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The impact of the 'cost of living crisis' in Britain: energy saving actions by fuel-poor households in winter 2022/23

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Abstract

The Smart Energy Research Laboratory (SERL) Observatory, which collects smart meter data from nearly 13,000 British homes, has the scope to gather additional data in times of change. In early 2023 a survey was sent out to participants to gauge the impact of the 'cost of living crisis' and associated steep rise in UK energy prices. More than 5,000 households provided information about their income levels and whether they were struggling to pay fuel costs. Within this group we identified households spending more than 10% of their income on energy (designated Expenditure Fuel Poverty: EFP) and those who reported being unable to afford to heat their living room to a comfortable temperature (designated Feeling Fuel Poor: FFP).

In this paper we apply epidemiological techniques to SERL data to identify the demographic and dwelling characteristics of the EFP and FFP groups and compare these with the rest of the survey respondents. To examine the impact of energy-saving actions following the steep rise in prices, we assess the relative percentage reduction of gas demand for the two groups between winter 2021/22 and winter 2022/23 using a machine-learning counterfactual model. There was an overall reduction in gas demand of 9.5% for the whole sample in January to March 2023 compared to the previous winter, suggesting widespread energy saving actions at a time of very high energy prices. Those who reported feeling fuel poor reduced their gas demand on average by 17.5%, while the mean gas demand reduction of the larger EFP group was 10.0%.

We reflect on the benefits of epidemiological techniques applied to large scale, longitudinal smart meter and survey data, and discuss the implications for data collection and analysis and for policy to identify and support those in fuel poverty.

Introduction

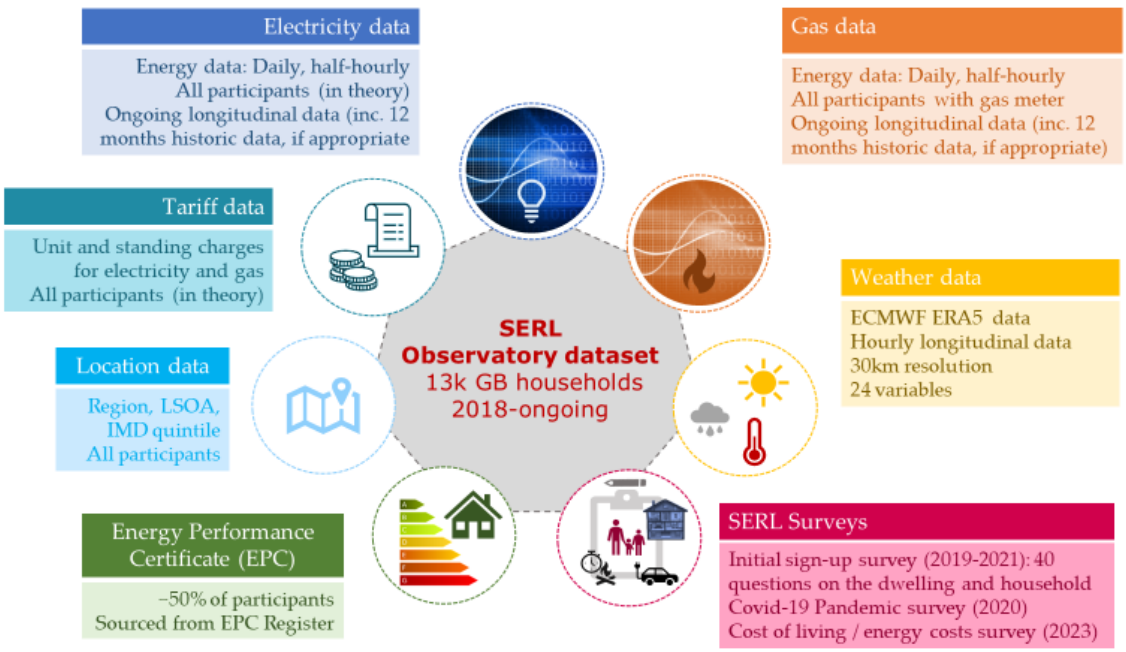
This paper investigates changes in energy demand and energy saving behaviour during times of crisis, based on the experience of the UK's Smart Energy Research Laboratory (SERL) in monitoring the impact of the "Cost of Living Crisis" in Winter 2022/23. Our focus is on the challenges of identifying those households in fuel poverty and providing policy-relevant information about their circumstances.

The SERL Observatory dataset

The SERL Observatory has been gathering smart meter and contextual data from British[1] homes since 2019 and currently holds data from nearly 13,000 households. Daily and half hourly gas and electricity data is collected, as well as climate data and information from Energy Performance Certificates (EPCs).

The SERL dataset is enriched by contextual information gathered in surveys. Almost all the participants in the SERL Observatory completed a recruitment survey giving demographic information about the household and details of the type, age and tenure of their home. The survey includes a series of questions about their heating system and appliance use and the participants' behaviour and attitudes to energy saving.

The combination of contextual and smart meter data has enabled a wide variety of analysis based on the SERL Observatory, for example linking half-hourly energy demand patterns to type of heating and ownership of EVs (Pullinger et al., 2024) and investigating the socio-technical drivers of energy consumption in buildings (McKenna et al., 2022).



Summary of SERL Observatory dataset

SERL has been fortunate to gain funding for additional surveys to respond to major events which affected domestic energy demand. In 2020 around 1,000 SERL participants responded to a survey which investigated changes in energy using practices during the Covid 19 pandemic. Analysis drawing on the survey (Huebner et al., 2021; Zapata-Webborn et al., 2023b) explored topics such as linking changes in demand detected in smart

[1] SERL Observatory homes are located in England, Scotland and Wales but not in Northern Ireland.

meter data to household characteristics, for example whether they worked from home or had school-age children.

In early 2023 the SERL team sent out a survey to gauge responses to the steep rises in energy prices experienced during 2022. This "2023 survey" provides the key contextual information discussed in this paper. The survey included questions on household income, affordability, energy efficient actions such as turning down the thermostat (Huebner et al., 2023). Several recent papers have drawn on this survey data (Huebner et al., 2023; Zapata-Webborn et al., 2023a).

The 'cost of living crisis' and fuel poverty in the UK

Domestic energy prices in the UK increased steeply during 2022, following Russia's invasion of Ukraine (Bolton and Stewart, 2024). Typical UK annual energy bills increased by 86% between winter 21/22 and winter 22/23 (DESNZ, 2023; Ofgem, 2021) during a period when inflation was also affecting many other elements of household budgets, frequently referred to as a "cost of living crisis"(Office for National Statistics, 2024). The media and charities drew attention to those who were struggling to pay energy bills, sometimes having to choose whether to "heat or eat"(Age UK, 2021; Viner, 2023).

In October 2023 the "Energy Price Guarantee" (EPG) was introduced by the UK Government, setting a maximum amount that energy suppliers could charge domestic customers (and compensating the suppliers by paying them the difference between the EPG level and the price they would otherwise have charged), ensuring that typical bills did not increase beyond £2,500 (approx. €2,900) per annum, but this was still roughly twice the level at which prices had been capped in the previous winter. The EPG set maximum unit costs and daily standing charges (which were the same for households with high and low demand). In addition, virtually all households received £400 in the Energy Bills Support Scheme in monthly instalments between October 2022 and March 2023 (Bolton and Stewart, 2024).

This paper looks at how those likely to be in fuel poverty can be identified from SERL Observatory data during this time of crisis. Fuel poverty was first defined specifically in a UK context by Boardman (1991) to cover households whose domestic energy expenditure was greater than 10% of their income (Moore, 2012). Since then many indicators have been proposed and critiqued (Liddell, 2012; Moore, 2012; Tirado Herrero, 2017; Waddams Price et al., 2012).

The current government "Low Income, Low Energy Efficiency" (LILEE) metric of fuel poverty in England[2] (DESNZ and BRE, 2023) illustrates the complexity and multiple dimensions involved in assessing fuel poverty. Under LILEE, a household is considered to be fuel-poor if it meets two key criteria:

1. Low energy efficiency. This includes all households with a Fuel Poverty Energy Efficiency Rating (FPEER)[3] of band D or below
2. Low income. This includes all households whose residual household income would be below the official poverty line if they were to spend their modelled energy costs.

Three dimensions of this definition are apparent:

- Cost of energy, taking into account the household's ability to pay.
- Energy 'needed for adequate warmth'. This is based on modelled data, not on actual energy use or occupants' assessment of comfort. The SAP (Standard Assessment Procedure) model used for EPC energy rating assessment is used to calculate the energy required to heat the house to 21°C in the living room and 18°C in other rooms following a 'standard heating pattern' (BRE, 2012).
- Dwelling characteristics (which influence the energy needed to maintain thermal comfort): under the LILEE definition households in more efficient homes (effectively EPC band C and above) do not qualify as fuel-poor.

In this paper we investigate three fuel poverty indicators derived from SERL data. These are based on actual rather than calculated energy demand, and on participant responses about whether they can afford to heat their home comfortably. We conclude our discussion by considering the differences between these and the official LILEE indicator.

Energy epidemiology

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[2] FP definitions set by the devolved administrations of Scotland and Wales are different

[3] FPEER is based on the EPC energy rating bands but includes an adjustment for fuel bill subsidies (DECC, 2014)

This paper aims to illustrate the benefits of applying epidemiological techniques to domestic energy demand data. Energy epidemiology draws on principles and techniques developed in the field of health epidemiology. The focus is on patterns of energy demand and energy-demand related behaviours across populations. This is valuable in providing an evidence base for energy policy and supporting the development of models which estimate energy demand under changed circumstances (Hamilton et al., 2017, 2013b).

The discipline of epidemiology was developed to trace the prevalence and incidence of diseases, and to identify effective treatments to address disease experienced within a population. It has more recently come to public attention during the Covid 19 pandemic, as models were used to predict future incidence of the disease if restrictions were (or were not) applied. Epidemiologists study associations between risk factors and population health. They draw on a wide range of study designs and statistical techniques to assess the level of certainty of risks and outcomes. Health epidemiology frequently involves combining data for large numbers of physiological, environmental, lifestyle and other variables, necessarily working across disciplines and information sources and assembling 'messy' real world data into coherent models.

There is much energy researchers can learn about experimental design and interpretation of results from epidemiology. While the 'gold standard' of randomised control trials is rarely achieved in energy studies, techniques for analysis of natural experiments, observational studies, and field trials are all very relevant for energy research, as are common principles to ensure consistency and reliability of data reporting.

Just as health epidemiologists study associations, for example between air quality and asthma or diet and obesity, energy epidemiologists can explore associations between household energy use and household characteristics and (for example) uptake of energy efficiency interventions (Hamilton et al., 2013a) or dwelling age and indoor temperature (Hamilton et al., 2017)

Overview of paper

The research questions addressed in this paper are:

- What indicators of fuel poverty is it possible to derive from the SERL smart meter and contextual data?
- What is the prevalence of fuel poverty (measured using these indictors) in the sample during the 'cost of living crisis' in winter 2022/23?
- Can policy-relevant information about the characteristics and energy saving behaviour of households likely to be in fuel poverty be derived from the SERL data?

We describe the questions that have arisen as we analysed the data and introduce the epidemiological and other techniques we have used to tackle these. The focus of this paper is on sharing what we have learned about different approaches rather than providing a comprehensive set of descriptive results. In addition to reporting new results about the characteristics and actions of those likely to be in fuel poverty, we draw on previously published work to provide examples of the techniques discussed and the conclusions that can be drawn by applying these to the SERL dataset.

Data

The SERL Observatory holds smart meter gas and electricity data for nearly 13,000 homes. While the SERL Observatory contains a sample of British homes that is largely representative by region and IMD (Index of Multiple Deprivation) quintile, there is a higher proportion of owner-occupied homes compared to the 2021 English Housing Survey (EHS) (DLUHC, 2022). The age profile of the properties is similar. The proportion of flats in the SERL Observatory is lower than that in the English stock. Further descriptive information for the SERL Observatory dataset is provided in Webborn et al. (2021).

The analysis focused on gas-heated homes (around 85% of UK households (CCC, 2016) are heated with gas) and used gas demand data from 2022 in calculating the percentage of income spent on energy and to calculate counterfactual gas demand using the method described in Zapata-Webborn et al. (2023a).

The SERL Follow Up Survey 2023 was sent to 12,001 households in February 2023 and 5,829 responses were received. This survey included questions asked about household income, whether they could afford to be keep their living room comfortable warm, and how difficult the household found it to meet their heating costs.

The SERL Observatory contains Energy Performance Certificate (EPC) information for those homes which have an EPC (approximately 60% of the Observatory homes). This was used to provide information about EPC rating and floor area for the analysis. Data for 2022 annual gas and electricity consumption for each home was used to derive the EFP fuel poverty indicator described below.

Approach

Fuel poverty indicators

Drawing on the long tradition of fuel poverty research (Boardman, 1991; Moore, 2012; Waddams Price et al., 2012), we investigate 3 indicators of fuel poverty for this study:

The first is an objective measure, "Expenditure Fuel Poverty" (EFP): the proportion of household income spent on energy (Waddams Price et al., 2012). The EFP metric chose to identify those likely to be in fuel poverty was households spending more than 10% of their estimated gross income (before housing costs) on gas and electricity. A binary variable "EFP" was set to true if the percent spend was >10%, and false otherwise.

The second and third indicators are subjective, based on participants own evaluation of their circumstances:

- "Feeling Fuel Poor" (FFP). This is based on the answers to two questions in the 2023 survey which is the same as the combination of questions originally proposed by Waddams Price et al. The binary variable FFP was set to true to indicate those households which answered "no" to the question "During the cold winter weather, can you normally keep comfortably warm in your living room?" and additionally respond that they gave this answer because "you feel it is difficult to afford the fuel to heat your home".
- "Struggling to meet fuel costs" (SMFC) identified those respondents who replied "fairly difficult" or "very difficult" to the question "How easy or difficult is it for you to meet your heating/fuel costs?" in the 2023 survey. A binary variable "SMFC" identified these respondents.

Estimating Expenditure Fuel Poverty

The income data from the 2023 survey was combined with annual gas and electricity consumption derived from the SERL smart meter data for each household, to provide an estimate of the percentage of income spent on energy (the EFP indicator). As described in Hanmer et al. 2024, a number of assumptions were made for this calculation:

- The survey asked participants to report their gross household income band (e.g. £30,000 to £40,000). The band midpoint was used in the calculation (£105,000 for the highest "above £100,000" band). (£10,000= approx. €12,000). This matches the method used in Waddams Price et al. (2012).
- It was assumed that the energy tariff for all households was the same as the Energy Price Guarantee cap level for January-March 2023. This level, set by the government, varies by region and payment method (DESNZ, 2023)[4]. Some households may have more favourable tariffs from their suppliers but the UK trend was for all suppliers to set prices at or extremely close to this cap level.
- The annual expenditure for gas and electricity was calculated based on the annual demand for the calendar year 2022 recorded by the smart meters i.e. projecting that the energy demand of the household did not change. This represents the cost households would have foreseen in January 2023 if they had calculated their likely future spend on energy based on the current prices and their demand in the previous year.
- Costs for non-metered fuels (oil, LPG etc) were not available from SERL data and so were not included. The calculations of EFP was only carried out for households who confirmed they had gas central heating and for which both gas and electricity meter data was available.

Odds ratio calculation

We used odds ratio (OR) to assess the likelihood that a group with a particular characteristic (e.g. households with children under 5) meet a fuel poverty definition compared with a group with a different characteristic (e.g. households with no members under 5). The odds ratio for the likelihood of EFP and FFP for a particular category compared to the reference was calculated using the R epitools package (Aragon et al., 2020).

The OR represents the odds of an outcome (e.g. FFP=True) in a group with a specific characteristic over the odds of having that outcome for a reference group. For binary characteristics the comparison is between those for which the characteristic is true (e.g. there is household member over 65) and those which it is false (e.g. there is no household member over 65). For categorical characteristics (e.g. EPC rating) the comparison is between those with a particular level (e.g. EPC rating =E) and a reference category (e.g. EPC rating =D). The largest grouping within the sample is chosen as the reference category to increase the confidence level of the comparison. If an outcome shows no association with the characteristic the odds will be the same in both groups

[4] Subsides and support to households including the Energy Bills Support scheme discount of £400 over the period October 2022 to March 2023 were not included in the calculation, as the total amount for each household was unknown.

(i.e. OR= 1). If a characteristic is associated with a lack of a feature the OR is less than 1. Upper and lower limits (95% confidence intervals) are used to assess the significance of OR results: where the upper confidence level is >1 and the lower confidence level is <1, no evidence of significant association is assumed. (Hamilton et al., 2013a).

The calculation of odds ratios is a technique widely used in epidemiology. Odds ratio should not be confused with risk ratios, which give the probability of an outcome given a combination of characteristics. OR is a relative measure of the odds of an outcome between two groups and can also be used to derive risk ratio if the overall prevalence of the characteristic in the population (P_0) is known. However, in samples not drawn randomly from the whole population (for which P_0 is not known) OR is a useful way to explore associations. OR is valuable in its own right to look at differences in risk between segments of the population.

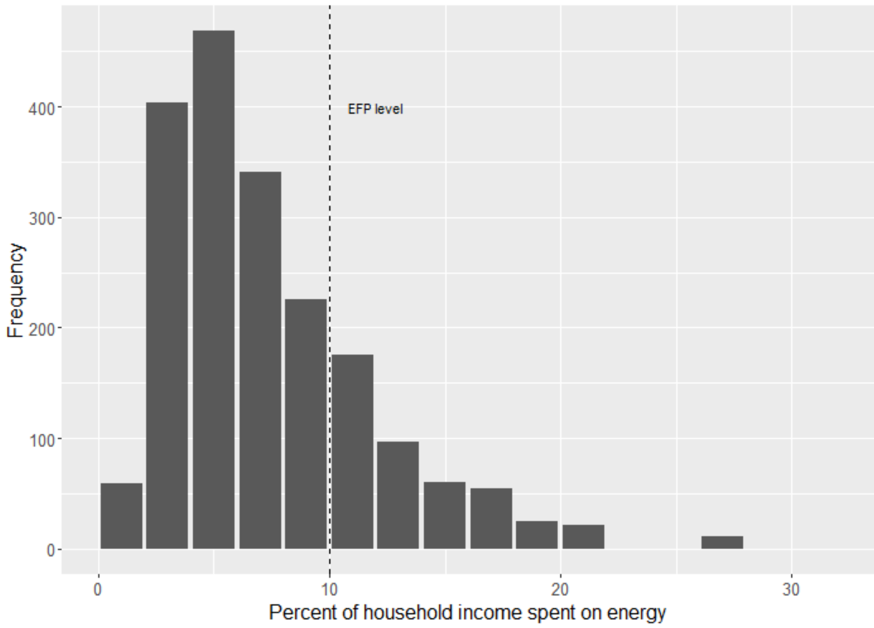
Energy demand counterfactual

In order to investigate demand reduction in the period of crisis, we drew on a counterfactual model. This model, described in Zapata-Webborn et al. (2023a) predicts the energy demand that would have occurred if energy costs (and all other circumstances apart from weather) had remained the same as in winter 2021/22. The counterfactual was calculated using a machine learning algorithm trained on data prior to the cost-of-living crisis that was then run with the weather during the cost-of-living crisis. Detailed information about the model training, selection and performance is provided in Appendix B of Zapata-Webborn et al. (2023a).

In this study, we compare the actual and counterfactual gas demand for the months of January, February and March 2023, comparing mean energy saving for different fuel poverty indicators.

Results and discussion

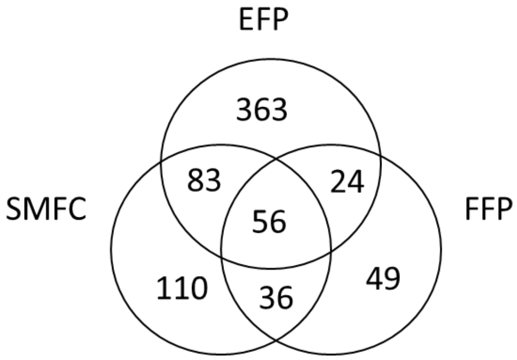
The results below are derived from 5,829 responses to the 2023 survey. Some respondents did not answer all questions or chose "prefer not to say" as an answer and so were excluded from analysis of that question. 4,390 provided information on household income, and of these 2,024 both had sufficient data to calculate energy spend and dual fuel (gas and electricity) customers.



Distribution of % spend on energy in sample (bars <10 suppressed)

The histogram in the figure above shows the distribution of energy spend as a percentage of estimated income. Following statistical data control procedures, results for less than 10 home are not shown. If these had been included, this would extend the right-hand tail of the distribution to a percentage even greater than 28% of household income.

Of the 2024 households for which EFP data was available, 165 (8%) homes were classified as FFP (feeling fuel poor) and 285 (14%) as SMFC (struggling to meet fuel costs) based on their survey answers. The Venn diagram below shows the overlap between the different fuel poverty metrics for the sample. Only 56 (8%) of the 721 households concerned were identified under all three metrics. It is notable that many of those who report struggling to pay bills or to afford to keep their home comfortably warm do not qualify under the EFP (expenditure fuel poor) fuel poverty metric of expenditure on energy >10% of estimated income. This suggests that the EFP is an inaccurate estimator for subjective FP (FFP, or SMFC) while FFP is a more accurate predictor of EFP.



Venn diagram showing numbers and overlap between those who fall into different fuel poverty metrics (for N=2024 households with EFP data available)

Characteristics of homes classified as EFP/ FFP

The table below shows odds ratios for the association of a range of household demographic and dwelling characteristics with FFP and EFP. It should be noted that not all information is available for each household so the totals for each category are different.

Odds Ratios for homes with particular characteristics falling into EFP and FFP categories

* indicates OR significantly >1 (lower 95% CI >1) ** indicates OR significantly <1 (upper 95% CI <1)

	Expenditure Fuel Poverty				Feeling Fuel Poor			
	N	OR	upper limit of OR (95% CI)	lower limit of OR (95%CI)	N	OR	upper limit of OR (95%CI)	lower limit of OR (95%CI)
Household member(s)								
Less than 5 years old	104	0.36**	0.64	0.19	217	1.36	2.10	0.84
Over 65 years old	1063	3.18*	3.96	2.56	2663	0.64**	0.80	0.52
Over 85 years old	104	4.62*	6.98	3.09	275	0.44**	0.79	0.21
Number of occupants								
1	483	2.29	2.92	1.79	1180	2.22*	2.92	1.70
2 (reference)	841				2018			
3	199	0.67	1.00	0.44	489	2.14*	3.04	1.49
4 or more	176	0.35**	0.58	0.20	381	1.73*	2.58	1.13
EPC rating								
A or B	30	0.28**	0.96	0.04	122	0.78	1.56	0.34
C	272	1.04	1.49	0.72	705	1.30	1.79	0.94
D (reference)	486				1084			
E	164	1.27	1.90	0.83	358	0.97	1.48	0.61
F or G	26	0.90	2.28	0.29	57	0.85	2.15	0.25
Floor area								
Less than 50 m^2	53	1.11	2.06	0.56	146	1.67*	2.66	1.01
50 to 100m^2 (reference)	553				1268			
100 to 150m^2	267	0.69**	0.99	0.48	632	0.64**	0.91	0.44
150 to 200m^2	66	0.31**	0.69	0.12	185	0.52**	0.96	0.25
More than 200m^2	39	0.80**	1.72	0.33	94	0.41	1.01	0.12

	Expenditure Fuel Poverty				Feeling Fuel Poor			
	N	OR	upper limit of OR (95% CI)	lower limit of OR (95%CI)	N	OR	upper limit of OR (95%CI)	lower limit of OR (95%CI)
Dwelling built								
Before 1900	200	0.96	1.37	0.67	477	0.95	1.40	0.63
1900 to 1929	258	0.74	1.04	0.53	562	1.12	1.58	0.77
1930 to 1949	305	0.72**	0.99	0.52	739	0.94	1.32	0.66
1950 to 1975 (reference)	551				1357			
1976 to 1990	301	0.71**	0.98	0.51	693	0.77	1.11	0.53
1991 to 2002	210	0.54**	0.80	0.36	501	0.87	1.29	0.57
2003 onwards	135	0.36**	0.59	0.20	321	1.06	1.63	0.66

Considering demographic characteristics:

- Households with members over 65 are three times more likely to be in EFP and those with members over 85 are four times more likely. Despite this they are less likely to report FFP than the rest of the sample. Those of pension age in the UK received Winter Fuel Payments of between £250 and £600 in winter 2022-23, (Department for Work and Pensions, 2023). This extra support (which is not included in our EFP calculations) may have contributed to the different perceptions of this older age group.
- Households containing children under 5 are less likely than the rest of the sample to be in EFP but there is no significant difference in FFP.
- Single occupant households are more likely to be in EFP than the reference two-person category, three- and four-person households are less likely. A three-person household is most likely to report FFP, with one- and four-person households also having higher odds of FFP than the two-person reference.

Considering building characteristics:

- EFP is less likely for homes built after 1929 (compared with the 1950 to 1975 reference)
- EFP is less likely for homes rated EPC A/B (vs D).
- Both EFP and FFP less likely for homes with floor area >100m^2
- FFP is more likely in the under 50m^2 category

An analysis of the breakdown of EFP and FFP showed that:

- All those households with income less than £10,000 pa (approx. €12,000) classified as EFP, as did 71% in the £10,001 to £20,000 pa category.
- 28% of the <£10,000 pa group reported FFP.
- 20 households with an income greater than £40,000 pa were classified as EFP. This group would almost certainly not fall into the UK government LILEE fuel poverty metric (see discussion below). There were also 25 homes in the £40 to £50k category who reported FFP.

Energy saved by those in fuel poverty groupings

Of the 2,541 homes in the sample for which a counterfactual was available, 1712 had enough data to assess EFP. The table below shows the 17.5% gas savings associated with the FFP group are much higher than the sample mean of 9.5%, while the EFP group savings of 10.0% were very similar to those of the rest of the sample.

Difference to predicted (counterfactual) gas demand for Q1 2023

	N	Mean gas demand Q1 2023	Mean proportional difference to counterfactual	Mean absolute difference to counterfactual (-ve is saving)
		kWh	%	kWh gas demand Jan-Mar 2023
Whole sample	2541	159	-9.5%	-19.6
EFP=True	458	171	-10.0%	-21.8
EFP=False	1254	155	-9.4%	-18.7
FFP=True	192	117	-17.5%	-25.7
FFP=False	2349	163	-9.1%	-19.0

Exploring energy saving actions by those in fuel poverty

Other publications from the SERL team have described energy saving actions reported in the 2023 survey (Huebner et al., 2023; Zapata-Webborn et al., 2023a). In this section we briefly introduce an example of epidemiological techniques applied to questions about energy saving actions. We investigated whether those in fuel poverty were more likely to adopt an energy-saving behaviour (reducing heating thermostat setting), and also considered whether they have already been more active saving energy in the past than the rest of the sample.

The table below is reproduced from Hanmer et al. 2024. This analysis looks at odds ratios of thermostat reduction by groups with different characteristics. Because this analysis includes a previously reported temperature setting, it is possible to examine whether those in EFP and FFP groups were already making more effort to save energy than others (i.e. had lower means thermostat settings when recruited into SERL), as well as comparing their actions during the cost of living crisis.

The table below shows the results for EFP/FFP classifications. $T_{recruit}$ is the mean heating thermostat setting reported in the SERL recruitment survey (at some point between 2019 and early 2021). T_{2023} is the mean temperature setting reported in the 2023 survey. The mean setting reported by all groups reduced between the time of recruitment and the survey in early 2023. The FFP group were more likely to turn down their thermostat compared to the rest of the sample, while the EFP group showed no significant difference in reducing thermostat temperature to the non-EFP respondents. Not only were FFP more likely to reduce their thermostat, they also did so from a lower mean starting point[5].

Results from Hanmer et al. 2024 showing difference in mean temperature setting in recruitment survey and 2023 survey

Characteristic	N	$T_{recruit}$	T2023	∆T	OR	upper limit of OR (95%CI)	lower limit of OR (95%CI)
		°C	°C	°C			
EFP	389	20.30	19.10	-1.20	1.04	1.32	0.83
FFP	259	20.15	18.21	-1.94	2.11*	2.84	1.59
STMC	506	20.41	18.86	-1.56	1.46*	1.79	1.20

Comparison with LILEE official fuel poverty indicator for England

The three indicators described in this paper are less complex than the LILEE official definition described in the introduction. Our EFP calculation is based on income bands, not the exact household income. In the LILEE definition, income is taken after housing costs and adjusted for number of people in household (DESNZ and BRE, 2023). As our metric EFP uses income before housing costs, it is a conservative evaluation. If income after housing costs (as used in the English government LILEE definition) were available, then our expenditure fuel poverty levels would be even higher.

Our calculation of energy cost is based on actual demand, not that modelled to meet standard heating levels. The actual heating levels may be different to model assumptions for several reasons:

- The household cannot afford to heat their home to this level.
- The SAP calculation may overestimate the energy required for comfortable temperatures. Detailed data on building fabric, ventilation and heating system is required to model energy demand. Some data available from EPC assessments may be of questionable accuracy (Jenkins et al., 2017).
- The household could afford to heat their home to the ‘required for comfort’ level but might decide not to do so, i.e. they are satisfied with lower temperature to achieve comfort. The thermostat results from the SERL surveys (mean thermostat setting 20.2°C in recruitment survey, 19.2°C in 2023 survey) and from previous surveys of internal temperatures (Huebner et al., 2013; Pullinger et al., 2022; Shipworth, 2011) suggest that many British households are satisfied with lower temperatures than the SAP assumes.

Our results indicate that there are some groups not meeting the LILEE definition who are facing fuel poverty along at least one of the three metrics calculated in this study.:

[5] The sample size differs because only those who confirmed they had gas heating and provided thermostat temperatures settings in two surveys are included.

- For LILEE the home must be EPC D or worse for the household to be in fuel poverty. 302 SERL Observatory households assessed as EFP are living in homes rated EPC C or better (12% of those with EPC rating data) would not count as fuel-poor under this definition.
- The low-income threshold in LILEE (60% of median income after housing costs) excludes many in higher income bands who report they are struggling to pay bills.

The indicators based on SERL data are relatively inexpensive to derive (requiring only smart meter data and the answer one or two questions), compared to LILEE which is underpinned by detailed face-to-face interviews and physical surveys. This means the SERL indicators are potentially available for a wider set of homes, with no requirement for EPC data to be available.

Conclusions

The analysis in this paper (and in other papers based on SERL data) illustrates the value of combining longitudinal data on energy demand with “in the moment” surveys in response to major changes and crises. Smart meter-based energy epidemiological research studies like the SERL Observatory can address the data-gaps in the field of energy in buildings and provides insights for policy decision-making. Flexibility on the part of funders and researchers is required to respond to unexpected crises such as the Coronavirus pandemic and the steep rise in energy prices following the invasion of Ukraine.

Epidemiology provides a framework for looking at energy demand at the population or large sample level, with robust methods for establishing patterns and trends based on bottom-up data collection. Epidemiological techniques relevant for energy researchers include study design, rigorous statistical analysis of observations and developing predictive models combining social, economic and physical data. Studying fuel poverty within an epidemiological frame provides an opportunity to explore the variation of household incomes and their requirements for thermal comfort combined with the impact of the energy efficiency of their homes on affordability of energy bills.

Results from the SERL Observatory data for the first quarter of 2023 suggest that elderly and low-income households were those objectively most likely to require support to meet increased fuel bills (spending more than 10% of their income on fuel). However the indicator based on income is in stark contrast to subjective feelings of fuel poverty among elderly households who were less likely to say they were ‘feeling fuel poor’ than the rest of the sample.

The differences between the groups identified by three fuel poverty metrics highlight the multiple dimensions and complexity of identifying those struggling to pay energy bills. No single indicator is likely to capture all these dimensions. Our assessment of Expenditure Fuel Poverty (EFP) based on SERL Observatory data is less sophisticated than the official English LILEE metric, but requires considerably less data to be collected. Monitoring EFP and subjective measures of fuel poverty (such as the FFP and SMFC indicators we have described) provides an opportunity to identify trends and characteristics relevant to fuel poverty policy development. Smart meter based national surveys could be a relatively inexpensive and rapid way to produce national statistics that could complement existing expensive and resource intensive methods of producing statistics for monitoring fuel poverty levels.

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References

Age UK, 2021. The cost of cold.

Aragon, T.J., Fay, M.P., Wollschlaeger, D., Omidpanah, A., 2020. epitools: Epidemiology Tools.

Boardman, B., 1991. Fuel poverty: from cold homes to affordable warmth.

Bolton, P., Stewart, I., 2024. Domestic energy prices. House of Commons Library.

BRE, 2012. The government's standard assessment procedure for energy rating of dwellings. Build. Res. Establ. Watford UK.

CCC, 2016. Next steps for UK heat policy. Committee on Climate Change, London.

DECC, 2014. Fuel Poverty Energy Efficiency Rating Methodology.

Department for Work and Pensions, 2023. Winter Fuel Payment statistics for winter 2022 to 2023 [WWW Document]. GOV.UK. URL https://www.gov.uk/government/statistics/winter-fuel-payment-statistics-for-winter-2022-to-2023/winter-fuel-payment-statistics-for-winter-2022-to-2023 (accessed 1.28.24).

DESNZ, 2023. Energy Price Guarantee: regional rates, October to December 2022 [WWW Document]. URL https://www.gov.uk/government/publications/energy-price-guarantee-regional-rates/energy-price-guarantee-regional-rates (accessed 9.13.23).

DESNZ, BRE, 2023. Fuel Poverty Methodology Handbook (Low Income Low Energy Efficiency).

DLUHC, 2022. English Housing Survey 2021 to 2022: headline report [WWW Document]. URL https://www.gov.uk/government/statistics/english-housing-survey-2021-to-2022-headline-report/english-housing-survey-2021-to-2022-headline-report (accessed 9.13.23).

Few, J., Manouseli, D., McKenna, E., Pullinger, M., Zapata-Webborn, E., Elam, S., Shipworth, D., Oreszczyn, T., 2023. The over-prediction of energy use by EPCs in Great Britain: A comparison of EPC-modelled and metered primary energy use intensity. Energy Build. 288, 113024. https://doi.org/10.1016/j.enbuild.2023.113024

Hamilton, I., Summerfield, A., Oreszczyn, T., Ruyssevelt, P., 2017. Using epidemiological methods in energy and buildings research to achieve carbon emission targets. Energy Build. 154, 188–197. https://doi.org/10.1016/j.enbuild.2017.08.079

Hamilton, I.G., Steadman, P.J., Bruhns, H., Summerfield, A.J., Lowe, R., 2013a. Energy efficiency in the British housing stock: Energy demand and the Homes Energy Efficiency Database. Energy Policy 60, 462–480. https://doi.org/10.1016/j.enpol.2013.04.004

Hamilton, I.G., Summerfield, A.J., Lowe, R., Ruyssevelt, P., Elwell, C.A., Oreszczyn, T., 2013b. Energy epidemiology: a new approach to end-use energy demand research. Build. Res. Inf. 41, 482–497. https://doi.org/10.1080/09613218.2013.798142

Hanmer et al. (2024). Actions to save heating energy during an energy cost crisis: insights from British survey and smart meter data. *Manuscript submitted for publication*

Huebner, G., Hanmer, C., Zapata-Webborn, E., Pullinger, M., McKenna, E.J., Few, J., Elam, S., Oreszczyn, T., 2023. Self-reported energy use behaviour changed significantly during the cost-of-living crisis in winter 2022/23: Insights from cross-sectional and longitudinal surveys in Great Britain. https://doi.org/10.31235/osf.io/984yh

Huebner, G.M., McMichael, M., Shipworth, D., Shipworth, M., Durand-Daubin, M., Summerfield, A., 2013. The reality of English living rooms – A comparison of internal temperatures against common model assumptions. Energy Build. 66, 688–696. https://doi.org/10.1016/j.enbuild.2013.07.025

Huebner, G.M., Watson, N.E., Direk, K., McKenna, E., Webborn, E., Hollick, F.P., Elam, S., Oreszczyn, T., 2021. Survey study on energy use in UK homes during Covid-19. Build. Cities 2, 952–969. https://doi.org/10.5334/bc.162

Jenkins, D., Simpson, S., Peacock, A., 2017. Investigating the consistency and quality of EPC ratings and assessments. Energy 138, 480–489. https://doi.org/10.1016/j.energy.2017.07.105

Liddell, C., 2012. Fuel poverty comes of age: Commemorating 21 years of research and policy. Energy Policy, Special Section: Fuel Poverty Comes of Age: Commemorating 21 Years of Research and Policy 49, 2–5. https://doi.org/10.1016/j.enpol.2012.02.036

McKenna, E., Few, J., Webborn, E., Anderson, B., Elam, S., Shipworth, D., Cooper, A., Pullinger, M., Oreszczyn, T., 2022. Explaining daily energy demand in British housing using linked smart meter and socio-technical data in a bottom-up statistical model. Energy Build. 258, 111845. https://doi.org/10.1016/j.enbuild.2022.111845

Moore, R., 2012. Definitions of fuel poverty: Implications for policy. Energy Policy, Special Section: Fuel Poverty Comes of Age: Commemorating 21 Years of Research and Policy 49, 19–26. https://doi.org/10.1016/j.enpol.2012.01.057

Office for National Statistics, 2024. Cost of living latest insights [WWW Document]. URL https://www.ons.gov.uk/economy/inflationandpriceindices/articles/costofliving/latestinsights (accessed 1.28.24).

Ofgem, 2021. Supplementary model - default tariff cap level v1.9.

Pullinger, M., Berliner, N., Goddard, N., Shipworth, D., 2022. Domestic heating behaviour and room temperatures: Empirical evidence from Scottish homes. Energy Build. 254, 111509. https://doi.org/10.1016/j.enbuild.2021.111509

Pullinger, M., Zapata-Webborn, E., Kilgour, J., Elam, S., Few, J., Goddard, N., Hanmer, C., McKenna, E.J., Oreszczyn, T., Webb, L., 2024. Capturing variation in daily energy demand profiles over time with cluster analysis in British homes (September 2019 – August 2022). https://doi.org/10.31219/osf.io/ckyb6

Shipworth, M., 2011. Thermostat settings in English houses: No evidence of change between 1984 and 2007. Build. Environ. 46, 635–642. https://doi.org/10.1016/j.buildenv.2010.09.009

Tirado Herrero, S., 2017. Energy poverty indicators: A critical review of methods. Indoor Built Environ. 26. https://doi.org/10.1177/1420326X17718054

Viner, K., 2023. Millions in Britain are choosing between heating and eating. It's not too late to help them. The Guardian.

Waddams Price, C., Brazier, K., Wang, W., 2012. Objective and subjective measures of fuel poverty. Energy Policy, Special Section: Fuel Poverty Comes of Age: Commemorating 21 Years of Research and Policy 49, 33–39. https://doi.org/10.1016/j.enpol.2011.11.095

Webborn, E., Few, J., McKenna, E., Elam, S., Pullinger, M., Anderson, B., Shipworth, D., Oreszczyn, T., 2021. The SERL Observatory Dataset: Longitudinal Smart Meter Electricity and Gas Data, Survey, EPC and Climate Data for over 13,000 Households in Great Britain. Energies 14, 6934. https://doi.org/10.3390/en14216934

Zapata-Webborn, E., Hanmer, C., Oreszczyn, T., Huebner, G., McKenna, E.J., Few, J., Elam, S., Pullinger, M., Cheshire, C., Friel, D., Masters, H., Whittaker, A., 2023a. Winter demand falls as fuel bills rise: Understanding the energy impacts of the cost-of-living crisis on British households. https://doi.org/10.31219/osf.io/83a4t

Zapata-Webborn, E., McKenna, E., Pullinger, M., Cheshire, C., Masters, H., Whittaker, A., Few, J., Elam, S., Oreszczyn, T., 2023b. The impact of COVID-19 on household energy consumption in England and Wales from April 2020 to March 2022. Energy Build. 297, 113428. https://doi.org/10.1016/j.enbuild.2023.113428

Hanmer et al. (2024). Actions to save heating energy during an energy cost crisis: insights from British survey and smart meter data. *Manuscript submitted for publication*