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Caveats for Policy Development when Combining Energy Ratings, National Building Energy Models, and Empirical Statistics

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ABSTRACT

Energy policy evaluation and development can often involve the combined use of evidence from energy ratings, national housing energy models, and empirical statistics. Limited research has been done, however, to look at systematic differences in the energy consumption estimates from these different tools or sources.

This paper compares annual gas consumption estimates from two versions of the Cambridge Housing Model (CHM), a national energy stock model, with empirical data from over 2.5 million gas-heated homes in England in the National Energy Efficiency Database (NEED). The analysis investigates differences by dwelling type, size, and age band. It also compares gas consumption across different rating bands estimated from Energy Performance Certificates (EPC). The findings show systematic overestimation by the CHM for larger older dwellings and far lower savings than would be expected from upgrading dwellings to a minimum of EPC Band C.

This has implications for use of building energy models that assume uniform operational settings across all dwellings, especially where older larger dwellings are the target of energy efficiency initiatives. It suggests that the models should be regularly reviewed and revised based on empirical evidence and that greater uncertainty should be ascribed to predictions of energy savings in the residential sector.

1. Introduction

The process of policy development often involves a synthesis or triangulation of evidence and indicators from a variety of sources, including outputs from models and empirical data. For energy policy in the residential sector these include combining the outputs of energy ratings, national energy stock models, and national energy statistics. Each of these tools or sources of evidence operate under differing assumptions, which renders this approach problematic for the kind of quantitative evaluation and guidance typically expected, such as estimates of energy savings and reductions in carbon emissions from targeted sub-sectors to help meet national quantitative carbon reduction targets.

The 2017 UK government Clean Growth Strategy (CGS) provides a case study of how this triangulation works in practice for the residential sector [BEIS 2017]. The CGS cites national energy statistics to show that although the number of dwellings in the UK has increased by about 25% since 1990, total energy demand has remained essentially constant and carbon emissions have declined by around a 20%. This reduction per dwelling is mainly ascribed to the impact of energy efficiency measures, such as improvements in building codes/regulations. In the UK, national energy models of the building stock are used to support the formal cost benefit analysis of policies. The evaluation and key levers for policy proposals are framed in terms of Energy Performance Certificates (EPCs), which are the UK's national energy labelling standard as part of the implementation of the EU Energy Performance of Buildings Directive [EC 2003, EC 2010]. Thus for the residential sector to contribute to national energy and emissions objectives, the CGS proposes to target dwellings currently rated as EPC Band D or below that should be upgraded to at least Band C by 2035, including all "fuel poor" dwellings by 2030. Crucially the policy recognises that expected energy efficiency savings may not be realised in full in cold dwellings, but instead result in improvements in indoor temperature conditions with potentially positive indirect effects on the use of health services by occupants.

This paper is not meant as a critique of the CGS, as the underlying policy development process in not explicitly known. Instead the intention is to explore and clarify the systematic differences between the use of EPCs, national energy models, and empirically based data. Specifically, the analysis compares estimates of mean gas demand from two versions of a national housing model with empirical gas consumption data, disaggregated by dwelling type and construction age. It then examines the empirical variation in gas consumption across EPC bands.

1.1. Background

To understand the issues involved, it is necessary to look at the models and sources of evidence in more detail. The first is the Standard Assessment Procedure (SAP) [DECC 2014], which in this or a simplified form – Reduced data SAP (RdSAP) – is the basis of generating energy ratings for EPC bands. SAP is a building physics model originally created to produce an energy label for a dwelling that would enable an occupant to compare the energy efficiency of one dwelling against another, independent of location or occupant behaviour. It therefore assumes a standard occupancy pattern and specifies an internal demand temperature as part of its calculation, irrespective of the type or size of the dwelling, and even location (for the 2009 version of SAP [DECC 2009]). The standard pattern of heating operation *applied to all dwellings* is intended to provide most people with a 'comfortable' internal environment [DECC 2014]. These indoor conditions are specified for Zone 1, which refers to the heated area and is assumed to be 25% of the total floor area. The remaining area, referred to as Zone 2, is not directly heated, but instead the indoor conditions are obtained or derived from the heating operation of Zone 1 and the thermal properties of the dwelling as a whole. SAP specifies that all dwellings have:

- demand temperature of 21°C for Zone 1;
- heating period of 9 hours per day on week days and 16 hours on weekends;
- a total heating season of 8 months per year.

Second, national housing energy models – typically also based on building physics models like SAP – are used to estimate energy demand across the residential stock as a whole or in key sub-sectors of interest, such as solid-walled dwellings. For example, the Cambridge Housing Model (CHM) [Hughes et al. 2013] covers household energy demand across the residential stock in the UK and has underpinned the data used in the Housing Energy Fact File (HEFF) [Palmer & Cooper 2014] and Energy Consumption in the UK (ECUK) [DECC 2015]. For this paper, however, two versions of CHM are used with the analysis limited to dwellings in England. The first variant of CHM adopts SAP 2012 settings and assumptions for heating as described above and is referred to as CHM(SAP). Findings from a comparative study of three bedroom dwellings have suggested that the earlier version of CHM tended to overestimate gas consumption slightly for most age bands, but particularly for pre-1919 dwellings (which are typically solid wall construction) compared with estimates from empirical data [Summerfield et al. 2015]. In the version of the CHM currently used in practice, improved estimates for energy demand of both the whole of the residential stock and for specific sub-sectors of dwellings (such as solid wall dwellings) two simple adjustment have been made, with this model referred to here as CHM Demand Temperature 19 or CHM(DT19):

- Demand temperature lowered to 19°C for SAP Zone 1 living area [Hughes et al. 2013]
- U-value for solid walls reduced from 2.1 to 1.4 W/m²K [Li et al 2015].

The third evidence source used here refers to empirical energy consumption data from a large sample of dwellings in the National Energy Efficiency Data-framework (NEED) [BEIS 2013] – specifically 2012 data for gas-heated dwellings in England. This study has taken NEED data to investigate the patterns of differences between the estimates for 2012 gas consumption in England from the CHM(SAP) and CHM(DT19), disaggregated by dwelling type and construction age. It then examines the gas consumption indicated by EPC Bands with respect to NEED data to compare discrepancies in expected savings due to improving energy efficiency of dwellings to a minimum of EPC Band C.

2. Methods

For clarity this study focuses its investigation on four types of dwellings (detached, semi-detached, end terraces, and mid-terraces) that account for the large majority of dwellings in England and characterised by differences in size and the number of external walls. It does not include flats (also known as apartments) since the number of external walls varies according to the location of the unit within the apartment block.

2.1. Cambridge Housing Model

The CHM is an open-access national-level stock model that covers household energy demand across the residential stock in the UK. It uses a physics model based on SAP and RdSAP that is applied to a dataset comprising 14,000 categories of dwelling drawn from UK housing surveys, which provide a representative housing stock to model. For instance, one category may specify the number of two-storey detached dwellings built between 1950-1966 with gas central heating, while another represents single story mid-terraces built between 1976-1982. Each category makes a weighted contribution to the overall estimate of energy demand (or in this case gas consumption). The CHM used average weather data for England in the model to calculate demand.

For England, the categories and dwelling weightings were obtained from the 2011/12 English Housing Survey (EHS) to calculate the contribution of each dwelling category to the overall estimates of gas consumption. It should be noted that CHM also includes energy use associated with electrical appliances and cooking, which are omitted from the SAP ratings calculation: appliances energy use is calculated based on SAP Appendix L, and cooking energy use is based on BREDEM-8 [Anderson et al. 2002] with adjustments for heat gain related to cooking [Palmer & Cooper 2014].

2.2. National Energy Efficiency Database – anonymised dataset

The NEED is a data-framework that matches individual (meter points) for gas and electricity consumption data, collected for the UK government sub-national energy consumption statistics, with information on energy efficiency measures installed in dwellings, from the Homes Energy Efficiency Database and other sources [Hamilton et al. 2013]. As noted above the gas consumption data based on meter readings have been weather corrected to standardised conditions for the annual period of 1 September 2011 to the 31 August 2012 (also known as the 2012 gas year). (This therefore differs slightly from the 2012 year of temperatures used in the CHM estimates above.) Records linked to Valuation

Office Agency (VOA) data have provided some information on basic physical characteristics, including size and dwelling type [BEIS 2016]. The anonymised research dataset made available from NEED in this analysis comprises over 2.5 million gas-heated dwellings (where this was specified as the main heating fuel) from the total of ~4.1 million dwellings in the sample.

NEED not only provides annual gas and electricity consumption, but some other key characteristics:

- Property age categories (when the dwelling was built). These broadly correspond to various building eras in the UK, for instance the majority of pre-1930 dwellings are solid wall, rather than cavity wall construction. .
- Dwelling type was categorised as Detached house (which includes bungalows), Semi-detached house, End terrace house, and Mid-terrace house.
- The dwelling size has four categories (0-50 m2, 51-100 m2, 101-150 m2, 151 m2 or more).
- EPC bands for dwellings in NEED are based on SAP 2009 or RdSAP2009, as the later version was not applied until after 2012, are given as A or B, C, D, E, F, and G.

It should be noted that the gas consumption for each age and type category reflects how these groups of dwellings were in 2012, not their original state, since many will have had insulation installed or upgrades to heating systems over the last two decades or more.

2.3. English Housing Survey

The English Housing Survey (EHS) for 2011-12 collected information about people's housing circumstances and the condition and energy efficiency of housing in England. The EHS is a continuous national survey commissioned by the Department for Communities and Local Government (CLG 2014). The EHS was used to obtain supporting data for the analyses used with CHM and NEED:

- The prevalence and floor area for each dwelling type and age band category.
- the variation of household size with dwelling floor area;
- mean floor area for each dwelling type and age band category.

2.4. EPC Bands and gas consumption

Since the NEED has data on dwelling EPC bands based on the older version of SAP, the range of gas consumption for each EPC Band was calculated using the CHM(SAP) but with SAP 2009 settings for standard UK external conditions, a demand temperature of 21°C, and occupancy levels based on floor area. By focussing on dwellings that used gas consumption for both primary and secondary heating (rather than electricity or other fuels) in the CHM, a series of clear linear relationships between SAP 2009 and Gas consumption were generated. These were used to estimate gas consumption for specific values of SAP 2009 at EPC band boundaries for dwellings with mean floor areas obtained from the EHS for each type and age band (see Table 1). Gas consumption above 50,000 KWh are provided for interest only, since in the NEED dataset this value is set as a maximum for residential gas consumption.

*Table 1: Estimated gas consumption [kWh] at the lower boundary of each EPC Band (based on SAP 2009), using mean floor areas for each dwelling type and age band from the EHS 2012.**

Dwelling Type	Age band	Floor Area (m2)	A&B (SAP=81)	C (SAP=65)	D (SAP=55)	E (SAP=39)	F (SAP=21)
Detached	Pre 1930	179	16900	30300	45900	63700	83800
	1930 to 1949	135	12700	23600	36200	50700	67000
	1950 to 1966	128	12100	22500	34700	48600	64300
	1967 to 1982	120	11300	21400	33000	46400	61400
	1983 to 1995	124	11700	21900	33700	47300	62600
	Post 1995	143	13500	24800	37900	53000	69900
Semi-detached	Pre 1930	112	10600	20100	31300	44000	58300
	1930 to 1949	85	8000	15900	25200	35800	47800
	1950 to 1966	81	7600	15300	24300	34600	46100
	1967 to 1982	79	7400	15100	24000	34100	45600
	1983 to 1995	69	6500	13500	21700	31100	41700
	Post 1995	77	7300	14800	23500	33600	44800
End-terrace	Pre 1930	98	9200	17900	28000	39600	52700
	1930 to 1949	76	7100	14600	23300	33200	44400
	1950 to 1966	72	6800	14000	22500	32100	42900
	1967 to 1982	76	7100	14600	23300	33200	44400
	1983 to 1995	65	6100	12900	20800	29900	40100
	Post 1995	79	7400	15000	23800	33900	45300
Mid-terrace	Pre 1930	84	7900	15800	25100	35600	47500
	1930 to 1949	74	6900	14200	22700	32400	43300
	1950 to 1966	74	6900	14200	22700	32400	43300
	1967 to 1982	74	6900	14200	22800	32500	43500
	1983 to 1995	67	6300	13200	21200	30400	40800
	Post 1995	80	7500	15100	24100	34300	45700

* The variation in predicted gas consumption for a specific SAP value as shown here is entirely due to the differences in mean floor area, for instance Pre 1930 dwellings are larger and so the gas consumption cut-off boundary for EPC Band C (SAP=65) is higher that other age categories.

3. Results

3.1. CHM and NEED comparison

The gas consumption figures from NEED are shown for each dwelling type in Table 2 and Figure 1 (which shows the index value relative to the gas consumption for the 1983-95 age band). The step changes shown reflect the width of the different age bands used in the CHM and in NEED, with the index = 100 chosen as 1983-95 as this was a convenient alignment of age bands between the Need and

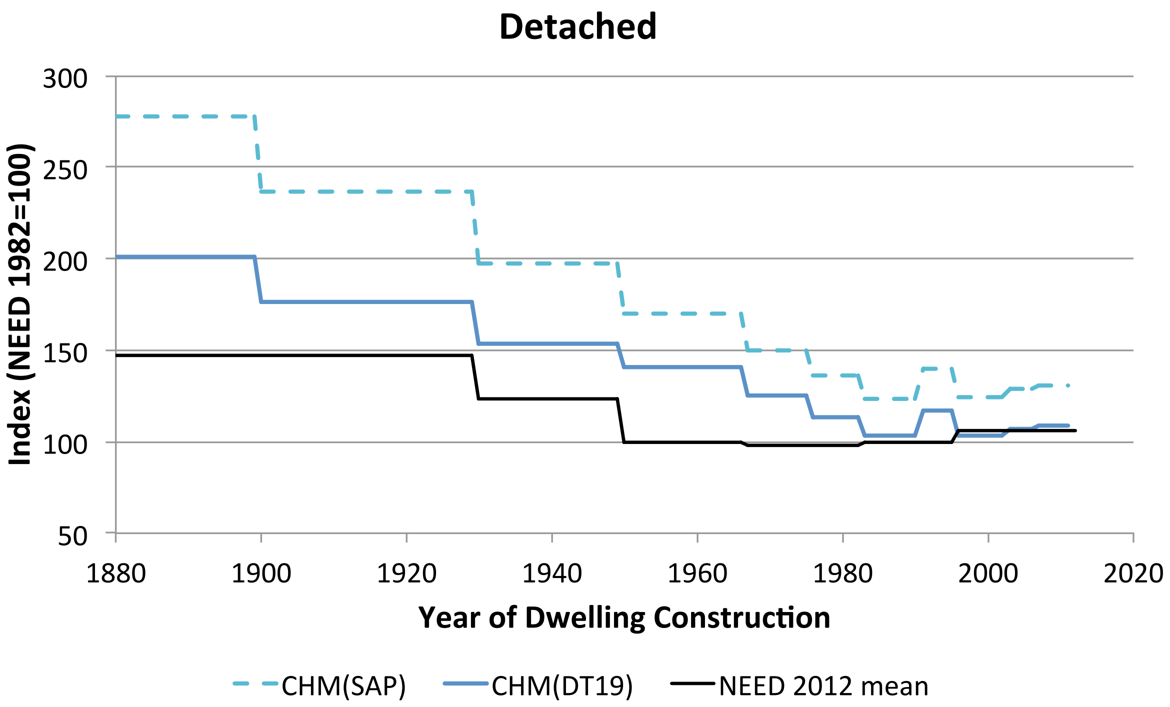
CHM and when the model estimates and empirical data tended to be closest. Also these figures represent a snapshot in 2012, and thus include any energy efficiency gains from retrofitted insulation, improvements in gas boilers, and other measures retrofitted in these dwellings up to 2012. A relative decline in gas consumption with dwelling age is evident, which tends to flatten out since the 1950s. For instance the gas consumption of detached dwellings built since 1950 appears almost unchanged, with a small percentage increase for dwellings built since 1995 that probably reflects increased average floor area. When comparing the modelled data, the estimates of gas consumption from CHM(SAP) results (Figure 1a-d) are considerably higher in older dwellings and show a steeper decline than the empirical data. The pattern is similar for CHM(DT19), but as expected mainly due to the lower demand temperature specified these estimates are lower than CHM(SAP) by around 40-20% for most age bands. The CHM(DT19) estimates still substantially overestimate gas consumption for older dwellings (pre-1930), but are in relatively close agreement for more recent age bands and in the case of mid-terraces built since 1983 even appear to under-estimate consumption.

The discrepancy in older dwellings, suggest this is to do with the modelling of solid walls in CHM which are highly prevalent in older dwellings producing particularly high gas consumption. The CHM(DT19) already includes a lower U-value of 1.4 W/m^{2}K for solid walls than is the case for CHM(SAP) and hence also used for EPC ratings. In a further analysis (data not shown) that further separated the gas consumption of NEED by wall construction type, the results still did not show a sufficient increase in gas consumption for solid walls compared with cavity walls to result in a closer agreement with the model estimates.

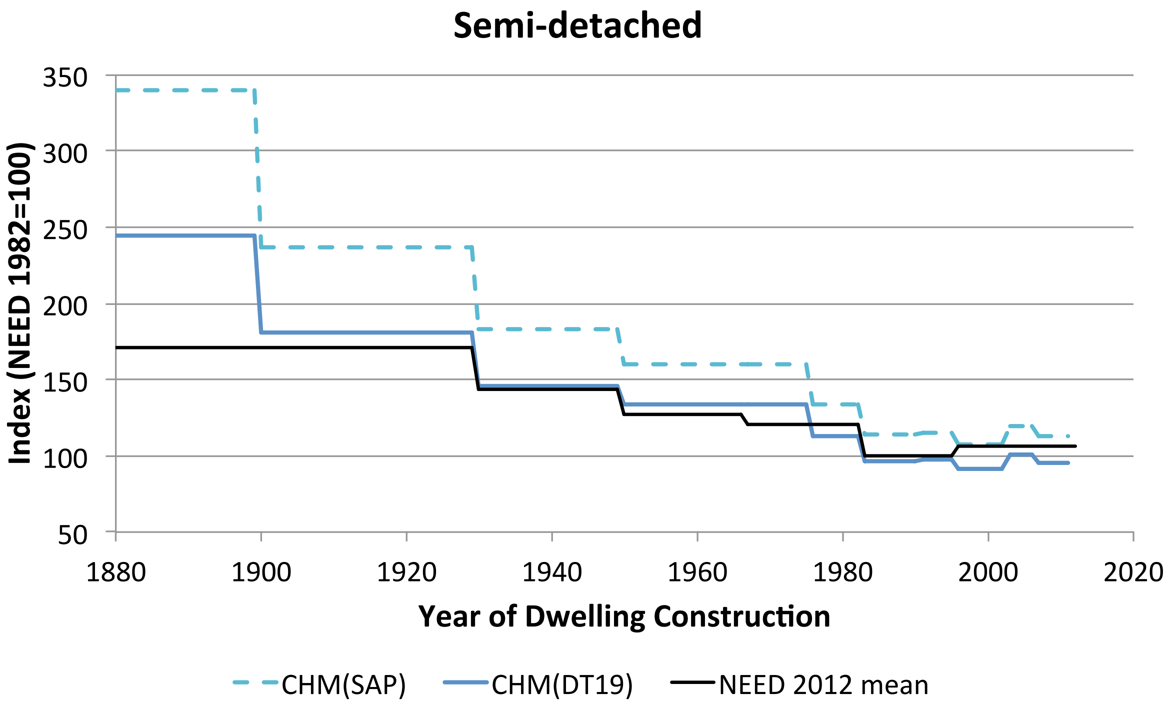
*Table 2: Mean gas consumption [kWh] of dwellings in NEED 2012 and estimates from two versions of the Cambridge Housing Model, (CHM(SAP) and CHM(DT19).**

Age Band	**Detached**		**Semi-detached**		**End terrace**		**Mid-terrace**	
	kWh	**Index**	**kWh**	**Index**	**(%)**	**Index**	**(%)**	**Index**
NEED 2012	**N=678,428**		**N=762,830**		**N=307,356**		**N=683,703**	
Pre-1930	23,256	147	18,105	171	15,431	153	13,201	142
1930-1949	19,551	123	15,284	144	13,563	135	12,336	133
1950-1966	15,822	100	13,470	127	12,325	122	11,537	124
1967-1982	15,551	98	12,762	121	11,805	117	10,677	115
1983-1995	15,854	100	10,588	100	10,083	100	9,277	100
post-1995	16,872	106	11,191	106	11,369	113	10,724	116
CHM(SAP)								
Pre-1900	44,069	278	35,957	340	29,340	291	21,979	237
1900-1929	37,480	236	25,109	237	20,832	207	19,784	213
1930-1949	31,275	197	19,357	183	15,566	154	14,798	160
1950-1966	26,994	170	16,949	160	14,875	148	13,464	145
1967-1975	23,816	150	16,909	160	15,191	151	12,863	139
1976-1982	21,588	136	14,195	134	13,146	130	11,196	121
1983-1990	19,536	123	12,113	114	11,481	114	9,792	106
1991-1995	22,223	140	12,162	115	12,788	127	9,998	108
1996-2002	19,669	124	11,378	107	11,612	115	9,781	105
2003-2006	20,379	129	12,638	119	13,064	130	11,979	129
2007-2011	20,680	130	11,948	113	12,179	121	11,407	123
CHM(DT19)								
Pre-1900	31,809	201	25,900	245	21,668	215	16,220	175
1900-1929	27,977	176	19,102	180	18,742	186	14,868	160
1930-1949	24,397	154	15,440	146	14,021	139	11,859	128
1950-1966	22,275	141	14,148	134	12,642	125	11,339	122
1967-1975	19,815	125	14,191	134	12,768	127	10,848	117
1976-1982	18,013	114	11,952	113	11,057	110	9,510	103
1983-1990	16,326	103	10,254	97	9,743	97	8,367	90
1991-1995	18,536	117	10,319	97	10,802	107	8,561	92
1996-2002	16,418	104	9,680	91	9,853	98	8,378	90
2003-2006	16,971	107	10,624	100	11,003	109	10,131	109
2007-2011	17,224	109	10,091	95	10,277	102	9,638	104

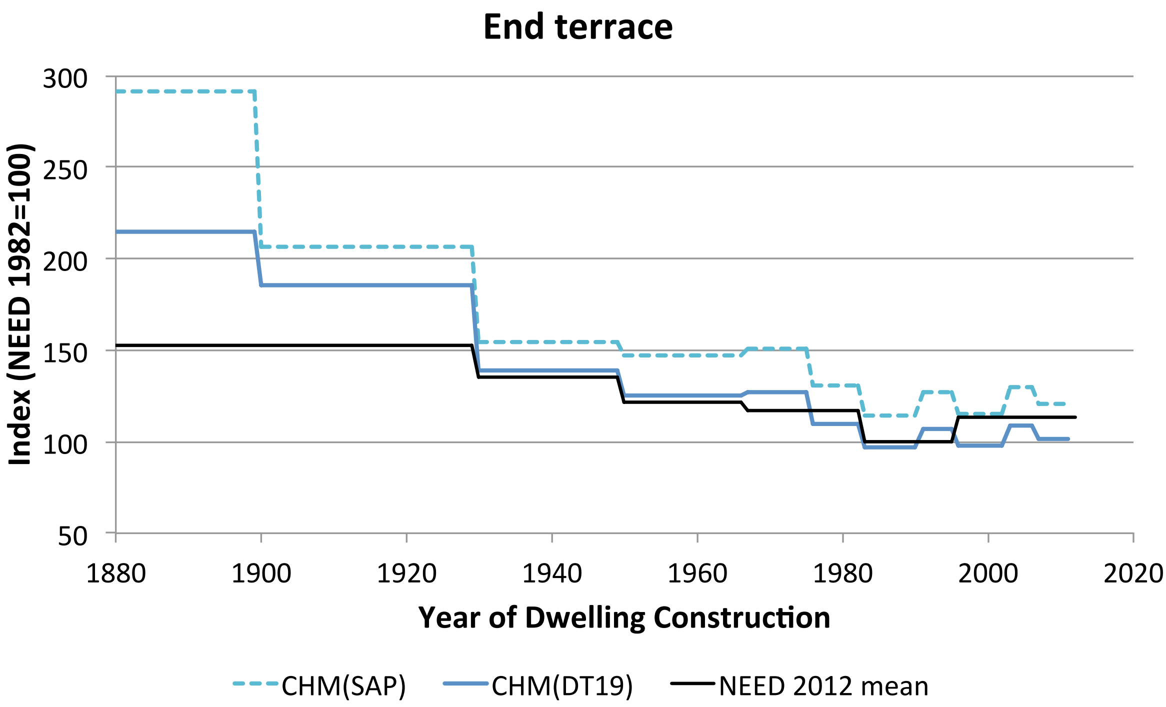
* The index of relative performance is based on the gas consumption from NEED 1983-95 = 100 for each dwelling type. This age band for NEED was chosen as it provided a useful alignment with CHM and was generally the closest between the model estimates and the empirical gas consumption.


Detached
300
250
200
150
100
50
Index (NEED 1982=100)
1880
1900
1920
1940
1960
1980
2000
2020
Year of Dwelling Construction
CHM(SAP)
CHM(DT19)
NEED 2012 mean

a


Semi-detached
350
300
250
200
150
100
50
Index (NEED 1982=100)
1880
1900
1920
1940
1960
1980
2000
2020
Year of Dwelling Construction
CHM(SAP)
CHM(DT19)
NEED 2012 mean

b



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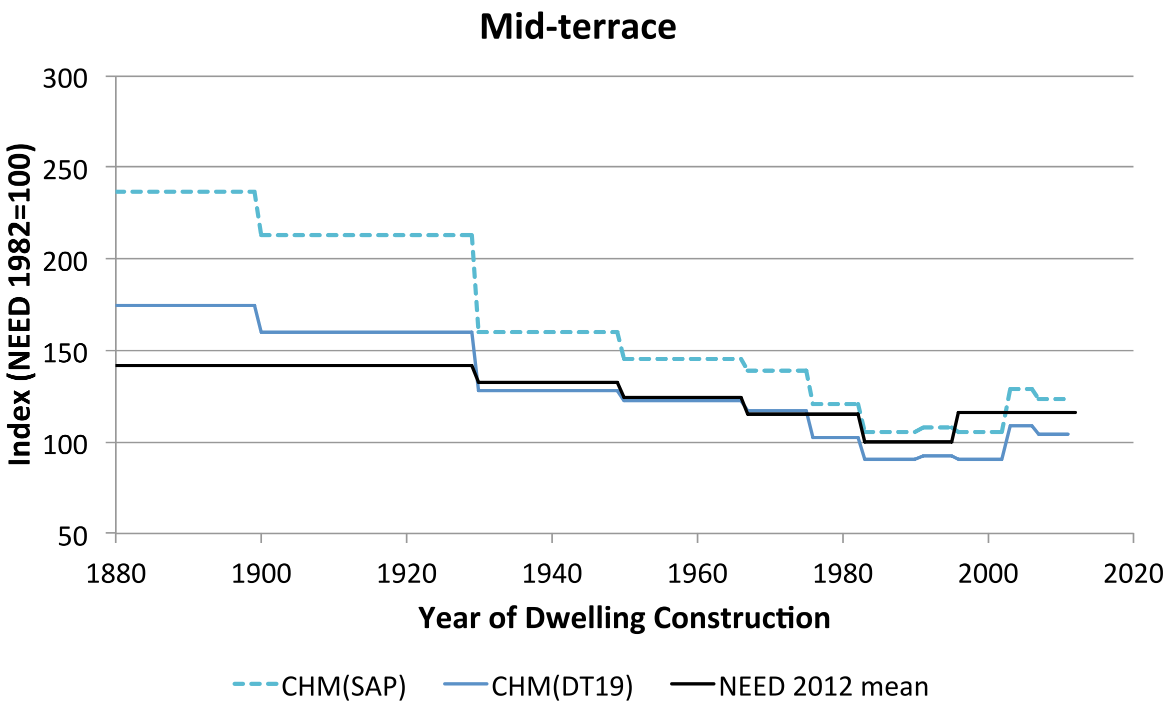
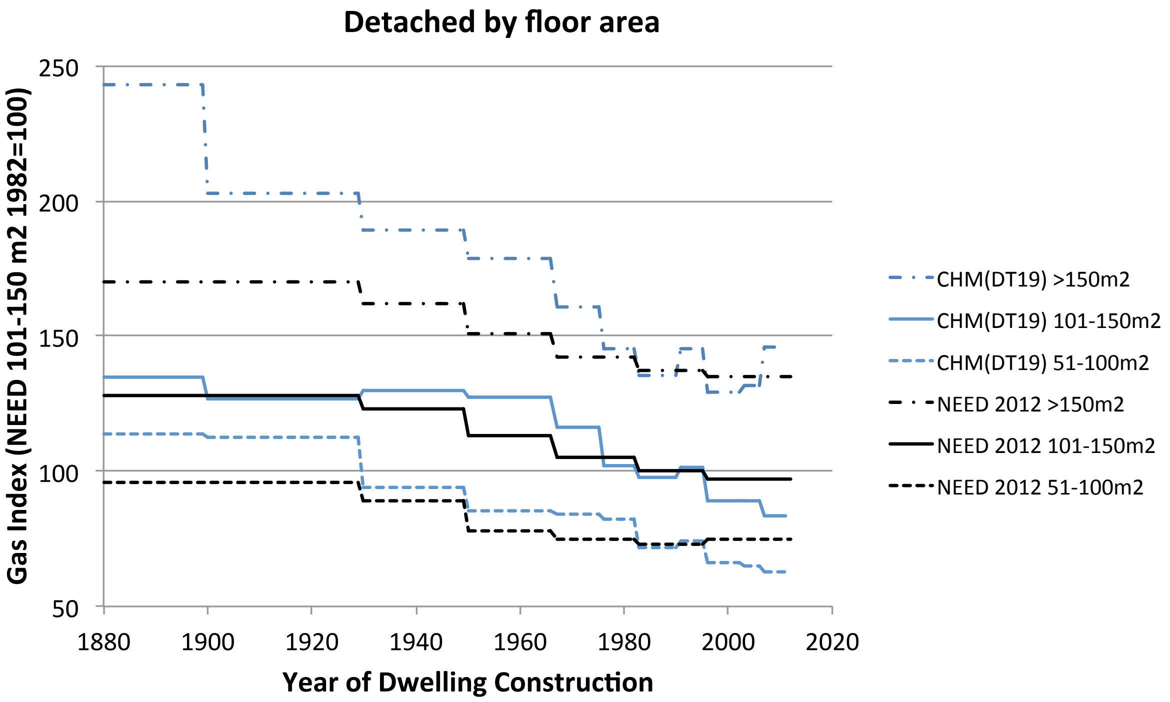


d

Figure 1: Relative mean gas consumption from NEED data (index = 100 for 1982-95) compared with estimates from CHM(SAP) and CHM(DT19) for a) detached, b) semi-detached, c) end-terraces, d) mid-terraces) by age category.

As an alternative line of investigation, Figure 2 compared estimates from CHM(DT19) with the relative NEED gas consumption by floor area categories for detached and mid-terrace dwellings. As expected the relative gas consumption increases with floor area for all age bands. In contrast to the relatively close estimates for detached dwellings of area 51-100 m^2 and 101-150m^2, for large (>150 m^2) detached dwellings – specifically those built before 1975 – the CHM(DT19) substantially overestimates gas demand (10-40%). For mid-terraces where CHM estimates are also consistently high for pre-1930 dwellings (and even more so for the 101-150 m2 group), but underestimate gas demand for those built since 1975. This suggests the issue underlying the modelling discrepancy that was highlighted by detached dwellings appears to reflect dwelling size since detached dwellings have a higher proportion of large dwellings than other groups.

In a further line of inquiry, our analysis of the EHS 2011-12 indicate that the mean number of people in the household only slightly increases from 2.6 to 2.9 persons as the floor area increases from 100-150 m2 to 200 m2 and over (detailed data not shown). This suggests that the level of occupancy, and hence the extent of space heating, does not just scale with dwelling size. Previous research on mean indoor temperatures under winter conditions also finds older and larger dwellings in the UK tend to have lower temperatures than other dwellings (Hamilton et al. 2017). Both sources of evidence question the use of standard heating patterns across the residential sector in the CHM and in EPCs, especially in the case of estimating gas consumption of larger dwellings.



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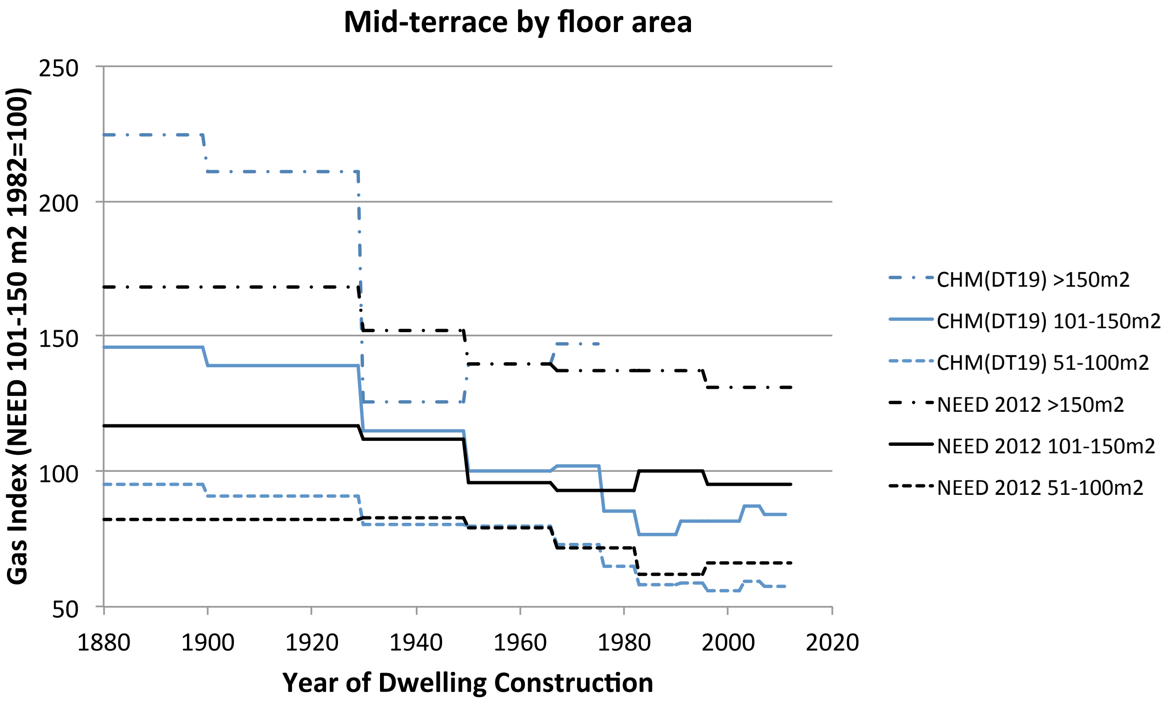

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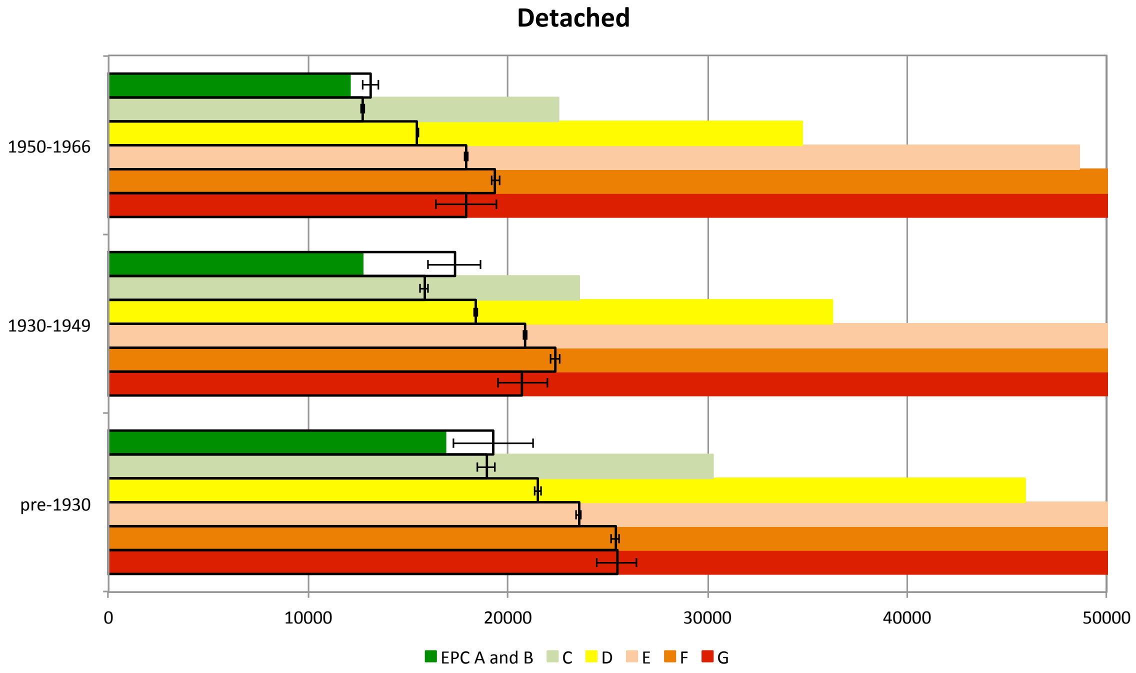
Figure 2: CHM(DT19) estimates compared with 2012 gas consumption from NEED based for a) detached and b) mid-terraces by floor area categories.

3.2. EPC bands and NEED gas consumption

Figure 3 compared the annual gas consumption indicated by EPC bands calculated using SAP or RdSAP 2009 (Table 1) with the mean 2012 gas demand from corresponding EPC rated detached and mid-terraces in NEED, disaggregated by age band. The graphs show dwellings constructed up to 1966, as these have the largest discrepancies with model results in the previous analysis and also still have sufficient number of dwellings in the lowest EPC Bands.

Overall the variation in NEED gas consumption is far less than that suggested by the EPC Band categories, where across all NEED dwellings rated EPC Band A and B to Band G the consumption is within that expected range of EPC BAND C (shown in light green). Specifically, for NEED dwellings in EPC Bands A and B gas consumption is above that expected, while for those in EPC Bands D or below gas consumption is in most cases far lower than expected. The EPC Band estimates include secondary gas heating, whereas some NEED dwellings may use electricity to achieve this and hence have lower gas consumption. If total electricity consumption is included in the NEED estimates, which also includes appliance use and is typically in the range between 3000-5000 kWh, it still results in gas consumption far lower than expected for EPC Bands D to G.

It is worthwhile to consider the implications of these systematic differences between gas consumption indicated by EPC ratings and the NEED data for the expected savings under the CGS plan for retrofitting inefficient dwellings. Figure 4 shows the energy saving expected from shifting all dwellings with EPC Band D or below up to EPC Band C for each dwelling age group (before 1966) and type category. These use gas demand calculated from the mean SAP 2009 rating for each EPC Band obtained from the EHS (Table 1). The equivalent savings calculated from NEED based on the weighted mean differences in gas consumption between EPC Bands are far less, typically in the range of 20-30% of that expected. The savings expected from NEED dwellings would be higher if electricity is included (not shown), but not enough to substantively alter the large divergence in expected savings.



a

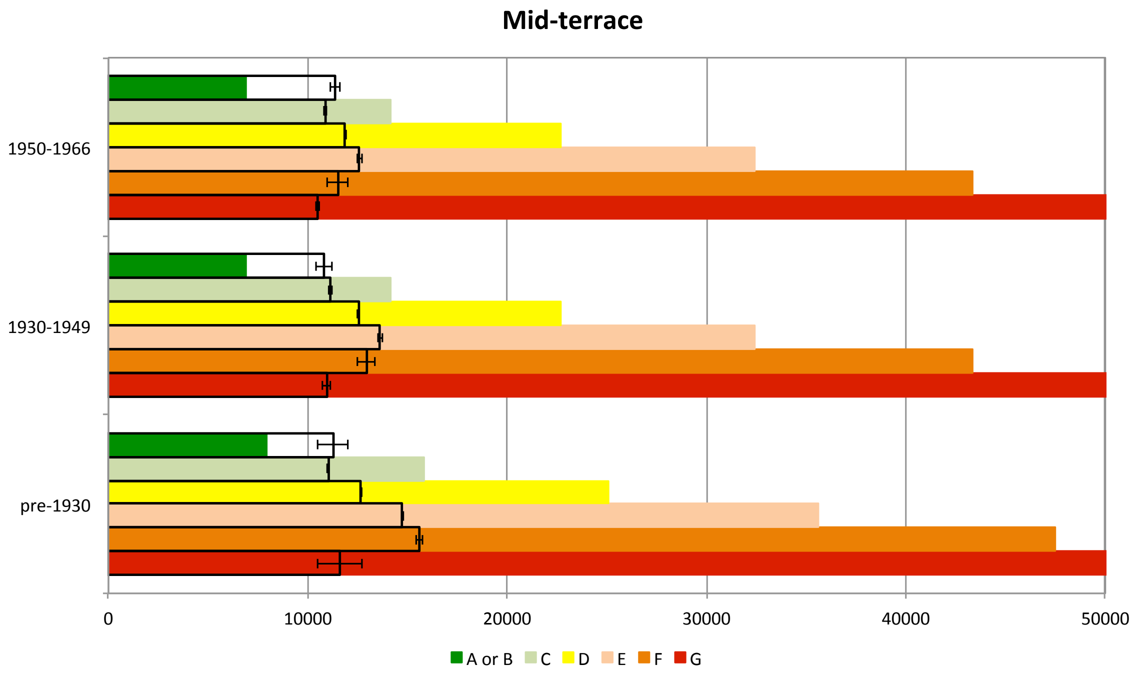


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Figure 3: Comparison of empirical 2012 gas consumption for dwellings in NEED (black outline bars and 95% confidence intervals) for each EPC band compared with the expected gas consumption based on SAP/RdSAP calculated EPC bands (shown in their respective colours) for detached (a) and mid terraces (b) for the three oldest age bands. (The figure does not show the EPC consumption above the maximum of 50000 kWh as this is the cut-off point for NEED residential gas consumption.)

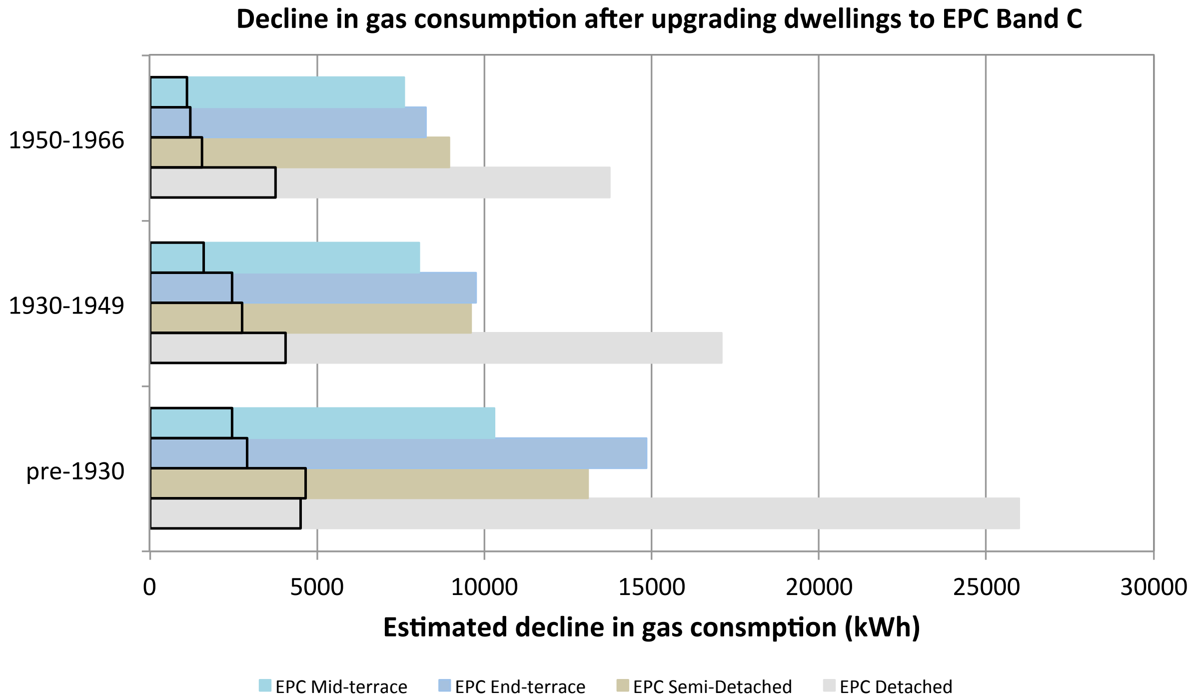

Figure 4: Comparison of the expected mean decline in gas consumption from EPC ratings after retrofitting dwellings up to EPC Band C by age and dwelling type (shaded bars), with the equivalent estimate using changes in NEED gas consumption data (indicated by the black outline bars).

4. Discussion

This study has identified key systematic differences between estimates of gas consumption from SAP based models and empirical data of dwellings by type and age in England, with the most notable divergence occurring in older and larger dwellings. The CHM(SAP), that uses SAP2012 settings for heating overestimates consumption by a large margin across all dwelling types and age bands. The CHM(19) with a lower demand temperature has far closer estimates for dwellings constructed since 1966, with the largest differences evident for detached dwellings. The further analysis of gas consumption floor area suggested that the discrepancy involves overestimates for large older dwellings, which are most prevalent for detached. This is consistent with a study by Sunikka-Blank and Galvin [2012] that identified this phenomenon or pattern of lower than expected consumption in less energy efficient dwellings as the 'pre-bound effect', which was evident in a number of datasets on energy demand from various European countries.

The first implication of this work is to question the adoption of *uniform operational settings in energy models across all parts of the residential sector*. This position is supported by empirical evidence from previous research on variations seen in indoor heating patterns [Huebner et al. 2014; Hughes et al. 2016]. The findings here also indicate that further changes to the CHM(DT19) are needed to the SAP operational parameters to match different parts of the sector. Evidence is currently lacking, however, to say that this should just be met with further adjustments in the assumptions for demand temperature and the thermal properties of solid walls applied to some groups of dwellings. Difference between the modelled estimates and the empirical data could be accounted by variations in numerous other factors including:

- heated floor area (and even some new unheated zones);
- ventilation rates;
- effectiveness of heating systems;
- other socio-technical responses by occupants to keep energy costs low on larger older dwellings, such as single room heating.

Understanding these factors is therefore also likely *to impact the effectiveness of specific measures in efficiency programs to save energy*.

Continuing in this vein, the second analysis of NEED dwellings according to their EPC rating revealed a consistent pattern for mean gas consumption that was higher than expected for Band A, within the range for Band C, and far lower than expected for Band D or below. Overall the empirical data showed far less variation in gas consumption than implied by EPC Bands. In almost all age and dwelling type categories the empirical results for all EPC bands were within the range specified by Band C. The subsequent prima facie evaluation of an upgrade program along the same lines proposed in the CGS (that aims to retrofit all dwellings in EPC Band D or below up to Band C) indicated that the reduction in gas demand could be far lower than expected. The results across most dwelling type and age bands suggested savings between 20-30% of that expected, but with older detached dwellings offering the most in terms of absolute energy savings. The CGS already acknowledges that for some dwellings the benefits of energy efficiency retrofits are a combination of alleviating fuel poverty, improved comfort with higher indoor temperatures, and related health benefits for the occupants. The consequent "correction factors", however, to the expected energy savings are not made explicitly clear.

The findings here are broadly consistent with, if somewhat lower than, previous studies from various other countries. For instance, in two studies on dwellings in France [Laurent et al. 2013] and in the Netherlands {Filippidou et al. 2018} the ratio of actual to expected energy savings after retrofit – referred to as the heating factor – typically ranged from around 40 to 60%. In addition, Kveselis and colleagues [2017] recently found a high degree of scatter or uncertainty in the post-retrofit energy consumption of dwellings in Kaunas, Lithuania.

One of the difficulties of these detailed validation analysis lies in the difficulty in achieving "like with like" disaggregated comparisons. In this case the NEED data provides sufficient numbers of specifically gas-heated dwellings of each age and type category, which allows for a reasonable spotlight on space heating. It should be noted, however, that here the EPC Band limits were calculated for all space and hot water heating from gas, including secondary heating that is assumed as 10% of total heating in SAP, whereas the NEED data includes some dwellings that would have used electricity for some secondary heating. However the magnitude of total electricity consumption in NEED (typically between 3000-5000 kWh, which includes appliances) indicates that any secondary electric heating is insufficient to account for the discrepancies. Inaccurate classification of EPC bands for NEED dwellings would also tend to reduce the differences in gas consumption across bands. Overall, however, the message is clear that the energy savings from a retrofit program are likely to be substantially lower than that suggested from calculations using EPC bands.

5. Conclusion

When policy makers draw on information from energy housing models, EPC Bands, and empirical statistics to develop policy considerable care is needed in understanding the parameters and assumptions involved. Discrepancies will likely impact the targeting and effectiveness of energy policy initiatives. In terms of energy savings though they may still have other benefits. Specifically, estimates of the cumulative quantitative savings from energy efficiency measures that aim to reach a minimum standard (or EPC rating) need to be assigned with a high degree of uncertainty, especially in their contributions to national carbon emissions targets, until a better understanding is reached of the socio-technical factors at work in explaining current energy demand.

For energy ratings and national housing energy models to be fully useful as evidence-based tools to develop and evaluate proposed policy initiatives, operational settings (heating regimes) should be as close to empirically based as possible. Detailed research is needed that combines detailed occupant and dwelling surveys, with smart energy metering and monitoring of indoor conditions to understand variations in the operational heating patterns and heated floor area. In the longer term, a move to energy labels not based only on modelled demand performance for uniform operation but actual consumption using smart meter data to improve our understanding of energy demand across sub-sectors of the stock would strengthen the evidence base for energy policy development.

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