POTENTIAL FOR A NEIGHBOURHOOD INCOME-BASED DOMESTIC ENERGY MODEL FOR ORDINARY ELECTRICITY USE IN ENGLAND

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Summary

Current domestic energy models in England currently only take floor area as an independent variable in modeling electricity consumption of a home. This work compared the algorithm in place from 2001-2005 with surveys of consumption in homes from 2002-2006 and census area-wide consumption for the year 2007 to examine the effectiveness of the model and the potential for improvement by adding in the variable of average income by area. The results were that the model underestimated consumption, and the survey data did not match the amount of consumption in census areas at the top of the income scale, notably in a comparatively more heavily urbanised and wealthy London.

Keywords: electricity, modeling, income, neighbourhood, area

1 Purpose

Building regulations that promote the conservation of energy use in domestic buildings in the United Kingdom are required under the building acts of its constituent nations as well as fulfilling the European Directive on the Energy Performance of Buildings. [1-3] For simplicity, this discussion will limit itself to the legislation and the current building regulations in place in England, which are supplemented by approved documents that provide supplementary guidance for fulfilling the requirements of the building regulations. For domestic buildings, this is Approved Document Part L1A which requires a target emissions rate (calculated as the number of kilograms of carbon dioxide per square metre) that is calculated from the Standard Assessment Procedure (SAP) derived from the Building Research Establishment Domestic Energy Model - 12 month (BREDEM-12) [4]. The basic BREDEM algorithm was published in 2001 for use in SAP between 2001-2005. The basic equations for electricity consumption for appliances, lighting, and cooking are as follows:

Lighting and Appliances (Gigajoules/year):

if ($TFA \times N < 750$)

$$Elec = 0.022\ TFA \times N + 2.16$$

else if ($TFA \times N > 750$ and $TFA \times N < 2475$)

$$Elec = 9.84 + 0.014\ TFA \times N - 2.63 \times 10^{-6}\ (TFA \times N)^2$$

else

$$Elec = 28.8$$

Cooking (Gigajoules/year):
1.70 + 0.34 x N

where *Elec* is electricity in gigajoules per year (there are 278 kilowatt-hours in a gigajoule), *TFA* is the total floor area, or gross external area, in square metres, and *N* is the number of occupants [5].

A supporting evidence paper [6] was written to accompany this last published revision of BREDEM in 2001 that detailed the rationale for socioeconomic impacts on energy use of appliances, lighting, and cooking. First there were two conclusions, that low income households have less appliances than average, and that they use the appliances they have less than average. The results shown in the Pennyland Project (an experiment on an estate of 177 houses in the Pennyland district of Milton Keynes to compare UK and Danish building energy efficiency standards) indicate that the 'gap' between measured and estimated fuel use was most severe at the low end of the scale. [7]

This paper seeks to examine the potential for income to be included as a factor in estimating what is called "ordinary" domestic electricity use in the United Kingdom by examining homes that were surveyed during the time that the BREDEM 2001 model was in force. Ordinary electricity use is approximated as the electricity use of lights, appliances, and cooking in the homes. It is noted that other sources of electricity may contribute to ordinary electricity use: boiler pumps (130 kwh/year), boiler and extract fans (72 kwh/year), and mechanical ventilation systems (394 kwh/year). [5]

2 Data Sources

There are three main data sources – the United Kingdom Office of National Statistics, the UK Department for Energy and Climate Change, and the English Department for Communities and Local Government. Census data from the Office of National Statistics was last collected in 2001. The Department of Energy and Climate Change developed a method of measuring energy in both the domestic and non-domestic sectors delivered in small scale statistical areas since 2004. Data is shown by consumption in kWh (split by ordinary electricity, economy7 electricity, industrial/commercial electricity, domestic gas and industrial/commercial gas), number of gas and electric meters and average consumption per meter [8]. The English House Condition Survey (EHCS) is a national survey of housing in England, commissioned by the Department for Communities and Local Government involved both an interview and a physical inspection of property by professional surveyors. From April 2002 to March 2008 the EHCS was run on a continuous basis with consistent and comparable datasets [9]. Other data has been extracted from the Experian Mosaic project on socioeconomic groups and income and the Market Transformation Programme for information on trends in cooking use[10, 11].

3 Methodology

This exercise compared electricity use for appliances, lighting, and cooking from survey data and modelling predictions from BREDEM-12 (2001) contained in the planning and building regulations in force from 2001 to 2005 [12, 13]. Electricity consumption data on all housing in England is currently released at the level of the Middle Layer Super Output Area (MLSOA). The MLSOA was first introduced in the 2001 census as a new statistical standard. They are relatively consistent in terms of population (minimum population of

5,000 equating to around 2,000 households). All metered data has been collected by the Department from energy companies and collated into each MLSOA yearly since 2005. To make this comparison, a new dataset for each MLSOA will need to derived building upon survey and census data as shown in Table 1.

Tab. 1 Referenced and Dervied datasets

English House Condition Survey (unit scale)	**DECC Regional Price Index (Regional scale)**	**ONS Census data / *Experian* (MLSOA scale)**	**EHCS/RPI/ONS Derived Dataset (MLSOA scale)**	**DECC Energy Data (MLSOA scale)**
Region	Region	Region	Region	Region
		MLSOA name	MLSOA name	MLSOA name
Dwelling type		Dwelling type	Dwelling type	
Area Type		Land Use	**Area Type**	
Gross Floor Area			**Residential Floorspace**	
Household Income / **Income group**		*Household Income / **Income Group***	Household Income / **Income group**	
Spending on ordinary electricity use	Price per kilowatt-hour		**Total ordinary electricity use**	Total ordinary electricity use
Method of payment	Method of payment			

Plain = given data **Bold = derived data**

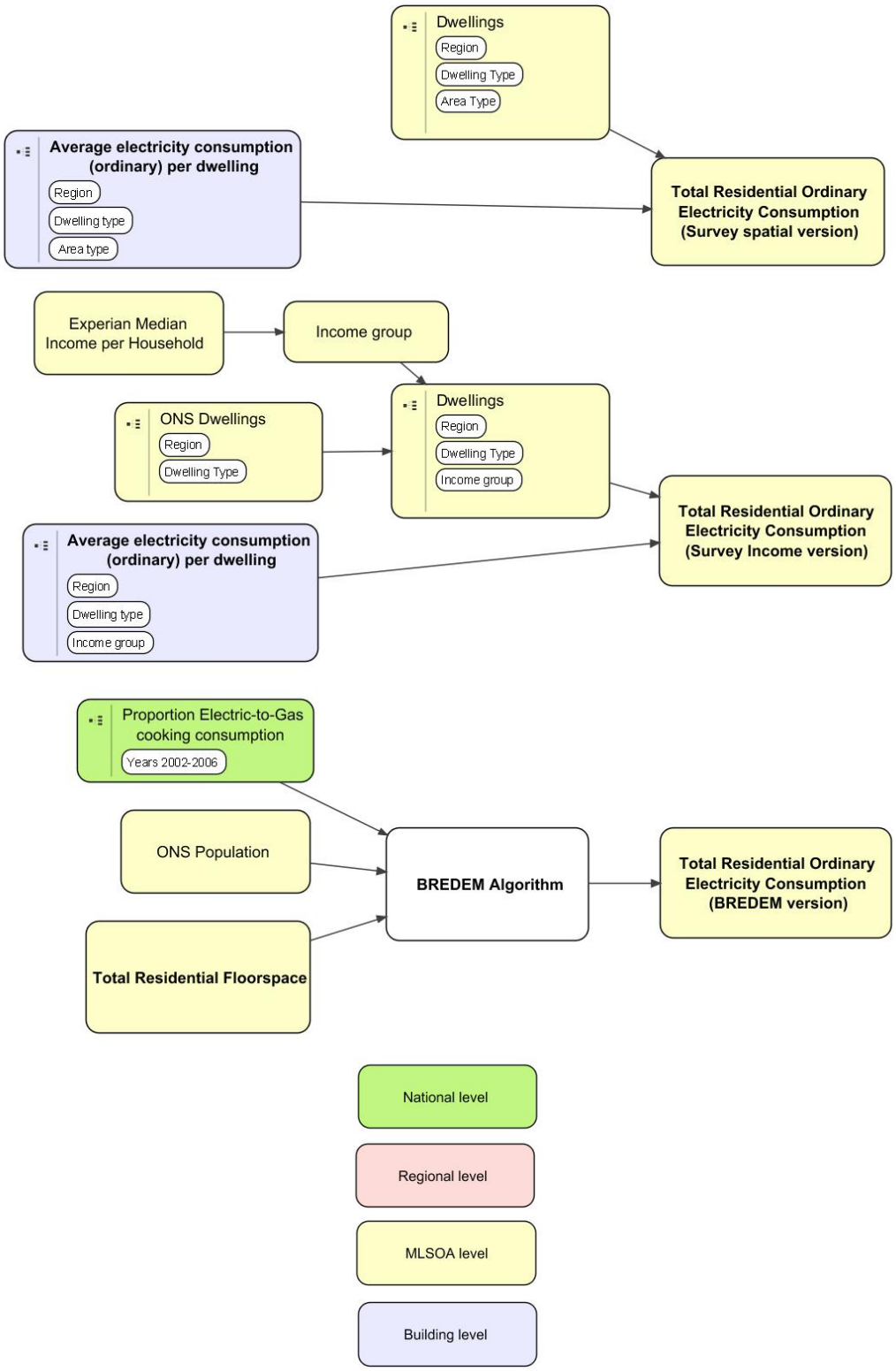

Fig. 1 Residential electricity consumption estimates and derived dataset requirements (in bold)

As shown in Figure 1, The EHCS/RPI/ONS Census derived dataset needs to both be able to produce an estimate for total residential ordinary electricity consumption for each MLSOA through analysis of the survey data and by running a large version of the BREDEM algorithm based on numbers of people, floorspace, and electric cooking trends.
The given information was:

- Numbers of dwellings by dwelling type and region in each MLSOA
- Population in each MLSOA
- Median Income per household in each MLSOA
- Proportion of Electric-to-Gas cooking consumption nationally

The required derived information to estimate each MLSOA total ordinary electricity consumption was:

- Average electricity consumption per dwelling by region, dwelling type, and area type
- Average electricity consumption per dwelling by region, dwelling type, and income group
- Total residential floorspace

An estimate for residential floorspace in each MLSOA was obtained by multiplying the number of dwellings by an average floorspace per dwelling. However, this approach is simplistic and does not take into account variance in dwelling types (e.g. detached house, flat/apartment) and urbanisation. For example, the average flat size could be smaller in London than the rest of the country, but a larger percentage of the housing stock.

To take into account intra- and inter-regional differences, each MLSOA was given an "area type" based on residential density in addition to its given region with the same three categories as the EHCS dataset. A mean gross floor area for each dwelling type by region and area type (as reported by the EHCS surveyor) was calculated from the 40,686 entries in the EHCS. Finally, the number of dwellings in each dwelling type in each MLSOA was multiplied by the mean gross floor area for that dwelling type, region of the MLSOA, and area type of the MLSOA to obtain a total floorspace for that dwelling type, and all those floorspace total were summed to obtain a total residential floorspace figure for the MLSOA. Figure 2 describes this process.

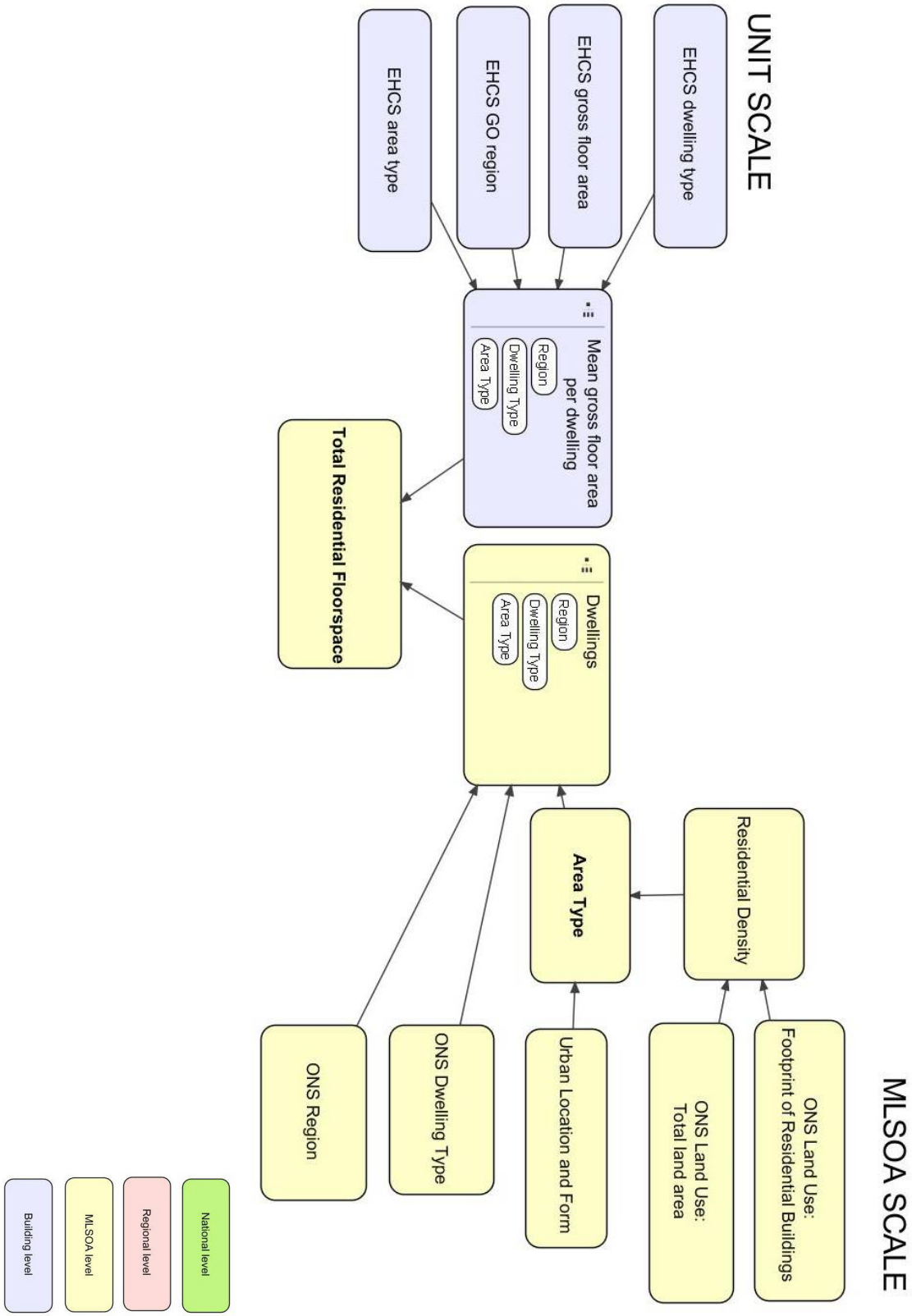

Fig. 2 Calculating total residential floorspace in each MLSOA

Obtaining an estimate for average electricity consumption for each dwelling based on the survey information was less straightforward. Data obtained on each dwelling in the EHCS survey were the region of England, dwelling type (e.g. detached house), urbanisation type (urban, surburban, and rural), household income level in Great Britain Pounds, payment type for electricity, and spending on appliances and lighting and cooking, which is closely connected to annual spending on ordinary electricity use [14].

The annual spend on electricity in each dwelling was converted to annual kilowatt-hours based on regional energy price data [15]. This data contained an average price per kilowatt-hour for a central city in each English region for each of the three main payment types in the UK. A mean ordinary electricity consumption per dwelling was averaged by region, dwelling type, and household income group (£0 - £15,000, £15,001 - £25,000, £25,001 - £40,000, £40,000 and above). For comparison, a 'spatial version' was also averaged by region, dwelling type, and area type.

However, cooking spending represents a mix of electric and/or gas hobs (stovetops) and ovens. National trends for each EHCS year (2002-2006) on ownership and usage of hobs and overs were merged to create a proportion of electric-to-gas cooking consumption per year [11]. This was converted to a proportion of electric-to-gas cooking electricity spend by region, payment type, and year that could be applied to each dwelling's reported cooking spend to obtain an estimated electricity amount. Figure 3 below details all the data and relationships involved.

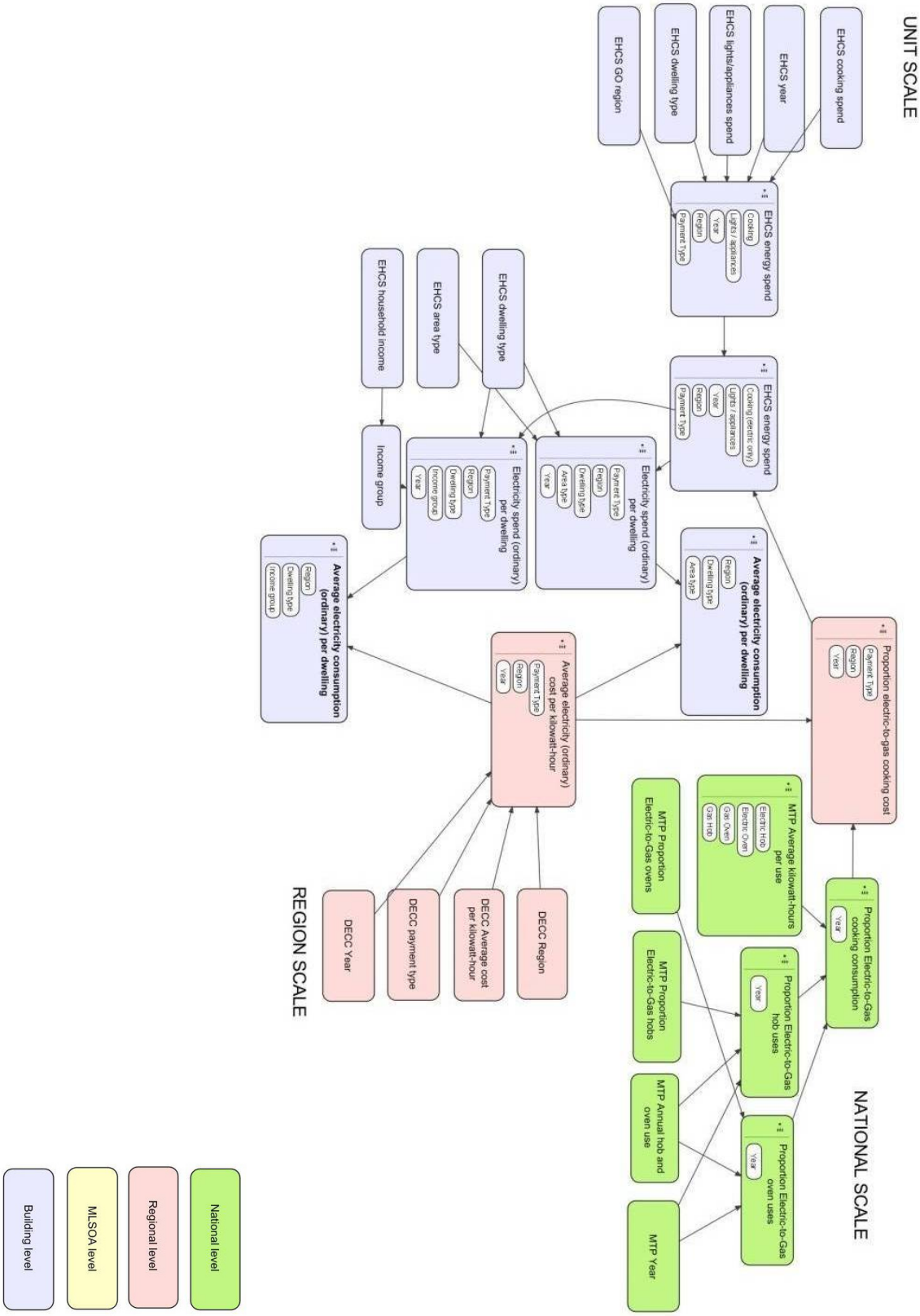

Fig. 3 Calculating average ordinary electricity consumption per dwelling

4 Results

For each MLSOA, the three estimates of total electricity use per household (survey - spatial version, survey – income version, and BREDEM 2001) were plotted against:

1. Total residential floorspace times population divided by households, which equals the floor area times numbers of occupants per household
2. Income per household

The reasons for the first comparison is the use of BREDEM of floor area times numbers of occupants per household in the algorithm for estimating electricity use for lights and appliances in the 2001 version, and an expectation that that would continue in the future [6].

Finding 1: The planning and building regulations in force from 2001-2005 underestimated the ordinary electricity consumption of households by half of both the reported energy use in the 2002-2006 EHCS surveys during which this model was in force for all newly built homes, and also by half or more the average electricity use per household reported in each MLSOA (the DECC data).

Finding 2: Both BREDEM and the survey data show a faster increase in consumption in proportion to floor area and numbers of people than the DECC data indicates. The rate of increase is closer to the DECC data in the case of the income version than in the spatial version of the survey data. The rate of increase is also closer in national datasets than in heavily urbanised areas such as the Greater London region.

Finding 3: When the EHCS survey, DECC data, and BREDEM electricity totals per household are plotted against income per household, the survey and BREDEM estimates show similar increases in energy use based on income compared with the DECC data. In the London region, however, there is little relationship between income and energy use in the EHCS survey data and in the BREDEM model estimates of energy use. The census area MLSOA data collected, however, shows a potentially strong relationship between income and energy use.

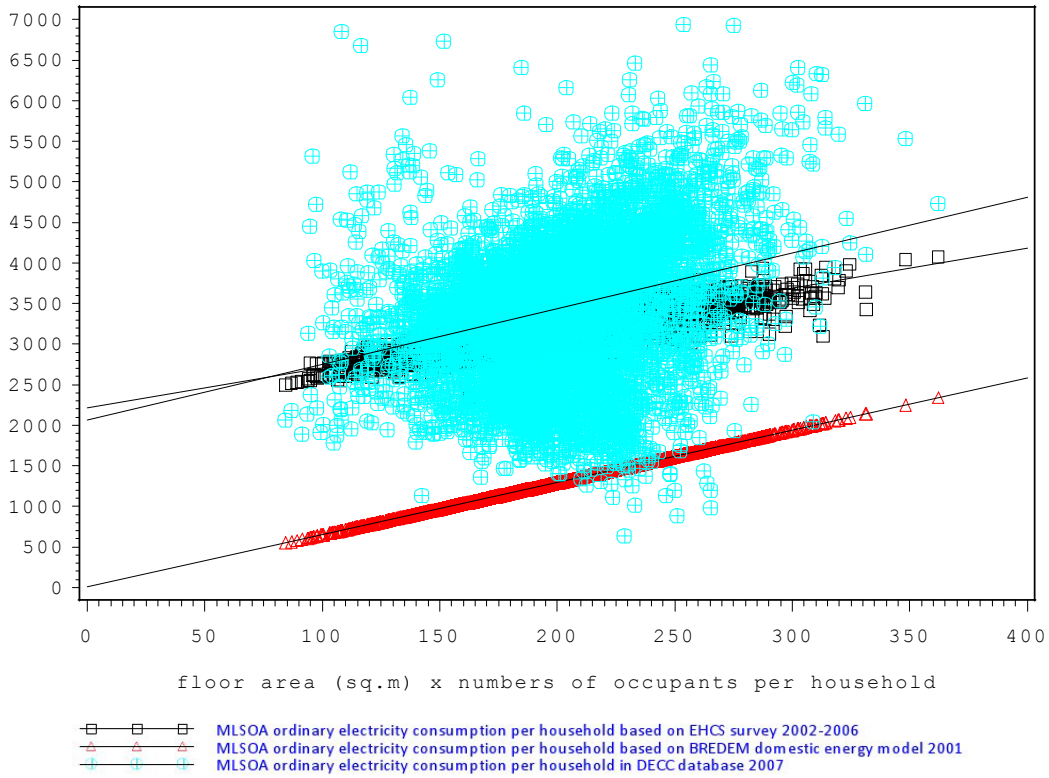

Fig. 4 Average electricity consumption per household v Floor area times number of occupants per household (Note: Survey - spatial version, all of England)

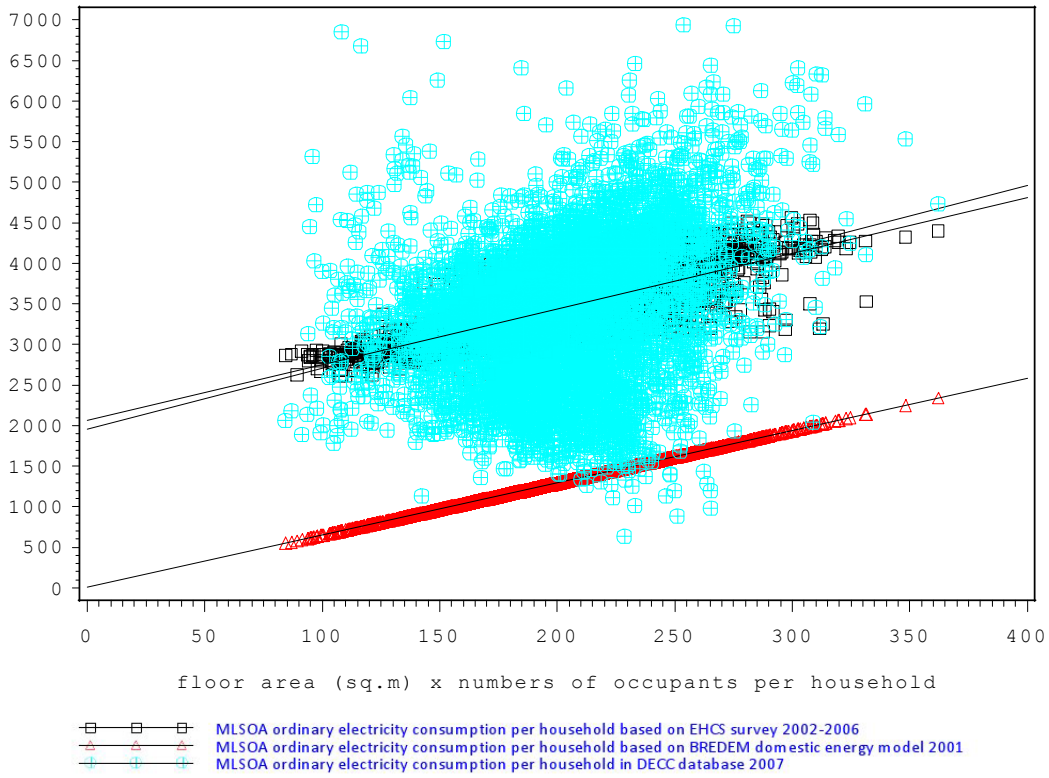

Fig. 5 Average electricity consumption per household v Floor area times number of occupants per household (Note: Survey - income version, all of England)

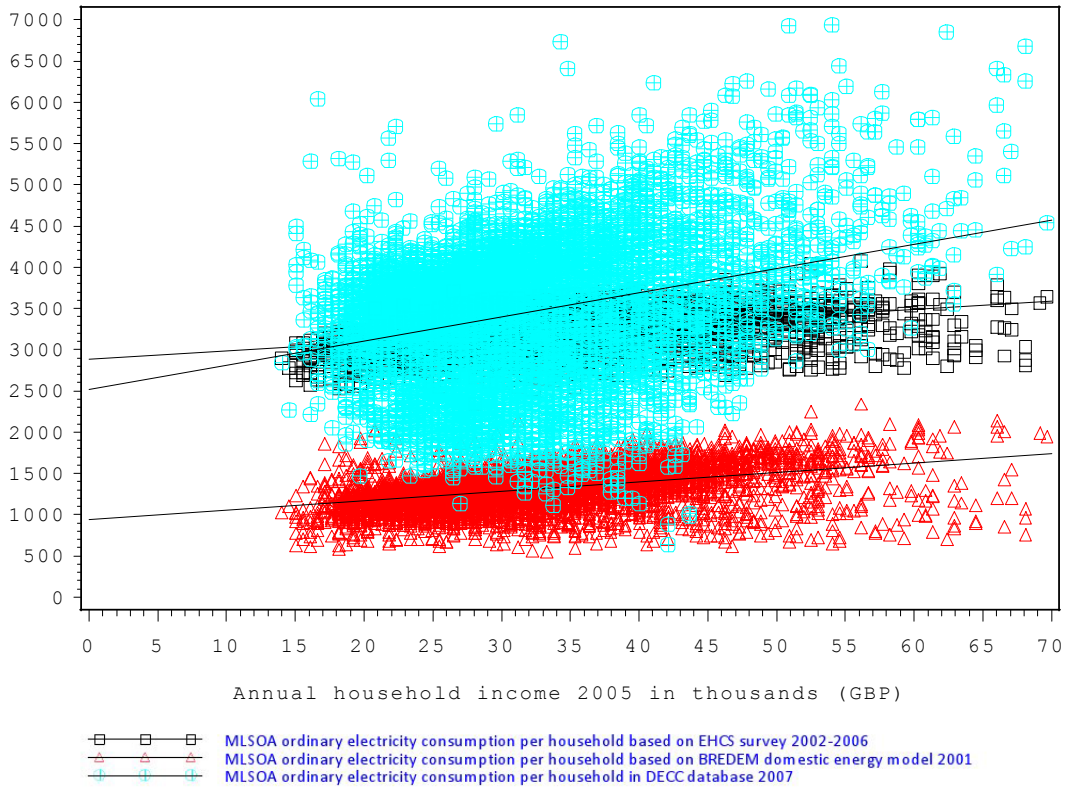

Fig. 6 Average electricity consumption per household v Income per household (Note: Survey - spatial version, all England)

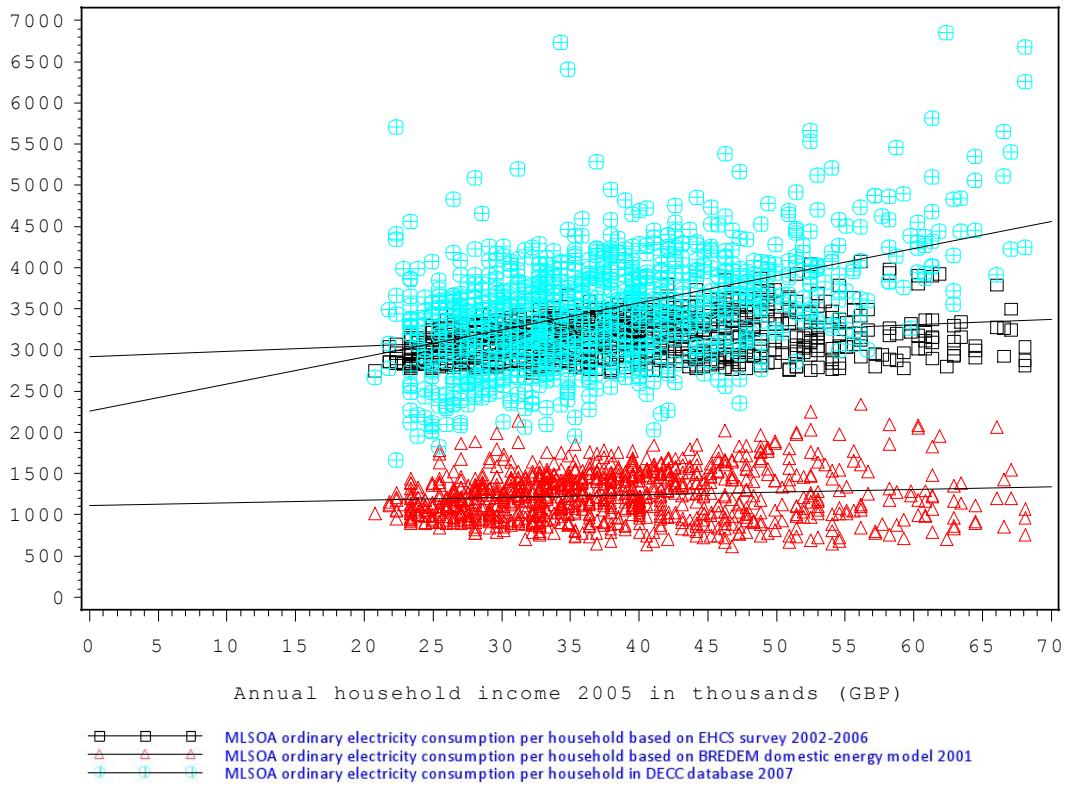

Fig. 7 Average electricity consumption per household v Income per household (Note: Survey - spatial version, London region only)

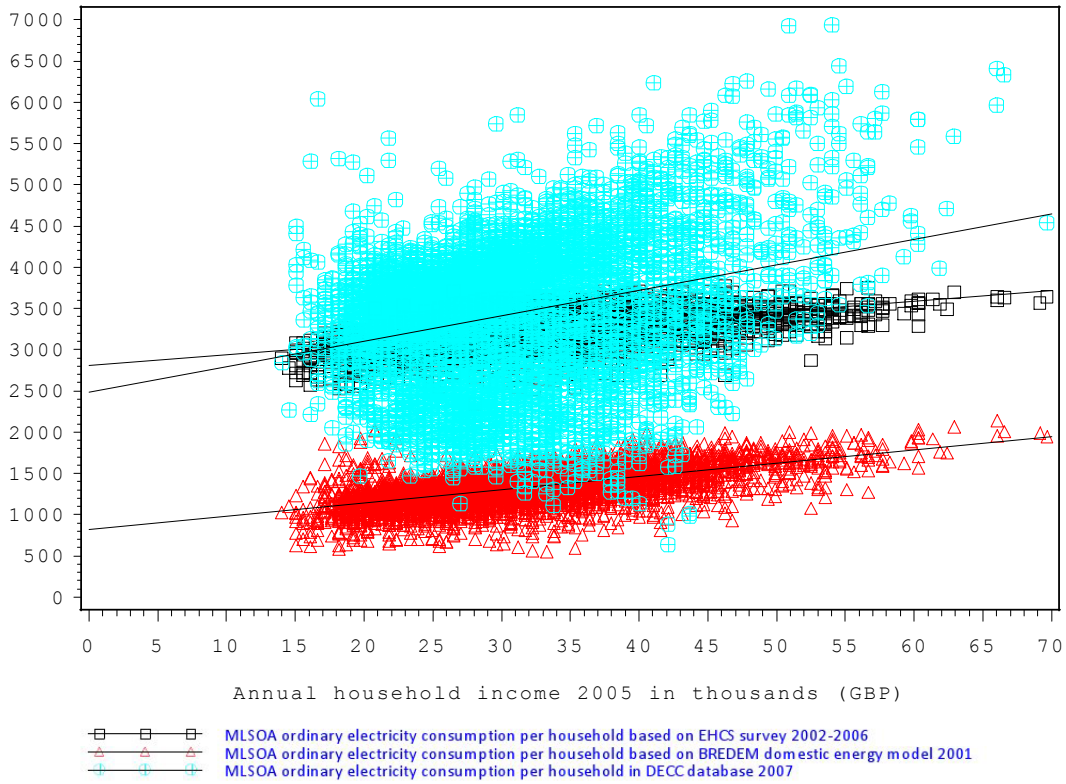

Fig. 8 Average electricity consumption per household v Income per household (Note: Survey - spatial version, all England except London)

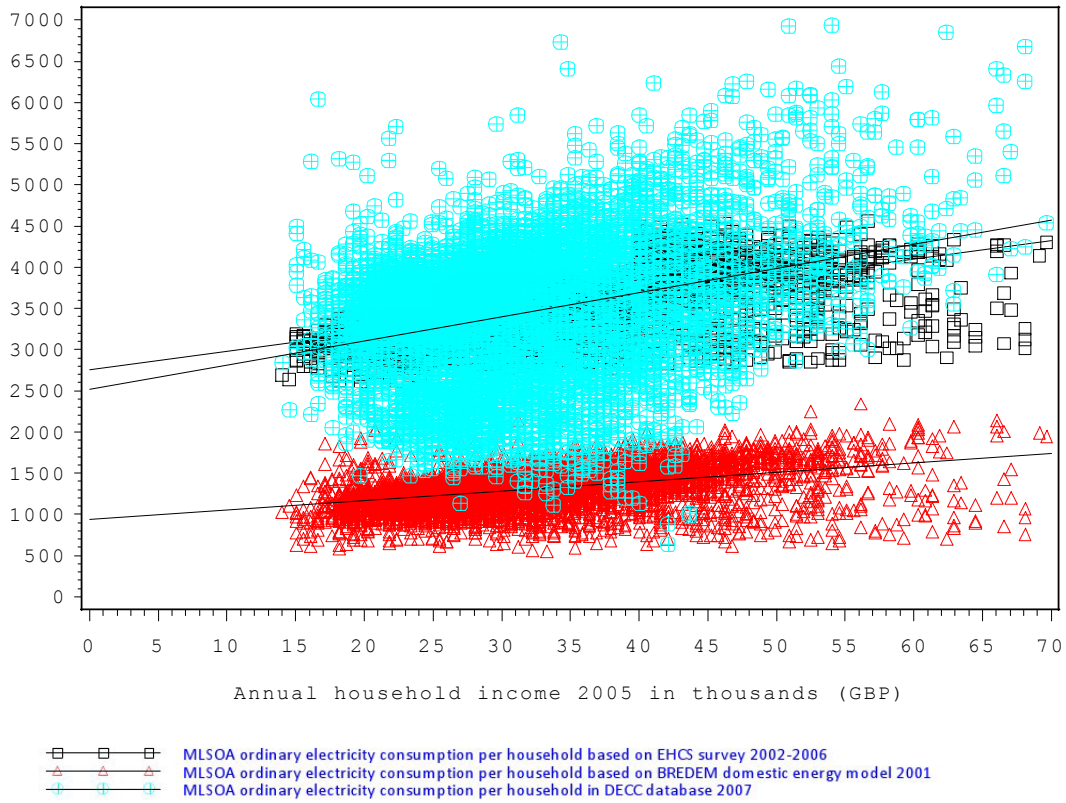

Fig. 9 Average electricity consumption per household v Income per household (Note: Survey - income version, all England)

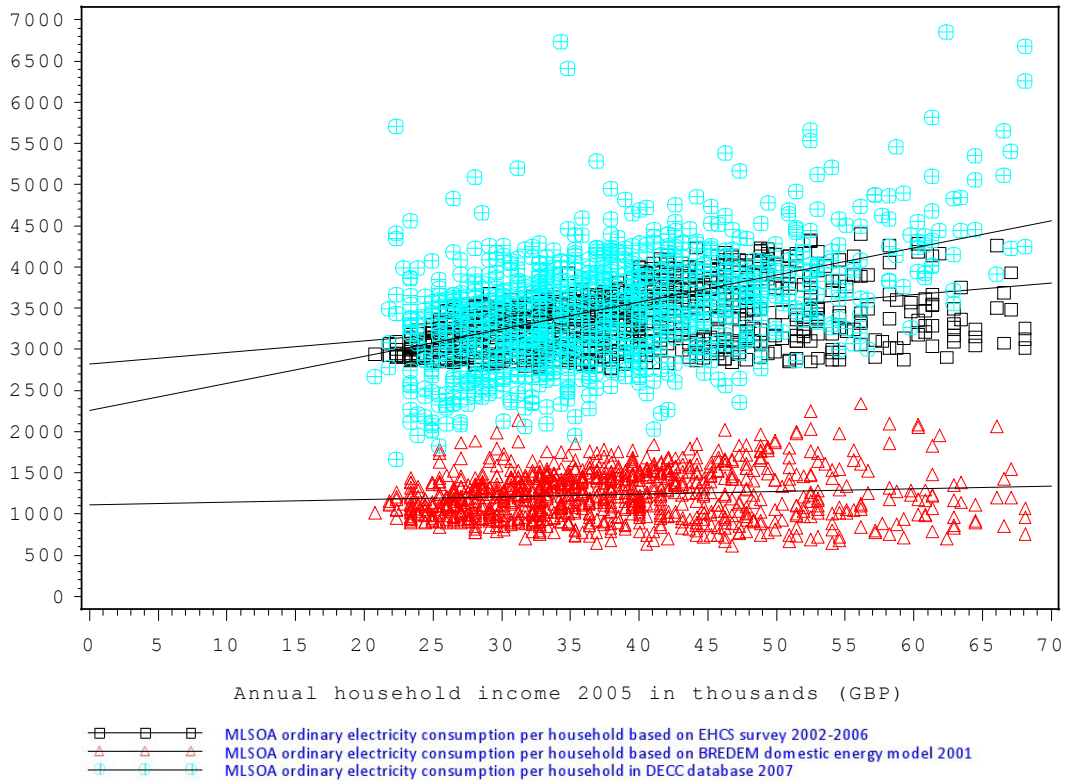

Fig. 10 Average electricity consumption per household v Income per household (Note: Survey - income version, London Region only

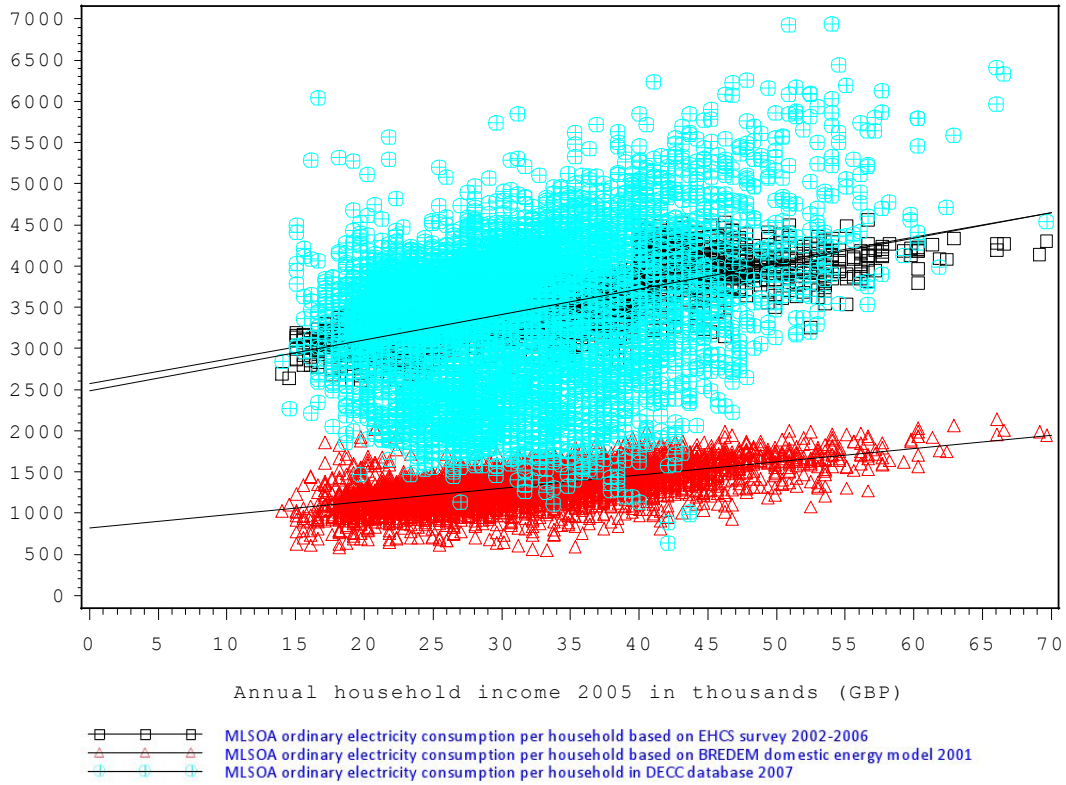

Fig. 11 Average electricity consumption per household v Income per household (Note: Survey - income version, all England except London)

Tab. 2 Regression formulas and r^2 for Figures 4 to 11

Figure 4: Average electricity consumption per household v Floor area times number of occupants per household				
Spatial Version	**England**			
Y	**X**	**Regression**	**R2**	**MLSOAs**
EHCS	Floor area x occupants	2209.32 + 4.92 * FN	0.749	6756
BREDEM	Floor area x occupants	4.44 + 6.45 * FN	1	6756
DECC	Floor area x occupants	2066.08 + 6.87* FN	0.253	6737

Figure 5: Average electricity consumption per household v Floor area times number of occupants per household				
Income Version	**England**			
Y	**X**	**Regression**	**R2**	**MLSOAs**
EHCS	Floor area x occupants	1952.64 + 7.527601*FN	0.651	6385
BREDEM	Floor area x occupants	4.438115 + 6.451084*FN	1	6756
DECC	Floor area x occupants	2066.083 + 6.868995*FN	0.044	6737

Figure 6: Average electricity consumption per household v Income per household				
Spatial Version	**England**			
Y	**X**	**Regression**	**R2**	**MLSOAs**
EHCS	Income	2879.963 + 10.08743*I	0.214	6756
BREDEM	Income	942.5958 + 11.34131*I	0.176	6756
DECC	Income	2512.243 + 29.44699*I	0.057	6737

Figure 7: Average electricity consumption per household v Income per household				
Spatial Version	**London only**			
Y	**X**	**Regression**	**R2**	**MLSOAs**
EHCS	Income	2914.077 + 6.569665*I	0.083	981
BREDEM	Income	1112.749 + 3.222702*I	0.008	981
DECC	Income	2261.081 + 32.90724*I	0.229	979

Figure 8: Average electricity consumption per household v Income per household				
Spatial Version	**England not London**			
Y	**X**	**Regression**	**R2**	**MLSOAs**
EHCS	Income	2809.32 + 12.93573*I	0.317	5773
BREDEM	Income	818.7402 + 16.13542*I	0.361	5773
DECC	Income	2488.189 + 30.89018*I	0.041	5756

Figure 9: Average electricity consumption per household v Income per household				
Income Version	**England**			
Y	**X**	**Regression**	**R2**	**MLSOAs**
EHCS	Income	2750.521 + 22.43517*I	0.383	6385
BREDEM	Income	942.5958 + 11.34131*I	0.177	6756
DECC	Income	2512.243 + 29.44699*I	0.057	6737

Figure 10: Average electricity consumption per household v Income per household				
Income Version	**London only**			
Y	**X**	**Regression**	**R2**	**MLSOAs**
EHCS	Income	2814.876 + 14.06832*I	0.177	981
BREDEM	Income	1112.749 + 3.222702*I	0.008	981
DECC	Income	2261.081 + 32.90724*I	0.229	979

Figure 11: Average electricity consumption per household v Income per household				
Income Version	**England not London**			
Y	**X**	**Regression**	**R2**	**MLSOAs**
EHCS	Income	2574.816 + 29.65204*I	0.587	5402
BREDEM	Income	818.7402 + 16.13542*I	0.361	5773
DECC	Income	2488.189 + 30.89018*I	0.041	5756

5 Analysis, conclusions, and further work

Indeed, income was found to potentially be a key influence, but survey data, and the collection of energy data from 'the willing' distorts all energy modellers immensely. The Department for Energy and Climate Change dataset for each MLSOA census contains the ordinary electricity use of all homes. However, researchers need data from individual homes in order to build a model for an individual home. Clearly, there has been and continues to be a bias in the mission of the EHCS survey to encompass all tenures and housing sizes from the bottom and top ends of the income scale, but the spread of individual homes' electricity use against household income shows an even spread of homes surveyed against both variables that belies the actual reports on the ground. The extremes of high income / low energy use and low income / high energy use are overreported in the EHCS and may have been the case for the reports that backed up the BREDEM domestic energy use model during the 1990s.

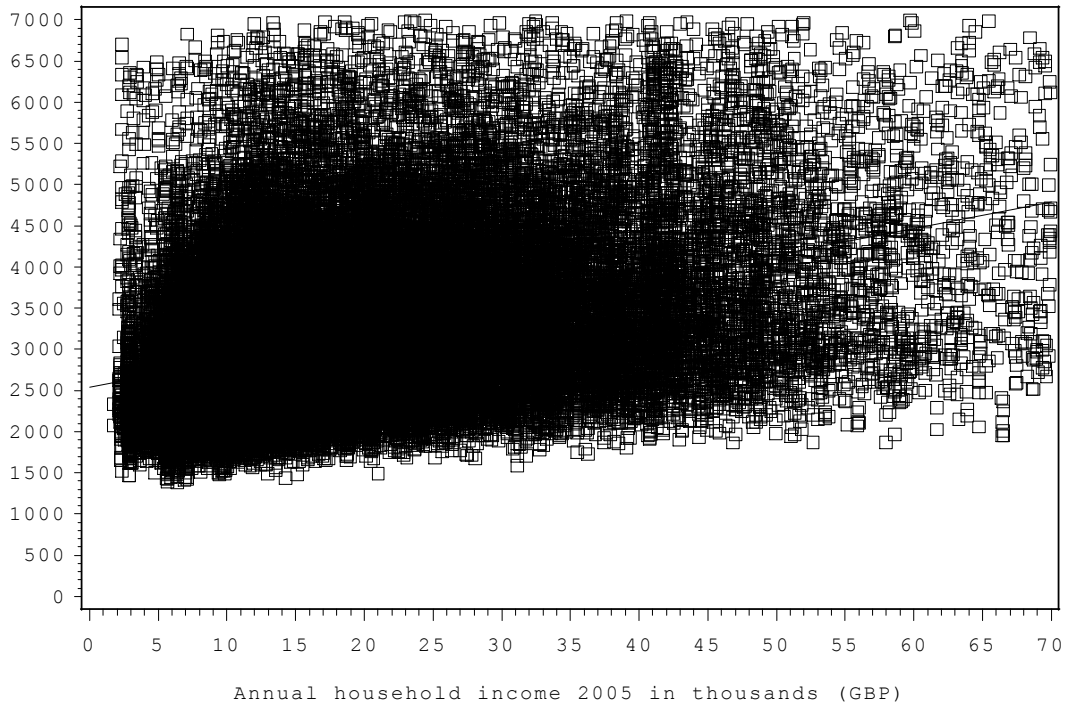

Fig. 7 Ordinary electricity use v Income in each EHCS surveyed home

The top end of the income scale shows the greatest difference between the DECC dataset and the derived EHCS dataset, most notably in the London region. This may be a case of underreporting high income households in the EHCS. The average income of the homes surveyed by the EHCS from 2002-2006 are less, and often significantly less, than the average household income reported by HM Revenue and Customs oven the equivalent time period. The London region showed a 24.5% difference, though most regions showed around a 10% difference between the EHCS and overall household figures. Further research should be done to examine heavily urbanised areas outside of London to confirm the lack of a link between electricity use in survey data and income and the strength of the link between the two when electricity use in MLSOA census areas are measured from totalling domestic electricity meters.

Tab. 3 Differences in EHCS survey and HMRC income reported

Region	Household Income – EHCS 2003-06 average	Household Income – 2004-05 Income tax report	% Difference
North East	15,715	19,127	17.8%
North West	17,778	20,483	13.2%
Yorkshire and the Humber	17,481	20,247	13.7%
East Midlands	18,573	20,868	11.0%
West Midlands	18,500	20,535	9.9%
East of England	22,115	24,401	9.4%
London	22,617	29,947	24.5%
South East	24,388	26,328	7.4%
South West	20,651	20,954	1.4%

The difference between the BREDEM model estimates and the EHCS and DECC data might be measured by increases in real terms of wealth per household. The index of net household wealth per head more than doubled between the early 1990s when the BREDEM 2001 version was first in development, and the mid-2000 when the EHCS and DECC data was taken [16]. If the result of the BREDEM calculation was multiplied by the increase in wealth, the resulting estimated electricity consumption would be very similar to the EHCS survey and DECC data.

Tab. 4 UK real household net wealth per head (Office for National Statistics 2009)

	Index numbers (1987=100)
1987	100.0
1988	118.1
1989	125.2
1990	116.1
1991	112.0
1992	108.4
1993	118.1
1994	111.9
1995	116.9
1996	122.4
1997	138.1
1998	148.7
1999	170.2
2000	176.2
2001	170.4
2002	173.1
2003	185.9
2004	198.4
2005	208.8
2006	220.7
2007	231.0

Further work in this area is needed to gain clarity on the impact of income on ordinary electricity use in domestic buildings. This includes:

- Isolating datasets that address low income and high income households and their energy use
- Investigating increasing household wealth as an adjustor of established domestic energy models
- Examining differences between heavily urbanised and other areas in relation to income and other socioeconomic factors

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