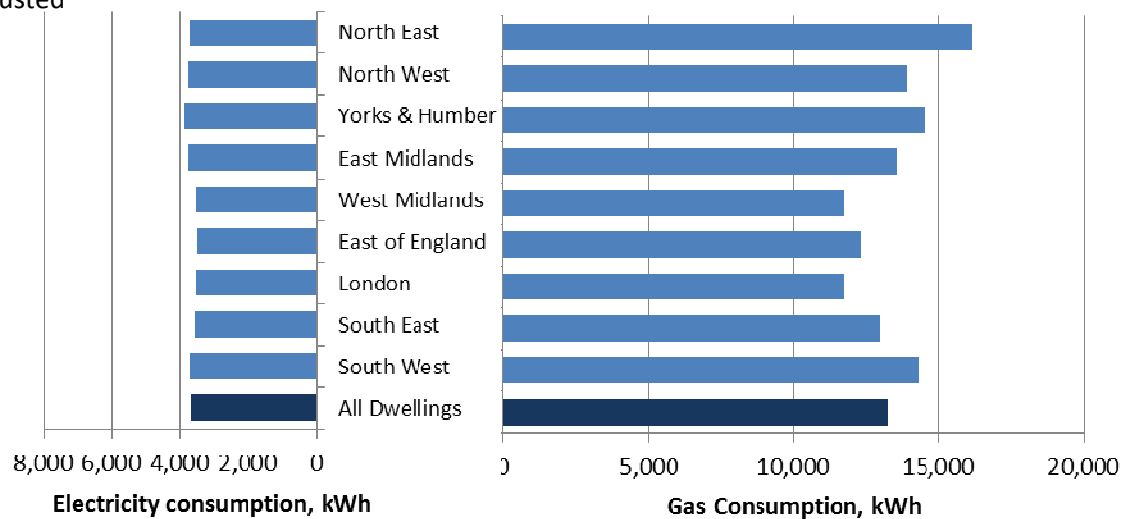|	Gas Use			Electricity Use		
Tenure	CHM (Adjusted)	NEED	Difference	CHM (Adjusted)	NEED	Difference
Owner-occupied	18,067	15,400	-2,667	3,991	3,700	-291
Privately rented	12,916	11,500	-1,416	3,790	3,100	-690
Council/Housing Association	10,012	10,900	888	3,188	3,000	-188

Region

NEED
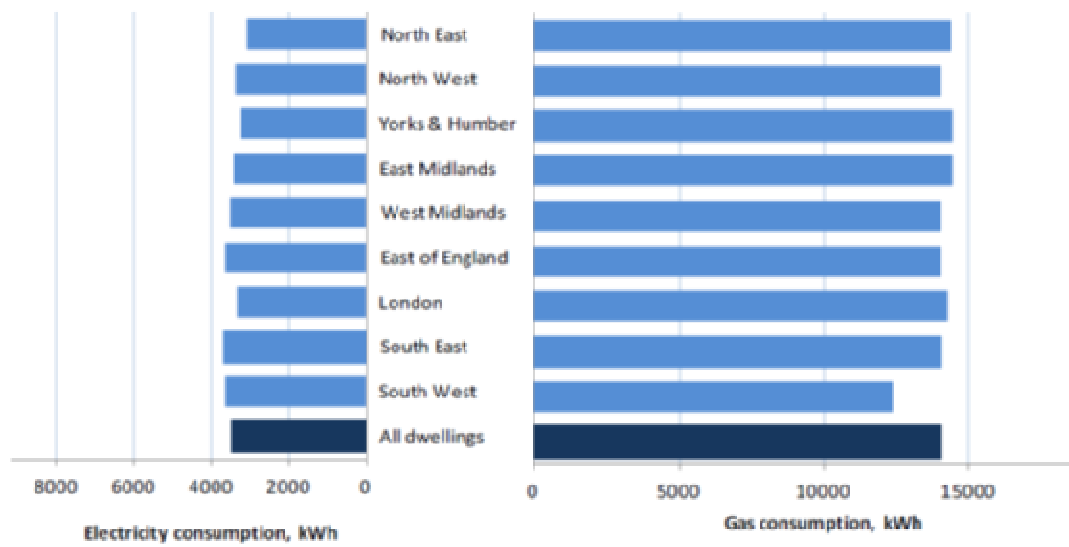
CHM Unadjusted

CHM Adjusted

Region

The Cambridge Housing Model uses the same nine Government Office regions as NEED to define geographic locations. Curiously, the NEED data shows remarkably even gas consumption between regions – all but the South West has median gas use between 14,000 and 14,400 kWh of gas for 2010. The South West shows median gas use of 12,400 (this is as you would expect – the South West was milder than other regions).

In contrast, CHM estimates indicate much greater diversity of gas use between regions, with a much lower estimate for London (-18%) and the West Midlands (-16%), and much higher for the North East (12%). This may suggest that climate is not as significant in shaping gas use as we currently assume in the model.

For electricity use, precisely the opposite pattern emerges, with NEED values showing quite a big variation in electricity use between regions , and the CHM estimates showing much more even electricity consumption between regions. This suggests that the model algorithms may not put sufficient weight on climate and/or latitude for the electricity estimates. (Income may also be an intervening variable – for both electricity and gas use.)

Implication: We need to re-evaluate how climate, and especially external temperature, affect space heating estimates in the model. We also need to re-examine how the electricity use algorithms are affected by region.

Area	Gas Use			Electricity Use		
	CHM (Adjusted)	NEED	Difference	CHM (Adjusted)	NEED	Difference
North East	16,164	14,400	-1,764	3,727	3,100	-627
North West	13,876	14,100	224	3,746	3,400	-346
Yorks & Humber	14,500	14,400	-100	3,865	3,200	-665
East Midlands	13,541	14,400	859	3,764	3,400	-364
West Midlands	11,776	14,100	2,324	3,525	3,500	-25
East of England	12,327	14,000	1,673	3,494	3,600	106
London	11,772	14,300	2,528	3,534	3,400	-134
South East	12,983	14,000	1,017	3,557	3,700	143
South West	14,271	12,400	-1,871	3,706	3,600	-106

Income
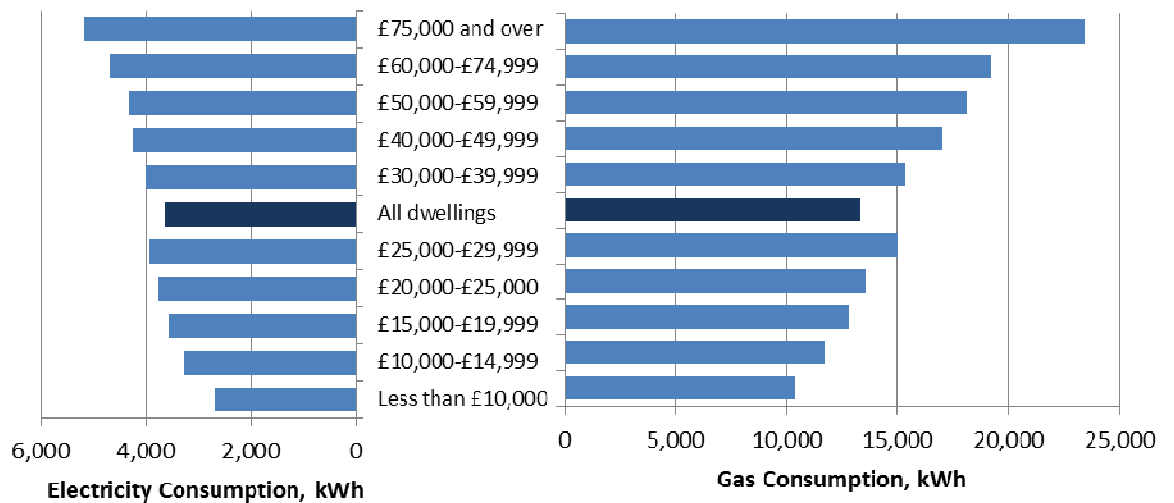
NEED
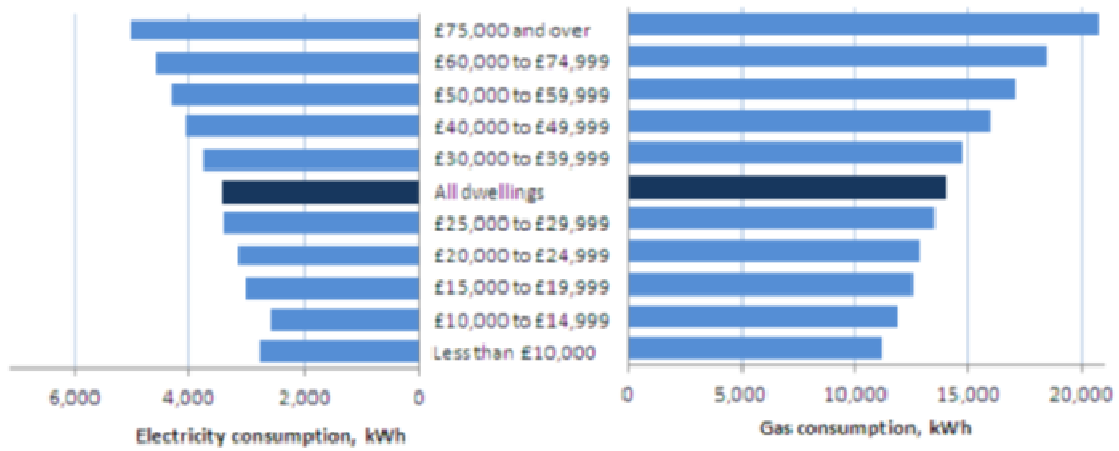
CHM Unadjusted
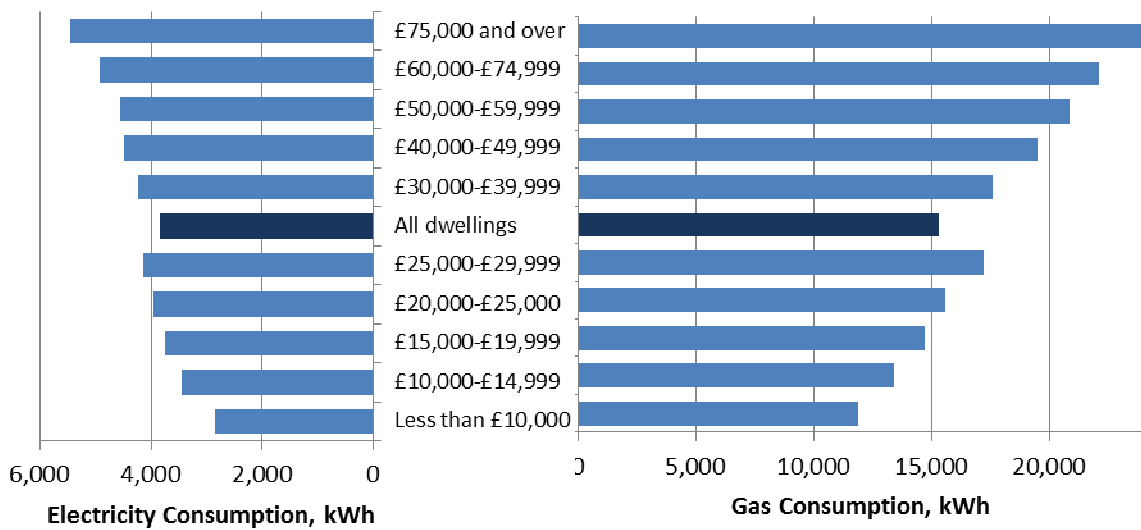
CHM Adjusted

Income

When CHM estimates are split up to match the stated NEED income bands, the modelled estimates show a very similar pattern to the 'measured' values from NEED. In both cases, poorer households in almost every increment use less gas and electricity than wealthier ones. The sole exception is for electricity use in homes with incomes below £10,000, which NEED suggests use slightly more electricity than the next-highest band (£10,000-£14,999).

Clearly, this is as you would expect, with wealthier households both able to spend more on energy, and (on average) living in larger dwellings.

However, within this pattern there remain some significant discrepancies between the CHM and NEED. On gas use, the CHM estimates appear to significantly over-estimate for homes with incomes of £25,000-£29,999, and those above £40,000. Conversely, it appears to under-estimate gas use for the poorest households. Income is not an input in the CHM, so it is unclear how we could act on this. The effect is probably linked to dwelling size, discussed above.

On electricity use, the adjusted CHM estimates appear to be too high for all incomes apart from the poorest – unlike the gas estimates, they appear to be closer for higher income households. Again, this is probably linked to the correlation between income and dwelling size, and the presumption in the model that electricity use rises in proportion to floor area.

Implication: Income effects appear to be reflected better in the model for electricity than for gas.

	Gas Use			Electricity Use		
Income	CHM (Adjusted)	NEED	Difference	CHM (Adjusted)	NEED	Difference
Less than £10,000	10,343	11,200	857	2,715	2,800	85
£10,000 to £14,999	11,691	11,900	209	3,271	2,600	-671
£15,000 to £19,999	12,805	12,500	-305	3,570	3,000	-570
£20,000 to £24,999	13,578	12,800	-778	3,756	3,100	-656
£25,000 to £29,999	15,005	13,500	-1,505	3,940	3,400	-540
£30,000 to £39,999	15,331	14,800	-531	4,027	3,800	-227
£40,000 to £49,999	16,984	16,000	-984	4,258	4,000	-258
£50,000 to £59,999	18,141	17,100	-1,041	4,341	4,300	-41
£60,000 to £74,999	19,219	18,500	-719	4,687	4,600	-87
£75,000 and over	23,428	20,800	-2,628	5,185	5,000	-185

**Comparing NEED against Sub-National Energy Use Statistics and DUKES**

DECC also produced a comparison of the NEED sample data against DUKES (Digest of UK Energy Statistics) data, produced at a national level, for both gas and electricity consumption. The two graphs below show the mean energy consumption in the housing stock, based on DUKES and NEED figures (the Sub-National Statistics are based on aggregate utility meter readings, as mentioned previously).

Mean Gas Consumption per Household
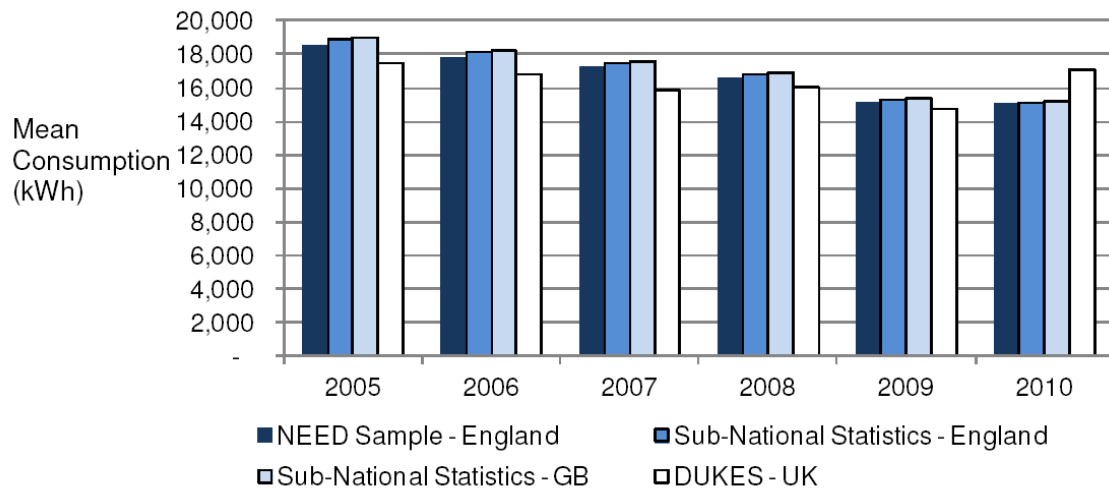
The key finding from the mean gas consumption analysis is that while the NEED sample consumption has historically been higher than the DUKES consumption, in 2010 the DUKES consumption is significantly higher. This is because the NEED sample is weather corrected, while the DUKES data is not, leading to discrepancies due to the changing climate patterns in the sample years.

Mean Electricity Consumption per Household
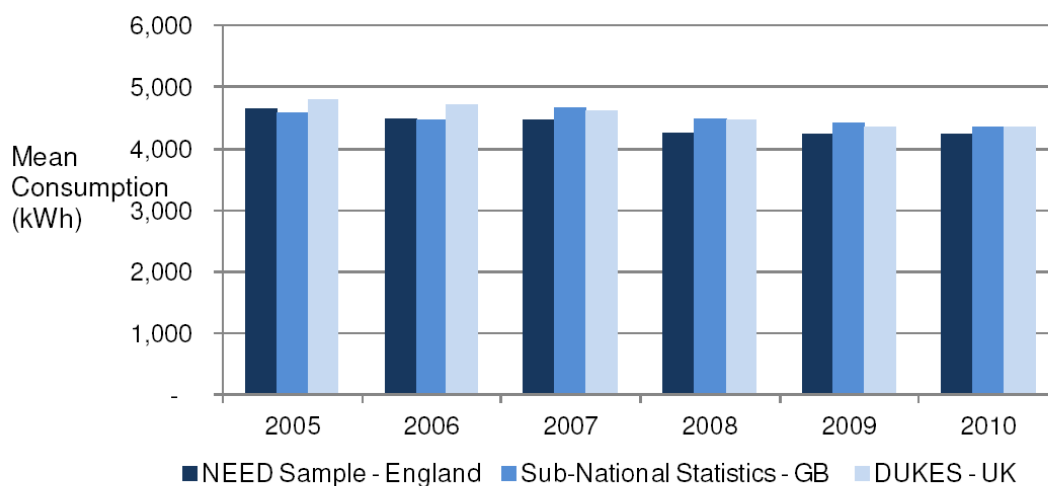
The 2010 NEED sample electricity use is slightly lower than the DUKES figure. This may be due to different sample distributions: DUKES is UK-wide, while NEED is just taken from England. It is also possible that the NEED sample is skewed in favour of more energy-efficient homes.