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WORKING PAPERS SERIES

Paper 233 - May 23

Transitioning The Residential Environment Of The Uk To Net-Zero: An In-Depth Analysis Of The Energy Performance Of The Building Stock And Its Local Social And Spatial Contexts

Project Technical Document

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TRANSITIONING THE RESIDENTIAL ENVIRONMENT OF THE UK TO NET-ZERO: AN IN-DEPTH ANALYSIS OF THE ENERGY PERFORMANCE OF THE BUILDING STOCK AND ITS LOCAL SOCIAL AND SPATIAL CONTEXTS

PROJECT TECHNICAL DOCUMENT

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Executive Summary

This report analyses the national database of residential building Energy Performance Certificates (EPCs) and reviews the factors that contribute to and are associated with a varied geography across the country.

The background context is a government ambition to transition the UK to a 'net-zero' carbon-emitting economy by 2050 – an ambition that if achieved will necessitate systems change across the big carbon emitting sectors. While transport and industry will clearly play an important part in this shift, the role of housing will also be central. Britain has some of the most energy inefficient housing stock in Europe and a transition to greater efficiency will require targeted interventions in order for change to occur at the rate required to meet the target set.

The energy efficiency of housing also plays a very big role in household expenditure – something which has been brought to the fore in recent times due to the rapidly rising cost of energy and more general inflationary pressure which have seen living standards decline across the UK. More efficient housing requires less energy to heat or cool and so there are clear socio-economic benefits as well as environmental benefits to hastening a transition to more efficient residential building stock. New legislation and shifting standards in relation to the rental sector also mean that the shift to more efficient stock could yet play out in unexpected ways in relation to the supply and demand of a scarce resource.

Who lives in or owns a property or where it is located can play an important role in its current energy efficiency or future potential, we also turn our attention in this report to the role that social and spatial factors play in explaining the current national landscape of building energy efficiency.

Section 2 of this report reviews the current UK government priorities as well as the current evidence gap and challenges that are presented in studying residential building energy performance. Section 3 gives an overview of our main research dataset – DLUHC's EPC database. In this section we give a broad overview of how the data are generated and what information is contained about the 18 million or so properties within it.

In Section 4 we carry out a three-stage analysis. Firstly, an overview of the housing stock in England and Wales in terms of its physical characteristics – in particular looking at Morphology, Age and Tenue and associating these characteristics with energy performance statistics. Older, larger, detached, owner occupied housing in rural locations is, on average, the most inefficient; more modern, smaller, social housing flat located in urban areas on the whole performs much better.

We find that the relationship between energy efficiency and environmental impact is not a linear one with it not uncommon to find properties that performing better in terms of environmental impact (mainly through being heated via cleaner fuel sources such as electricity, than they do in energy efficiency. The phenomenon of leaky houses merely heated more by less impactful fuel, is a real one, particularly in rural areas of England and Wales.

While the stock in some local authorities generally performs better on average – for example in Central London – these patterns at the local authority level can mask important neighbourhood level issues, particularly in rental stock. In London in particular, we see large number of private rental properties which are currently below the band C energy efficiency threshold which could cause problems of supply in the near future if landlords leave the market rather than upgrade their properties.

Modelling property level energy efficiency as a function of physical characteristics and location accounts for around a third of the variation in energy performance with over and under performance

relative to physical characteristics that are hard to change, largely a function of the fuel that is used. At the local authority level, just over half of the relative average performance of housing within local authorities across England is explained by the particular geodemographic characteristics of those places. In the 'London Cosmopolitan' areas – a small cluster of Local Authorities in Central London which has over representation of flats, over representation of social renting, large under-representation of owner occupation, high levels of good qualifications and, conversely, unemployment, as well as large ethnic minority populations, people in their 20s and 30s, and those born outside of the UK – we see a strong positive influence on relative energy efficiency performance, relative to an already fairly well performing reference group in East London.

At the other end of the scale, a cluster of Local Authorities labelled as 'Older Farming Communities' – found in the parts of the country with much worse energy performance, for example down in the South West, the Welsh Borders and the North – is characterised by an over-representation of detached houses and bungalows which are owner occupied, and over-representation of those aged over 45, 65 and 90+, those who are well educated, but who rely on cars to get around and are employed in hospitality and agriculture, fair much worse.

The analysis in this report reveals a clear social and spatial pattern to residential building energy performance that will need to be considered for future policy decisions around how national underperformance of residential building stock is to be tackled. While older owner occupied rural housing stock might be the most challenging to improve, local nuance in urban areas cannot be ignored, particularly where challenges in the private rental sector are near the surface and if not dealt with carefully with policy carrots as well as sticks, may result in negative impacts on housing availability for those who are most vulnerable in society.

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1 INTRODUCTION

We are living in challenging times. Climate breakdown is affecting the whole world and life on earth is facing an existential threat unless the human race rapidly finds solutions to decades of increasing energy consumption derived principally from the burning of fossil fuels. More locally, the UK is in the midst of a cost-of-living crisis as wages stagnate and the costs of essentials such as food, shelter and fuel continue to increase.

The need to change the way we live, particularly our relationship with the energy we consume in our daily lives, has never been more pressing. The 'decarbonisation' of our existence is now widely accepted as a priority by all within the political mainstream, but the complexity of the challenge which spans all aspects of our daily lives from the food we consume to the homes we live in or the ways we move around means that solutions will not be straightforward and may have unintended or unforeseen consequences.

Housing – alongside perhaps transport – sits at the very centre of the intersecting environmental and social challenges that decarbonisation and tackling the cost of living throws up. For many, it is their greatest expense – through both the costs of rent or mortgage repayments and through the costs of the energy used to heat (or increasingly cool) their homes and keep the lights on. In the UK, our building stock is some of the least energy efficient in the whole of Europe (Baker et al. 2022), losing more heat and requiring more energy to replace it than elsewhere in the continent and in the process contributing significantly to both greenhouse gas emissions and energy bills – as illustrated below in Figure 1.

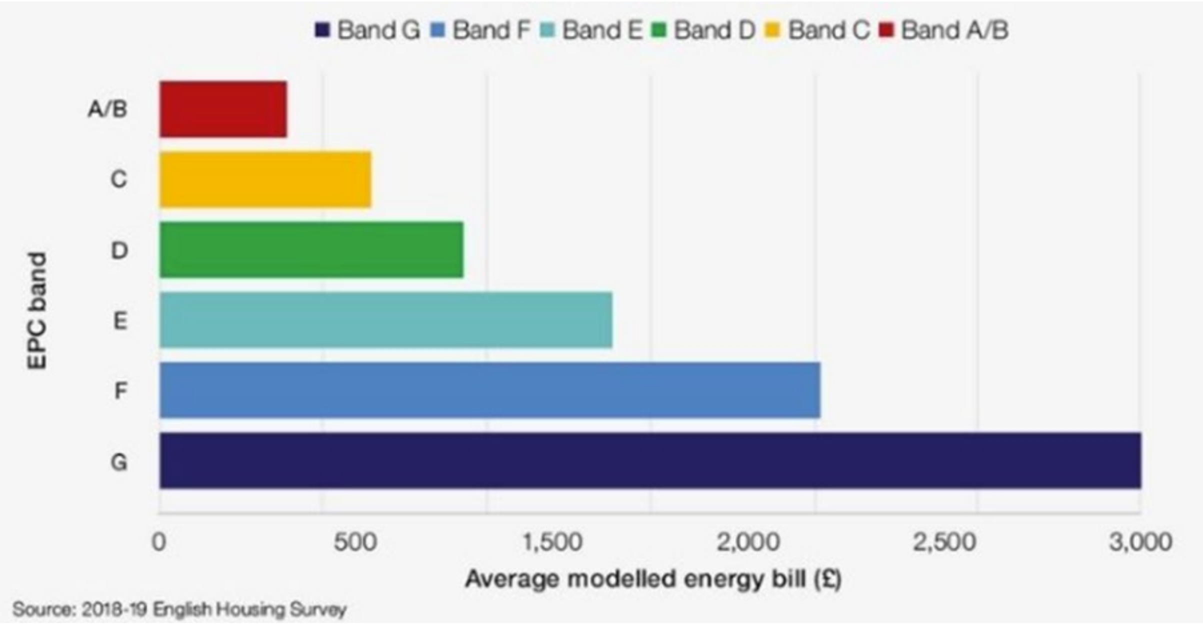


Figure 1-1. The Financial Cost of Poor Energy Performance

While some excellent high-level reports exist outlining the national priorities and challenges in relation to housing and decarbonisation – some of which we detail below – there is a conspicuous lack of analytical nuance, despite the data landscape improving markedly in recent years. This research project is a preliminary effort to redress the balance through a detailed spatial analysis of the Department for Levelling Up, Housing and Communities' (DLUHC) Residential Energy Performance Certificate (EPC) Dataset. The recent addition of the Unique

Property Reference Number (UPRN) enables the geolocation of each of the 18 million or so properties in the dataset, facilitating, for the first time, an analysis of where the best and worst performing properties are located, what their characteristics are and who is likely to be inhabiting.

This analysis is a crucial first step to being able to better target programmes of property improvement that might edge the country closer to having a residential stock which is more energy efficient. Is it the case, for example, that some poorly performing housing is inhabited by those who have the means to improve it? Are those who are struggling the most, financially, also living in the leakiest, most expensive to heat, properties? How does this picture vary across the country and by the local authorities frequently charged with the task of addressing the problem?

Given this context, we proceed with a series of overarching aims and more specific objectives which relate both substantively to the problem we have just outlined and more functionally to the data we will analyse, which has been under-utilised in its full richness by the research community up to this point. We aim to:

- Demonstrate the value of geo-located residential property energy performance certificate data in exploring the varied geography of building energy performance in England and Wales with a view to developing localised foresight into the implications of the existing legislative changes under the Minimum Energy Performance of Buildings Bill (2021).
- Highlight the challenges in and potential benefits of working with this extensive property-level dataset, exploring in particular the distribution and characteristics of properties with diverging energy efficiency and environmental impact ratings.
- Explore the factors that are influencing residential building performance. In particular examine how aspects of the social geography of England and Wales such as income deprivation interact with the residential built environment, using this evidence to comment on where particular areas of challenge or opportunity exist for policy makers and residents alike.

In order to achieve these aims, some more specific objectives will be to:

- geolocate and clean (de-duplicate) the EPC dataset in order to create a cross-sectional snapshot of the residential housing stock of the study area (England and Wales)
- carry out an exploratory descriptive analysis of the EPC dataset across a range of property dimensions and using a suite of graphical and other data visualisation methods, paying particular attention to spatial variation. In particular we will compare and appraise apparently dichotomous properties – those with good energy efficiency scored (i.e. low running costs), whist having an unfavourable environmental impact (high carbon emissions)
- explain some of the patterns that emerge through a building a spatially explicit explanatory energy performance model which uses attributes such as individual property characteristics, local income and other demographic information to disentangle the complex interactions between residential property and social geography.

The report proceeds as follows. In Section 2, we begin with a background overview of the political priorities informing this analysis and a review of the current evidence gap that exists. We then frame the complex and multifaceted challenge through a systems thinking lens which gives us a framework and a justification for incorporating social and spatial dimensions into this analysis. Section 3 details the data we use in this analysis: our main analysis EPC dataset – how the data are created, what information is contained, data quality issues; and other social and spatial datasets used, Section 4 is the analysis section and contains both the exploratory descriptive analysis and the explanatory modelling. Section 5 is a discussion section which reflects on our findings and looks to link what has been discovered back to the policy imperatives discussed at the top of the report and sets and agenda for follow-on work.

2 BACKGROUND

2.1 GOVERNMENT PRIORITIES

The UK Government has made it a central policy priority to transition the country to "net-zero" production of greenhouse gas emissions by 2050 (BEIS 2021b) in an attempt to limit global heating to 1.5c above pre-industrial levels. Most greenhouse gas emissions come from the burning of fossil fuels with transportation, buildings, industry and agriculture sharing the burden of emissions in the UK either through direct combustion of gas or oil for heating or petroleum products in vehicle engines, or indirect combustion through electricity generated through the burning of fossil fuels.

In transitioning the country to a net-zero society, the government has also seen a chance for a post-pandemic restructuring of the economy, with the shift to a lower carbon future seen as a potential economic opportunity driven by innovation across energy production, transport, industry and buildings leading to a re-skilling of the workforce and the creation of tens of thousands of new jobs in the process (BEIS 2021b; 2021a; Skidmore 2022) and as such the shift represents not just an environmental imperative but a rare chance to fundamentally reshape the economy and society of the country for the better, contributing to the 'levelling-up' agenda which has been at least a rhetorical political ambition for those running the country for a number of years now. Furthermore, recent global events have led to fossil fuel price increases which have exacerbated a national cost-of-living crisis and made the transition to more energy efficient homes a financial imperative for many.

Recognising the importance of a multi-system approach to the challenge, the government has published a series of strategic plans for sectors including transport (DFT 2021) and importantly for this work, Buildings (BEIS 2021a). Roughly 30% of the UKs emissions are attributed to buildings with some 17% directly the result of heating domestic properties (BEIS 2021a; Woodward 2021). It is recognised that the heating (and indeed more frequently now, cooling) of buildings will need to be decarbonised if the UK's net zero ambitions are to be realised (Skidmore, 2023). Buildings account for about 40% of total energy consumption and are – by far – the largest source of household energy consumption in Europe. Improving domestic energy efficiency is vital if the UK Government is to meet its Net-Zero policy commitments by 2050.

2.2 THE EVIDENCE GAP

The Heat and Buildings Strategy document (BEIS 2021a) represents a comprehensive high-level overview of the challenges and opportunities presented by the transition to net zero; the current national state of the residential stock across dimensions like tenure; where decision making will occur at national, sub-national and local levels; how we might measure building energy performance and improve those which fall below the standard; and how the economic and cultural environment of the UK could evolve to affect a shift. However, as a high-level strategic overview, it is deficient in the detail required - particularly any spatial nuance or social perspectives - to follow through on the opportunities identified or indeed the local decision making it advocated as part of the delivery strategy.

Both the Heat and Building Strategy document and the more recent net zero review by Skidmore (2022) recognise a degree of social interaction with the problem of energy efficient homes in addition to the more obvious physical characteristics of the properties and the fuels used to provide heat. But while some space is given to the role that, for example, housing tenure might play in helping or hindering home improvements alongside the cost implications, the spatial and social contexts within which all residential properties are situated and the role that *where* a property is and *who* lives in it plays in whether it is more or less likely to be energy efficient now or in the future, is left out of the discussion.

The strategy highlights the need for a balanced approach between national, regional and local decision making; impressing the importance of local knowledge and an appreciation of local landscapes in order that decarbonisation can be achieved. Alongside this, the role of data is highlighted as a key enabling component which will allow decision makers to develop a better understanding of local constraints and opportunities within the building stock, but there is a conspicuous lack of detail on how data might inform local knowledge, or indeed how analysis of data might support decision making at national, regional and local levels.

It is clear that there is a gap between the high-level strategic ambitions of the government to decarbonise the housing stock and a plan for how this might be achieved through a data-informed understanding of local housing conditions and the socio-economic environments residents occupy in every neighbourhood that could help or hinder a transition to a better state. Indeed it is noted by Delzendeh et al. (2017) in their comprehensive review of residential energy efficiency technology adoption that the lack of understanding of residential building energy behaviours at 'urban scale'; an issue for sound policy formation.

2.3 Epistemological Challenges

Throughout Skidmore's (2022) review, reference is made to 'systems thinking' as a solution to - or at least a guiding principle to tackle - the net zero challenge in the round. The idea that the energy system of the UK represents a complex system with multiple interacting elements is perhaps not controversial. Any transition of such a system to a new steady state - one which emits zero carbon - in a timeframe which at best is ambitious, will require 'joined-up thinking' that pays attention to all relevant parts of and influences on that system.

While the housing stock of the UK represents a branch of a larger carbon-emitting system including transport, industry and agriculture; a systems approach can still be applied to the understanding of this sub-system. One way of conceptualising the systems approach is as an epistemological perspective which eschews singular perspectives on a problem - in our case a narrow perspective might be perhaps examining current building energy performance as a problem of physical building characteristics. This approach seeks a "strategic vantage point [to] make sense of causality from perhaps various conflicting perspectives" (Houghton 2009, 2) and proceeds by "not avoiding the inevitable interconnectivity between variables" or "working on the basis of a single unquestioning perspective" (Reynolds and Holwell 2010, 6). In our case, this means building an evidence base which can incorporate perspectives related to local policy environments; for example, accounting for the fact that some local authorities will have an older housing stock or higher levels of social housing than others or that some might have already prioritised of energy performance retrofitting or been able to go further than others. It also means highlighting how local socio-economic conditions, ownership norms and levels of material deprivation may interact with physical building characteristics to impact dwelling performance.

In our analysis of the energy performance of the residential building stock in England we are not attempting to make use of the full systemic epistemology outlined by Houghton (2009), rather we are drawing inspiration from a systems perspective that impresses we cannot understand residential building energy performance without reference to residents or other relevant local and regional economic or governance environments. An acknowledgement that we should seek to understand the importance of *all* relevant dimensions of the system before we are able to make informed policy decisions about it. We also take inspiration from the systems approach advocated by Wilson (2022) who details the importance of defining the elements of one's system of interest - simplified as far as possible but incorporating all important inter-related elements, before articulating an initial theory of how the system (S) works and then testing this theory (T) using a set of defined methods (M). Wilson calls this the STM approach, which is a necessary precondition to a Policy (P), Design (D) Analysis (A) - or PDA - framework for planning and evaluating solutions to the systems problem. In this work, we only aim to tackle the STM part of Wilson's interdisciplinarity framework, but in doing so hope to provide a foundation for subsequent Policy, Design and further Analysis which will move us towards decarbonising our residential building stock.

2.4 SYSTEM, THEORY AND METHODS

Our system in this piece of work comprises physical, social, economic, political and cultural elements and is bounded within England and Wales. As detailed later in the Data section, our main analysis dataset is the Department for Levelling Up Housing and Communities' residential building Energy Performance Certificate (EPC) Dataset for England and Wales; properties within which are geocoded to precise address-level locations using the Unique Property Reference Number (UPRN) and via Ordnance Survey AddressBase products. EPC data are property level which, if using population census terminology, would be classed as 'microdata'. As such our primary unit of analysis is the individual building with us considering all buildings for which there are data in England and Wales.

All addresses within England and Wales can be situated within a hierarchy of administrative and statistical reporting spatial units for which other information can be obtained. Most residential buildings also have residents within, the latest detailed information about whom is contained within the 2021 Census of Population. Derived data products such as the English Indices of Deprivation (DLUHC 2019) or the national Rural Urban Classification (DEFRA 2021) are available for different levels within the hierarchy of statistical reporting units such as Output Areas (OAs) which contain somewhere between 40 and 250 households (and a similar number of properties) and Lower Level Super Output Areas (LSOAs), which contain somewhere between 400 and 1200 households (ONS n.d.). These statistical reporting units fit neatly within higher-level administrative units such as Local Authorities and Regions which have important statutory functions within UK housing legislation and whom are involved in the provision of social housing, either directly or through housing associations.

In this work we are concerned with the energy performance of residential buildings and there are of course a range of physical properties which will impact upon a building's energy performance - its construction materials, levels of insulation, glazing used, heating system etc. While older properties are less likely to have been constructed with energy efficiency in mind and consequently are more likely to perform badly in terms of how efficiently they use energy, more modern properties are held to higher standards in terms of building regulations and thus generally perform better. However, properties are intertwined with their owners and inhabitants. It is rare that buildings, however old, remain in their originally constructed state. To a greater or lesser degree, most buildings undergo some form of alteration during their lifecycle. Commonly in relation to energy usage, this might have been being wired up for electricity or having central heating fitted. It might have also involved installing insulation or double glazing. There are myriad ways in which building stock can be upgraded to improve its energy efficiency and all of them require input from either owners or inhabitants - and consequently due to the huge amount of heterogeneity in both building and owner/inhabitant populations, the picture across England and Wales is highly complex.

The theory and evidence behind the social and cultural influences on residential building stock performance derives from several studies which have explored how improvements in energy efficiency are influenced by a range of factors related to those who own (which could include both owner occupiers and private or institutional landlords) or reside in homes (both owners and tenants). Work by authors including Wilson et al. (2015), Mills and Schleich (2012), Camarasa et al. (2021), Delzendeh et al. (2017) and Beillan et al. (2011) has shown that across different countries there are a multitude of factors influencing these residential stakeholders.

Taking occupiers first, Mills and Schleich (2012) evidenced the role of factors such as education, age and household composition on the adoption of energy efficient technologies in homes across 11 European Countries, with levels of Education having a positive impact on adoption (via mechanisms such as reducing the costs of information acquisition or a broader awareness of energy issues or even the social status afforded to being seen to adopt environmentally friendly lifestyles) and with families with young children more likely to adopt energy efficient measures and those who were more elderly, less likely (possibly due financial cost of simply lower chance for a return on what is often a long term investment). These factors concur with those also found by Delzendeh et al. (2017) and Wilson et al. (2015) who also add that factors such as gender and decision making roles (and male and female thermal preferences), employment type and income levels, number of children and occupancy profile of rooms and all influence attitudes and adoption of energy efficiency measures in homes.

Examining owners more widely to also include both private and institutional landlords, Tenure comes up (C. Wilson, Crane, and Chryssochoidis 2015) as an important factor and one which interacts with age in the UK somewhat with younger people less likely to own and therefore either invest in property improvements themselves or if they do own, be more likely to move on up the housing ladder and more likely to avoid costly energy efficiency retrofitting. However more broadly the effects of low income on hindering or higher incomes on facilitating adoption of energy saving technologies is noted in a number of studies (Mills and Schleich 2012; Delzendeh et al. 2017; Piao and Managi 2023; C. Wilson, Crane, and Chryssochoidis 2015). Beillan et al. (Beillan et al. 2011) also note the potential role that financial incentives to retrofit buildings may play in different countries, however local and regional initiatives to encourage building improvements may currently provide more anecdotal evidence of efficacy.

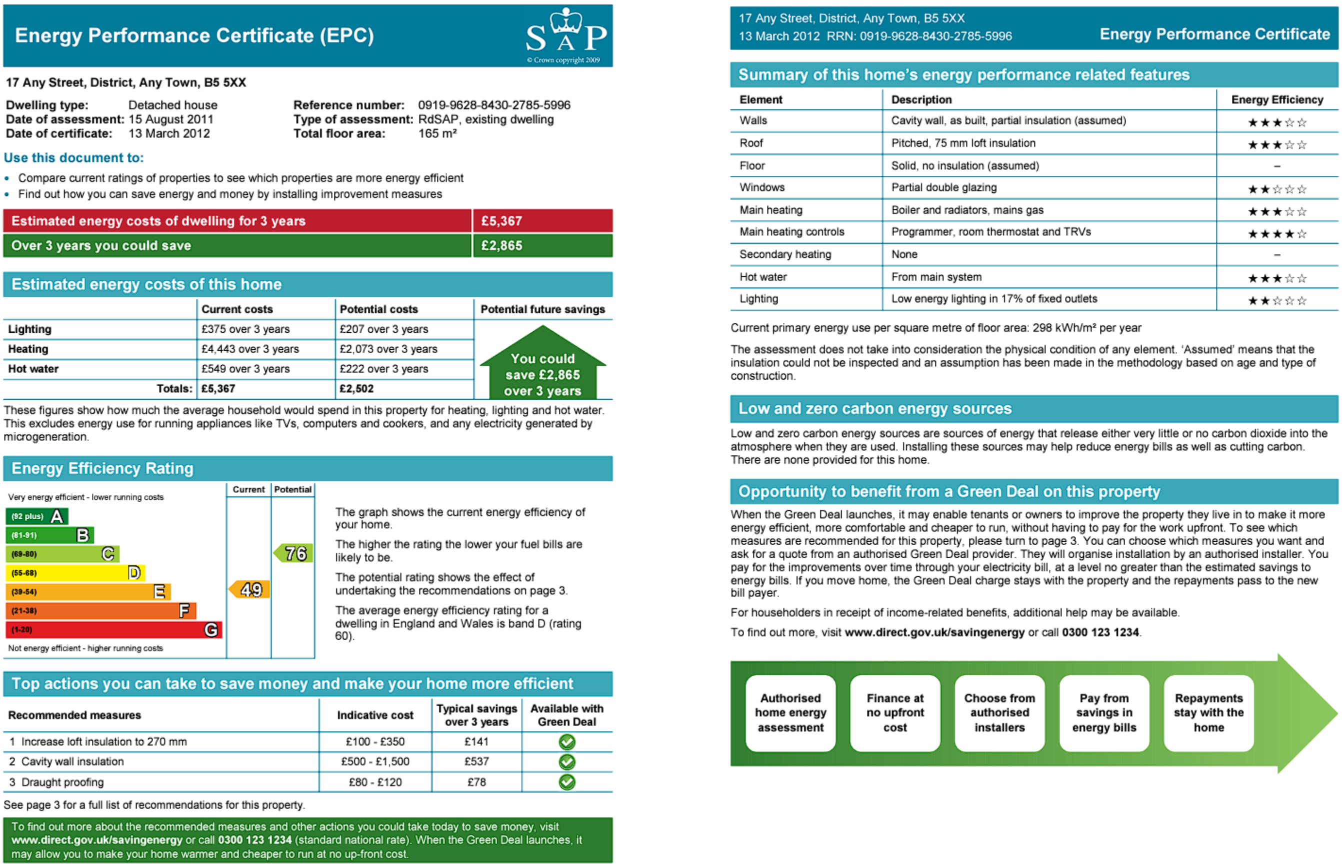
Having established the links between the social and physical fabric of residential buildings and energy performance this research will adopt a rigorous quantitative approach to try to shed light on the nuanced geography of good and bad performance in England and Wales. We will do so mindful of the political environment and in particular some of the relevant policy and regulatory initiatives which have emerged from ongoing consultations on building energy efficiency. At the time of writing changes to the governments Minimum Energy Efficiency Standards (MEES) are being consulted on with a view to requiring all landlords letting properties to ensure they meet a minimum Band-C standard by 2030. This is a somewhat watered down outcome which at the moment sets out an ambition to "to have as many private rented homes as possible being upgraded to EPC Band C by 2030, where practical, cost effective and affordable" (BEIS 2023), rather than the it being a blanket requirement for all rented homes from 2030 as earlier mooted. Despite this, having markers such as EPC Band-C as a meaningful reference points will aid subsequent analytical interpretations.

3 DATA

In this section we profile the features of our main research dataset; examining how the data are collected alongside issues that might be introduced during the collection process and more general data quality issues that should be acknowledged. We then detail some of the variables within the EPC dataset more relevant to our analysis, covering those more likely to have a direct impact on energy performance – directly measured variables such as size, age, building morphology or main heating fuel, rather than those which are in the dataset but less relevant or derived such as lighting cost.

3.1 ENERGY PERFORMANCE CERTIFICATES

Emerging from the 1997 Kyoto protocol, a 2002 European Directive on the energy performance of buildings led to a 2003 UK Government White Paper on creating a Low Carbon Economy. As part of these strategic documents, legislation across Europe and in the UK was drafted requiring energy performance certificates to be issued for all buildings – both residential and non-residential (Watson 2010). As documented by Chi et al. (2021), EPCs have been required by law since 2008 for all properties sold and rented in the UK. Data related to these certificates are collated and managed by the Department for Levelling Up, Housing and Communities (DLUHC) and made available via https://epc.opendatacommunities.org/. Several versions of the database have been published with the most recent updates now also including Unique Property Reference Numbers (UPRNS) which facilitate precise geolocation via Ordnance Survey AddressBase products – a vital innovation for this piece of research.



Energy Performance Certificate (EPC)

17 Any Street, District, Any Town, B5 5XX

Dwelling type: Detached house
Date of assessment: 15 August 2011
Date of certificate: 13 March 2012
Reference number: 0919-9628-8430-2785-5996
Type of assessment: RdSAP, existing dwelling
Total floor area: 165 m²

Use this document to:

- Compare current ratings of properties to see which properties are more energy efficient
- Find out how you can save energy and money by installing improvement measures

Estimated energy costs of dwelling for 3 years	£5,367
Over 3 years you could save	£2,865

Estimated energy costs of this home

	Current costs	Potential costs	Potential future savings
Lighting	£375 over 3 years	£207 over 3 years	You could save £2,865 over 3 years
Heating	£4,443 over 3 years	£2,073 over 3 years	
Hot water	£549 over 3 years	£222 over 3 years	
Totals:	£5,367	£2,502	

These figures show how much the average household would spend in this property for heating, lighting and hot water. This excludes energy use for running appliances like TVs, computers and cookers, and any electricity generated by microgeneration.

Energy Efficiency Rating

The graph shows the current energy efficiency of your home.

The higher the rating the lower your fuel bills are likely to be.

The potential rating shows the effect of undertaking the recommendations on page 3.

The average energy efficiency rating for a dwelling in England and Wales is band D (rating 60).

Top actions you can take to save money and make your home more efficient

Recommended measures	Indicative cost	Typical savings over 3 years	Available with Green Deal
1 Increase loft insulation to 270 mm	£100 - £350	£141	✓
2 Cavity wall insulation	£500 - £1,500	£537	✓
3 Draught proofing	£80 - £120	£78	✓

See page 3 for a full list of recommendations for this property.

To find out more about the recommended measures and other actions you could take today to save money, visit **www.direct.gov.uk/savingenergy** or call **0300 123 1234** (standard national rate). When the Green Deal launches, it may allow you to make your home warmer and cheaper to run at no up-front cost.

17 Any Street, District, Any Town, B5 5XX
13 March 2012 RRN: 0919-9628-8430-2785-5996
Energy Performance Certificate

Summary of this home's energy performance related features

Element	Description	Energy Efficiency
Walls	Cavity wall, as built, partial insulation (assumed)	★★★☆☆
Roof	Pitched, 75 mm loft insulation	★★★☆☆
Floor	Solid, no insulation (assumed)	–
Windows	Partial double glazing	★★☆☆☆
Main heating	Boiler and radiators, mains gas	★★★☆☆
Main heating controls	Programmer, room thermostat and TRVs	★★★★☆
Secondary heating	None	–
Hot water	From main system	★★★☆☆
Lighting	Low energy lighting in 17% of fixed outlets	★★☆☆☆

Current primary energy use per square metre of floor area: 298 kWh/m² per year

The assessment does not take into consideration the physical condition of any element. 'Assumed' means that the insulation could not be inspected and an assumption has been made in the methodology based on age and type of construction.

Low and zero carbon energy sources

Low and zero carbon energy sources are sources of energy that release either very little or no carbon dioxide into the atmosphere when they are used. Installing these sources may help reduce energy bills as well as cutting carbon. There are none provided for this home.

Opportunity to benefit from a Green Deal on this property

When the Green Deal launches, it may enable tenants or owners to improve the property they live in to make it more energy efficient, more comfortable and cheaper to run, without having to pay for the work upfront. To see which measures are recommended for this property, please turn to page 3. You can choose which measures you want and ask for a quote from an authorised Green Deal provider. They will organise installation by an authorised installer. You pay for the improvements over time through your electricity bill, at a level no greater than the estimated savings to energy bills. If you move home, the Green Deal charge stays with the property and the repayments pass to the new bill payer.

For householders in receipt of income-related benefits, additional help may be available.

To find out more, visit **www.direct.gov.uk/savingenergy** or call **0300 123 1234**.

Figure 3-1 EPC Certificate Sample

As is shown in the sample EPC certificate in Figure 3-1 EPC Certificate Sample (see Appendix 4 for the full certificate), alongside an energy efficiency rating, various other pieces of information about the property are recorded such as its type, size (floor area), address, built fabric, glazing, main heating type, lighting used etc. – in all, some 90+ directly measured and derived (such as CO2 emissions or Heating Cost) variables per property. These are all available for each property in the database.

The first round of data processing was carried out on version 10 of the EPC dataset, which consists of over 22 million rows and over 92 columns, with some properties having multiple entries (e.g. after a sale, upgrade or other transaction). Following an iterative process of variable vetting, harmonisation and geolocation, we produced a cross-sectional present-day sample of EPCs. We estimate this cross-sectional sample to cover over half the building stock in England and Wales, comprising over 17M unique addresses. All entries are identifiable at the building level, with most having a UPRN (~ 97% for the time being). Address matching was done using the OS AddressBase+ database (epoch 90).

3.1.1 EPC Creation

3.1.1.1 Standard Energy Procedure (SAP)

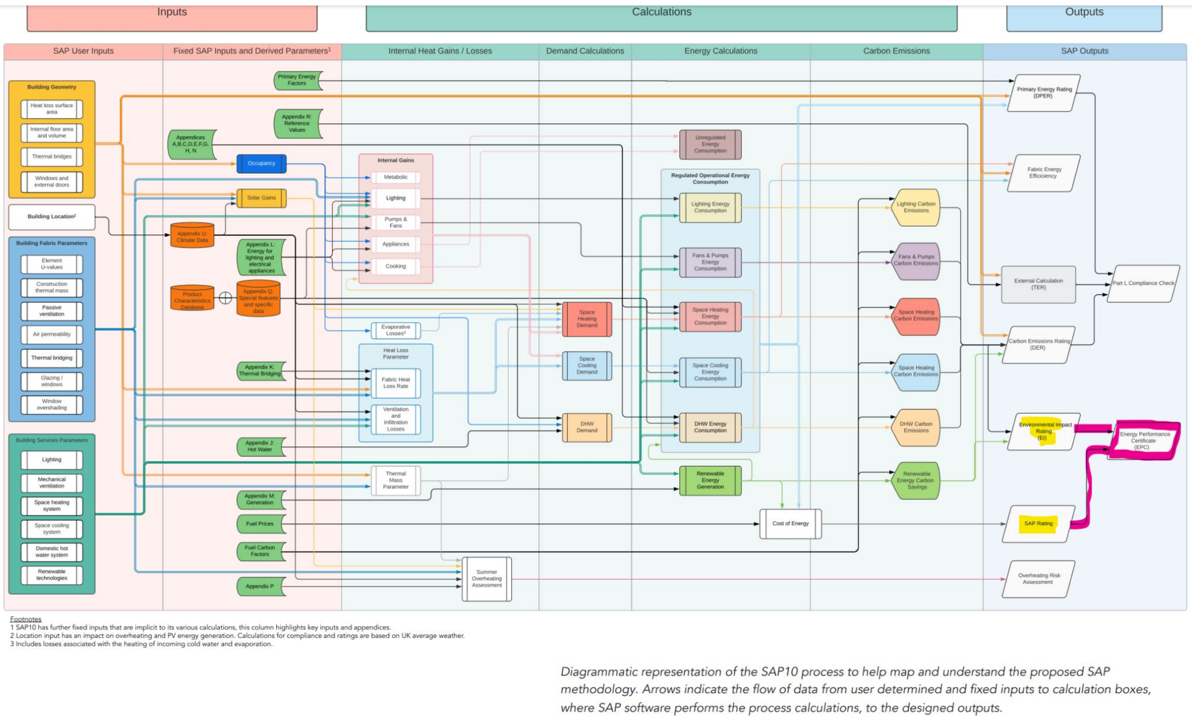


Figure 3-2 The Standard Assessment Procedure

EPCs are generated using manual inputs into 'black-box' software programs that implement the latest versions Standard Assessment Procedure (SAP), which is a UK government approved methodology of measuring energy performance for building regulation compliance. A full account of the methodology is given by Watson (Watson 2010) and see diagram above (Figure 3-2). There are two versions of the procedure, the full SAP for new dwelling including those that are produced through change of use; and reduced data SAP (RdSAP) for existing ones. RdSAP allows assumptions about the building based on when it was constructed ("Standard Assessment Procedure," n.d.). For example, the newer the building, the higher the Distribution Loss Factor (BRE, 2021, tbl. 12c).

The most recent SAP specification is V10.2 published 15 December 2021 by the Building Research Establishment (BRE) SAP V10 is also known as SAP 2012. Different versions of the calculation methodologies do not translate into large differences in the distribution of ECP energy efficiency ratings over time (Crawley et al., 2019, fig. 1). Energy Efficiency is a measure of energy cost given the floor area (Bown and et al, n.d., pp. 101–102; BRE, 2021, p. 36). The fuel prices and emission factors per type are listed in the full documentation (BRE, 2021, p. 182).

3.1.1.2 Measurement Error

Domestic energy assessors (DEAs), who can be trained in only 1-5 days without any prior experience (Elmhurst Energy, 2022), collect measurement data for entry into a SAP calculation. The calculation is particularly sensitive to how the building envelope is defined, as a proxy for where surfaces lose thermal energy to the outside environment. This means that for domestic EPCs, the judgement calls on the type of building form ('Semi-Detached', 'End-Terrace', 'Enclosed End-Terrace' etc.) could yield very different EPC letter ratings.

The Department of Energy and Climate Change (DECC, as of 2016 part of Dept. Business, Innovation and Skills) uniquely conducted a mystery shopper review of 29 Green Deal candidate properties across England and Wales (DECC, 2014, fig. 2.2). They found that across five EPC assessments on the same property, close to two thirds of properties were given letter ratings in different bands (DECC, 2014, fig. 4.2). Lacking a representative sample, these large variations are tentatively explained by building complexity, proxied by the building age band and form type: the oldest homes ('Construction Age Band' = 'before 1900') and those than are ambiguously contingent to neighbouring heated walls (derived on from assumptions on 'Built Form' combined with 'Property Type') show the highest difference in estimated energy efficiency results (DECC, 2014, p. 40).

3.1.1.3 The Environmental Impact Rating

Within the Energy Performance Certificate, alongside the energy efficiency rating more commonly recognised with the green to red scale a separate Environmental Impact Rating measures the dwellings' performance as CO^2 emissions and it is similar to the Dwellings Emission Rate (HM Gov, n.d., p. 83). CO^2 emissions are calculated as energy used – for heating, ventilation and lighting considering the space of the dwelling – minus any energy from generation technologies (BRE, 2021, p. 36). Unlike DER, EI will not be used for compliance with Building Regulations as of 2025.

3.2 EPC DATA VERSION 10

In this report we use the latest version (10) of DLUHC's domestic EPC database with over 22.2 million rows (Table 3-1) – each notionally representing a unique property, although duplicates exist. In all versions of the database, properties could be identified by address and postcode, although in the most recent iterations of the database, Unique Property Reference Numbers or UPRNs have been added by DLUHC A summary of the content of this version of the data is shown below and in Table 3-3.

Domestic EPCs V10 up to 31 March 2022		
Date downloaded	03/05/22	
File size (zipped/unzipped)	4GB/32GB	
Total number of row entries	22.2 million (22 243 396)	
UPRN assigned	Address matched	85% (18M 835 173)
	Energy Assessor	7% (1M716 164)
Missing	Originally	After augmentation
	8%	<3%

Table 3-1 EPC Version 10 Overview

3.2.1 Duplicates and Augmentation

Duplicates can occur when there are mistakes in entering the EPC certificate, as entries can only be added to the database, but not removed. Given the size of the dataset, identifying repeat entries required a rule-based system.

The Unique Property Reference Number (UPRN) is a data product maintained by the Ordnance Survey to uniquely identify objects in specific locations, including domestic properties (Geoplace n.d.). UPRNs serve the same purpose as text-based addresses – but are simpler to describe as points, less prone to error or repetition (e.g. 10 Market Street) and therefore less ambiguous. Some properties appear more than once in the EPC dataset, and any of these records can miss or include an UPRN. Thus, identifying duplicated (non-unique entries) was an important step in increasing UPRN coverage.

	Clashing Scenario	Resolution
	The same address string appears with more than one UPRN reference.	The most recently lodged UPRN is given priority.
	Different (non-empty) UPRNs are identified by DLUCH and the V9 look-up table.	DLUHC UPRNs are given priority.

Table 3-2 Rules Identifying Repeat Entries

Non-unique were identified based on three variables: 1) a complete match of all known address lines as a concatenated string 2) DLUCH's listed UPRNs that came directly with some EPCs and 3) UPRNs included through a dictionary comprising of a look-up-table generated based on address matching on the version 9 dataset provided by the team from Glasgow and all repeat addresses which had an assigned UPRN as some point within in version 10. Combining the repeat EPCs of properties in version 10 and look-up tables based on version 9, we achieved a UPRN linkage of approximately 97%.

Data analysis is considered in two streams: 1) longitudinally, where a property is observed more than once and 2) cross-sectionally which includes all properties seen once and the last record of those properties that are repeated.

	EPC Observations	Non-unique Entries (either UPRN or Address)	
	22 243 396	24 % (5 259 115)	
Cross Sectional Total:	**16 984 281**		
	Point-level	Missing UPRNs	Valid Postcode
Region			
North East	787 702	2%	803 219
North West	2 085 717	2%	2 135 080
Yorkshire and the Humber	1 522 916	2%	1 561 443
East Midlands	1 329 036	2%	1 359 149
West Midlands	1 541 273	2%	1 579 453
East	1 703 941	2%	1 743 282
London	2 337 232	8%	2 534 565
South East	2 482 344	3%	2 561 821
South West	1 606 197	5%	1 683 241
Wales	843 950	3%	874 141
Total:	16 240 308		16 835 394

Table 3-3 Cross Sectional Summary

The EPC dataset is organised into folders by local authorities (LAs), including one batch containing EPCs with an unassigned LA – there are 334 such csv chunks. These are unyielding for processing on a 32-bit machine, but the nested structure of the data means that operations can be carried out by the local authority chucks or by regions. Due to random access memory constraints, duplicate entries were first weeded out by aggregating local authority into regions. However, sometimes the same address would be listed in a different local authority and regions at two points in time. Examples are listed in Appendix – Changing LAs.

3.2.2 Geolocation

The addition UPRNs to EPCs in 2021 has opened up new possibilities for the use of the data – in particular facilitating more straightforward spatial analyses and aggregation. Table 3-3 shows that most entries in the EPC database have a UPRN. While the UPRN is open, its location is not. However, a precise geolocation of most UPRNs is possible through direct linkage the OS AddressBase+ database (epoch 90) which has detailed British National Grid Eastings and Northings for each UPRN. As Table 3-4 shows, it is not possible to geolocate every single UPRN – around 3% could not be found in AddressBase. This is likely either to be down to error with manual entry by EPC surveyors, or, a lag in the updating of AddressBase data where local authorities allocate UPRNs to new properties developed and it can take time for updates to propagate through the system.

Entries With An UPRN		
With UPRNs	100 % (21 536 867)	
Invalid UPRNs	Some UPRN given, but no found in AddressBase	3% (23 k)
Valid UPRNs	Geolocated through AddressBase (i.e. include with Lat/Long)	97% (21 M 5)
Total EPC Records Located At Point-Level	97% (Valid UPRNS / All Entries)	

Table 3-4 Total EPCs Geolocated with Valid UPRNs

UPRNs provide a unique identifier for each addressable location in the country, potentially enabling local authority managers to check whether a property has an EPC and can facilitate machine-readable data exchange (e.g. from usage meters in the future). Going forward, the combination of the two could encourage owners and landlords to make properties more energy-efficient, support the development and application of green home standards, improve the safety of housing, and save time and money for residents. Linkage of area attributes via URPNs also allows for contextual data on the neighbourhood or locality to be included for each property at the lowest geographical. (see Chi, Livingston et al. for a recent overview of the success or otherwise of this address matching process). Where UPRNs were unavailable postcodes were matched to OAs using the ONS postcode directory. Some postcodes could not be matched programmatically.

3.3 Building Attribute Variables

Each EPC is issued for a specific property, taking into account an approximate measure of the floor area to produce two main measures: the environmental impact (an estimate of C02 emissions) and the energy efficiency (an estimate of running cost). Alongside these two main metrics some 90 other attributes – directly recorded and derived – are recorded in the database.

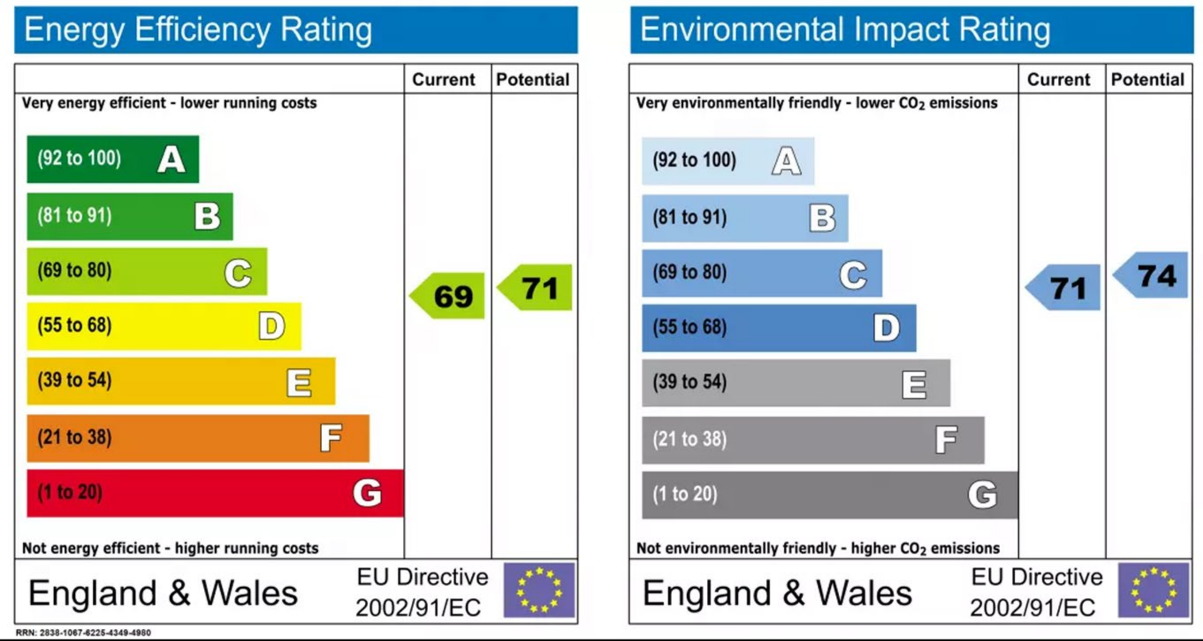


Figure 3-3 Energy Efficiency vs Environnemental Impact

3.3.1 Energy Efficiency

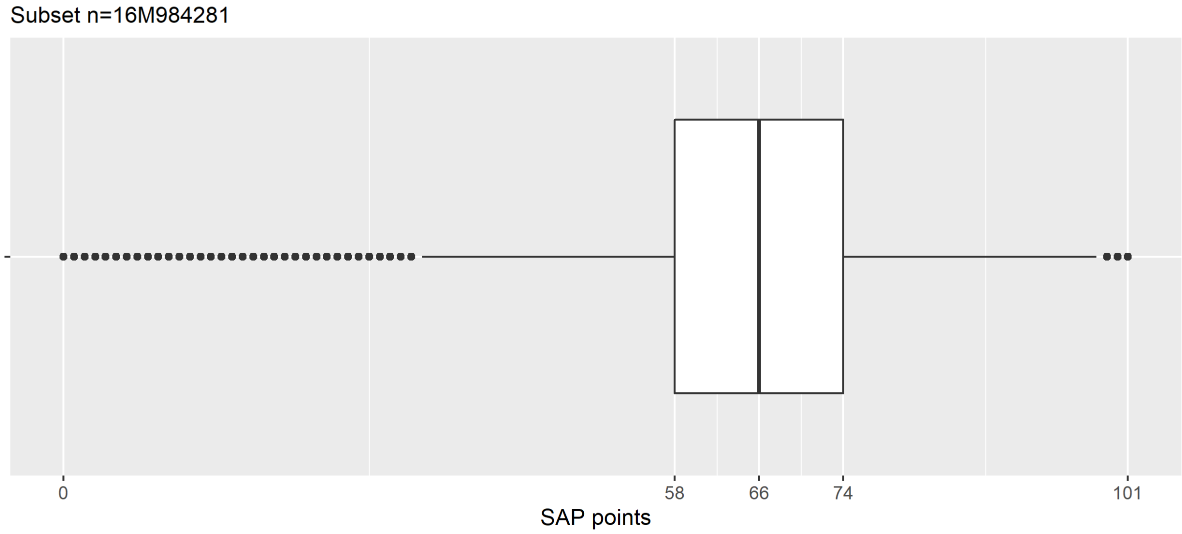


Figure 3-4 Distribution of Building Energy Efficiency within the Research Dataset

In the UK, Energy Performance Certificates (EPCs) rate the energy efficiency of a property on a scale from A to G, with A being the most efficient and G being the least efficient. The ratings are based on the energy efficiency of the property's building fabric (walls, roof, floors, windows, etc.) and its heating, ventilation, and lighting systems. A rating of 1 on the EPC scale would indicate that the property has very poor energy efficiency and is likely to have high energy bills. This means that the property is likely to be poorly insulated, have an inefficient heating system, and/or have inefficient lighting and appliances. We observe a small number of extreme EPCs with scores of '1'. These tend to be market-sales properties built pre-1900. As these are few but influential, they are excluded from modelling. A rating of 1 is very rare and is usually only given to the most energy-inefficient properties. Similarly a score of over 100 should not be possible, as the Energy Performance Certificate (EPC) scale ranges from A to G. A property with a rating above A would be considered to be generating energy, rather than consuming it. The mean energy efficiency score across our research dataset is around 66 out of 100 (Figure 3-4) or Band D (Figure 3-3)

3.3.2 Environmental Impact

Energy efficiency and environmental impact are related concepts that are measured on a similar scale, but they differ in what is being measured. Energy efficiency refers energy usage and is not concerned with where that energy is derived from, rather how it is being used or conserved. Environmental impact on the other hand refers to the impact of activities have on the environment as a whole – most notably where that energy is derived from, but also incorporating how efficiently it is used. Better energy efficiency can help reduce environmental impact by reducing the amount of energy needed to run a home. For example, a building that is well-insulated and uses energy-efficient fuel will require less energy to heat and cool, resulting in a lower carbon footprint and reduced environmental impact. However, environmental impact can be caused by a wide range of factors beyond energy consumption, including the amount of pollution cause by a home's main fuel source. The mean energy efficiency score across our research dataset is around 64 out of 100 (Figure 3-5) or, again, Band D (Figure 3-3).

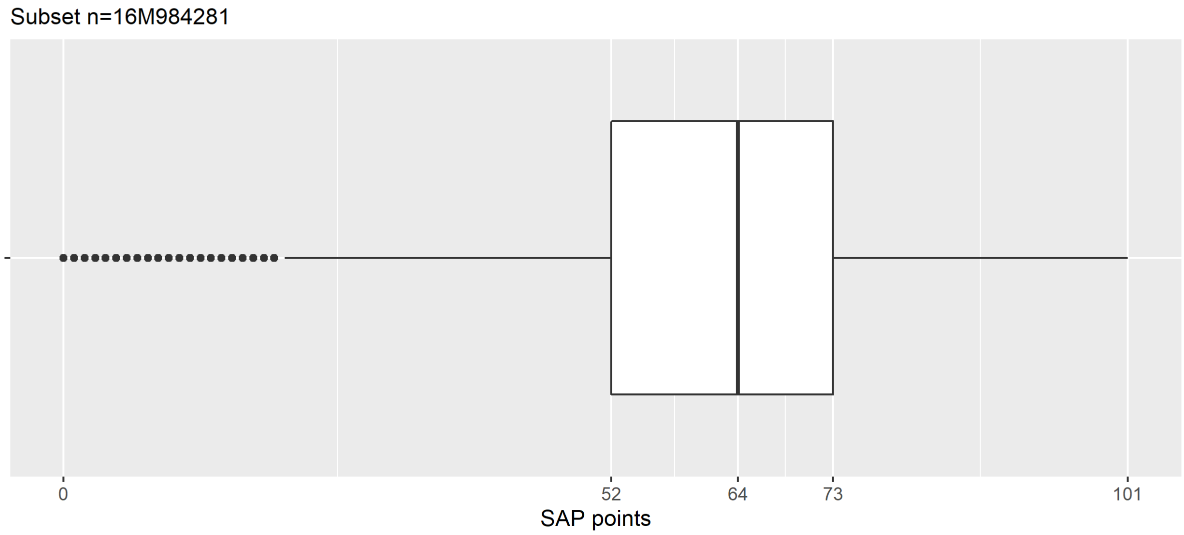


Figure 3-5 Distribution of Building Environmental Impact within the Research Dataset

3.3.3 Floor Area

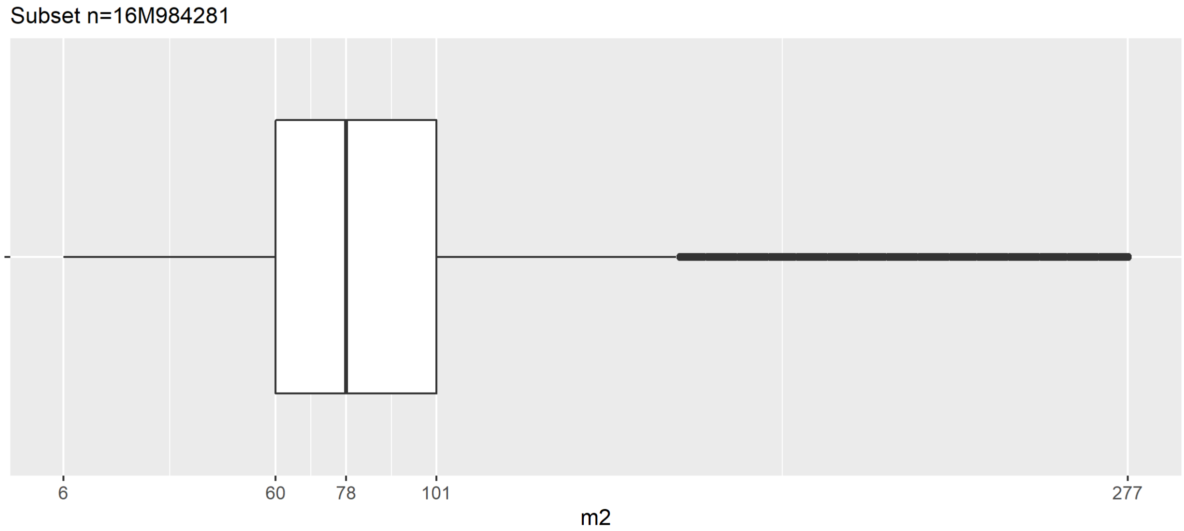


Figure 3-6 Distribution of Floor Area within the Research Dataset

Half of properties captured in the dataset where between 60-101 m^2 (Figure 3-6). The 99th percentile of floor area is 277 m^2 and the minimum bedroom size for adults is above 6 m^2. Larger properties often consume more energy than smaller ones and so there is some relationship between total floor area and energy efficiency / environmental impact, however improved building fabric and heating / cooling systems in modern buildings can mean that this is not always the case with larger modern buildings often more efficient than smaller older buildings.

3.3.4 Property Age

<table>
<tr><th>G1</th><th>G2</th><th>G3</th><th>G4</th><th>G5</th><th>G6</th><th>G7</th><th>Unique Properties</th></tr>
<tr><td>Pre-1900</td><td>Pre 1900s (e.g Victorian)</td><td>Pre-1900</td><td>Pre-1900</td><td>Pre-1900</td><td>Pre-1900</td><td>Pre-1900</td><td>1 624 992</td></tr>
<tr><td>Early Interwar</td><td>Edwardian (1900-29)</td><td>1900-1929</td><td>1900-1929</td><td>1900-1929</td><td>1900-1929</td><td>1900-1929</td><td>2 214 937</td></tr>
<tr><td>Near WW2</td><td>Circa WW2 (1930-49)</td><td>1930-1949</td><td>1930-1949</td><td>1930-1949</td><td>1930-1949</td><td>1930-1949</td><td>2 033 215</td></tr>
<tr><td>Post WW2</td><td>Post WW2 (1950-66)</td><td>1950-1966</td><td>1950-1966</td><td>1950-1966</td><td>1950-1975</td><td>1950-1975</td><td>2 579 217</td></tr>
<tr><td rowspan="3">Mid60s-90s</td><td rowspan="2">Modern (1967-82)</td><td>1967-1975</td><td>1967-1975</td><td>1967-1975</td><td>1950-1975</td><td>1950-1975</td><td>1 806 269</td></tr>
<tr><td>1976-1982</td><td>1976-1982</td><td>1976-1982</td><td>1976-1982</td><td>1976-1995</td><td>925 187</td></tr>
<tr><td rowspan="2">Post Modern (1983-95)</td><td>1983-1990</td><td>1983-1990</td><td>1983-1990</td><td>1983-1995</td><td>1976-1995</td><td>1 021 596</td></tr>
<tr><td rowspan="3">Post 1990</td><td>1991-1995</td><td>1991-1995</td><td>1991-1995</td><td>1983-1995</td><td>1976-1995</td><td>580 285</td></tr>
<tr><td rowspan="2">New (1996-06)</td><td>1996-2002</td><td>1996-2002</td><td>1996-2002</td><td>1996-2002</td><td>1996-2002</td><td>769 534</td></tr>
<tr><td>2003-2006</td><td>2003-2006</td><td>2003-2006</td><td>2003-2006</td><td>2003-2006</td><td>633 309</td></tr>
<tr><td rowspan="4">Post GFC</td><td rowspan="4">From 2007 onwards</td><td>2007-2011</td><td rowspan="4">2007 onwards</td><td rowspan="2">2007-2011</td><td rowspan="2">2007-2011</td><td rowspan="2">2007-2011</td><td>82 155</td></tr>
<tr><td rowspan="2">2007 onwards</td><td>87 280</td></tr>
<tr><td rowspan="2">2012 onwards</td><td rowspan="2">2012 onwards</td><td rowspan="2">2012 onwards</td><td>259 622</td></tr>
<tr><td>2012 onwards</td><td>207 383</td></tr>
<tr><td>unknown</td><td>unknown</td><td>unknown</td><td>unknown</td><td>unknown</td><td>unknown</td><td>unknown</td><td>2 159 300</td></tr>
</table>

Table 3-5 Property Age Groupings

Property age is augmented using the year of inspection of the EPC. Values tagged as '2007 onwards' are replaced with a more specific value ("2007-2011" or "2012 onwards"). Property ages can be organised into periods where recognisable morphologies tended to predominate. For example, pre-1900 was a period where lots of Victorian Terraced Houses were constructed in towns and cities across the country. Post-World War II saw a boom in the construction of the "suburban semi" which most recent construction in cities is dominated by flats. As such, different age bands can be associated with different levels of energy efficiency. Table 3-5 shows some of the variety of ways that age cohorts can be grouped into recognisable periods, with a frequency histogram showing how many properties in each of these periods appear in the research dataset.

3.3.5 Built Form & Property Type

G1	G2	G3	G4	G5	Unique Properties
Detached	House	Detached	Detached House	Detached House	2 395 948
Semi-Detached		Semi-Detached	Semi-Detached House	Semi-Detached House	3 609 526
Enclosed Mid-Terrace		Terrace	Terrace House	Terrace House	35 948
Enclosed End-Terrace					55 330
End-Terrace					1 417 586
Mid-Terrace					2 865 183
Unknown		Unknown	Unknown House	Unknown House	57 854
Detached	Flat	Detached	Detached Flat	Flat	842 920
Semi-Detached		Semi-Detached	Semi-Detached Flat		1 059 755
Enclosed Mid-Terrace		Terrace	Terrace Flat		171 727
Enclosed End-Terrace					197 953
End-Terrace					871 465
Mid-Terrace					1 590 307
Unknown		Unknown	Unknown Flat		328 887
Detached	Bungalow	Detached	Detached Bungalow	Bungalow	768 865
Semi-Detached		Semi-Detached	Semi-Detached Bungalow		499 116
Enclosed Mid-Terrace		Terrace	Terrace Bungalow		988
Enclosed End-Terrace					1 996
End-Terrace					95 560
Mid-Terrace					108 713
Unknown		Unknown	Unknown Bungalow		1 771
Detached	Park home	Detached	Detached Park home	Park home	6 786
Semi-Detached		Semi-Detached	Semi-Detached Park home		2
Mid-Terrace		Terrace	Terrace Park home		95

Table 3-6 Property Type Groupings

Property types can also be grouped into different morphology clusters (Table 3-6). Different morphologies are associated with different energy loss profiles. For example, houses and bungalows have heat loss through ground floors and roofs. By contrast, flats or maisonettes are used interchangeably and when part of multi-floor blocks can mean properties that are less likely to lose heat from above or below thanks to immediately neighbouring properties.

3.4 Contextual Social and Spatial Variables

As outlined in Section 2 of this report, the challenge of improving building energy performance is not simply a building fabric issue as buildings do not exist independently of their owners or inhabitants. Aside from tenure, which is recorded on the EPC certificate, associations with contextual social variables will need to be inferred from more aggregate neighbourhood effects. This, of course, is not perfect as it is easy to make false ecological inferences where neighbourhood or even local authority level characteristics are assumed to apply directly to an individual property, however it is also true to say that houses existing in a less deprived area are *more likely* to be inhabited by less deprived residents or houses in rural or urban areas are more likely to be occupied by residents with political and world views more commonly found in those areas. As with all microdata, what might resemble messy heterogeneity at the most granular level, with appropriate aggregation either to a higher level of geography or grouped by some variable such as tenure or age, can start to display patterns or trends. This section outlines the groupings used in this project, beginning first with the tenure variable contained in the EPC dataset, but then goes on to reference further contextual variables derived from other sources.

3.4.1 Tenure

The three tenures recorded on EPCs are:

- Owner-occupier: People who own the property they live in. They may have paid off their mortgage or may still be making mortgage payments.
- Private rented sector: Properties that are owned by private landlords and rented out to tenants. Rent is paid to the landlord, and tenants do not have the same level of security of tenure as owner-occupiers.
- Social rented sector: Properties that are owned by local authorities or housing associations and rented out to tenants. Rent is usually lower than in the private rented sector, and tenants have greater security of tenure.

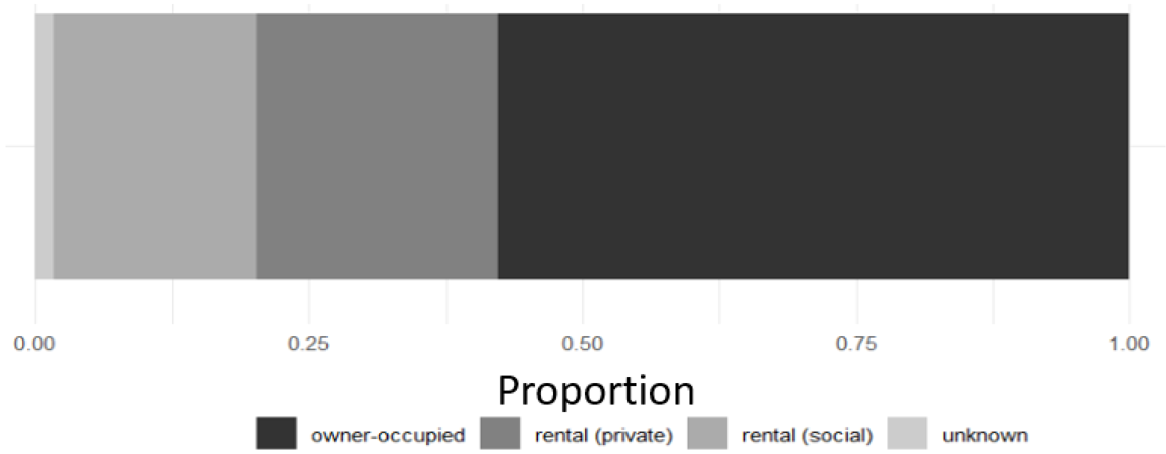


Figure 3-7 Tenure Proportions on Version 10

Figure 3-7 shows the relative distribution of these tenures in Version 10 of the EPC database. There are some stereotypes associated with different types of housing tenure in the UK. For example, owner-occupiers are often seen as being more financially stable and having greater control over their living environment. Private renters are sometimes seen as transient, with less investment in their communities, while social renters are sometimes stigmatized as being dependent on the state. Such stereotypes can be misleading and do little to improve our understanding of the likely quality of housing or its energy efficiency by tenure. For example, while owner-occupiers may be seen as having greater control over their living environment and in some senses 'richer' than those in other tenures, this does not necessarily mean that their homes are of higher quality or more energy-efficient than homes in the private or social rented sectors. Indeed, it can frequently be the opposite where owners have overstretched themselves financially to obtain a mortgage or perhaps purchased their property at a time when they were financially better off than they are today. Similarly, while social housing may be seen as more affordable, this does not necessarily mean that it is of lower quality or less energy-efficient than other types of housing – particularly where social housing landlords such as local authorities have invested heavily in upgrading these properties for the benefits of their tenants. In reality, the quality and energy efficiency of housing can vary greatly within and between different types of housing tenure and the local housing stock.

3.4.2 Urban & Rural Split

The 2011 Census rural-urban classification of output areas (OAs) for England, Wales and Scotland is a geodemographic classification system used to classify small areas into different rural and urban categories based on their population density and proximity to urban centres. The classification system was developed using data from the 2011 Census. The classification system includes six different categories, ranging from the most urban areas (category 1) to the most rural areas (category 6). The four categories that correspond to urban areas are categories 1, 2, 3, and 4. Categories 1 and 2 correspond to urban areas with populations of 10,000 or more, while categories 3 and 4 correspond to urban areas with populations of less than 10,000.

Evidence exists in the literature of urban heat island effects having a notable positive impact on building heating energy expenditure (and a conversely negative effect on cooling related energy expenditure) (Li et al. 2019). In additional, alongside ambient heating and cooling effects, the preponderance of more energy efficient building typologies such as flats and terraced houses in urban areas relative to higher instances of large, detached properties in rural areas means that grouping properties according to their urban or rural locations is likely to be informative in any analysis.

3.4.3 Indices of Deprivation

The English Indices of Deprivation include seven separate indices that measure different aspects of deprivation across England. Each index has a different denominator, which reflects the population group affected by the specific aspect of deprivation that the index measures. These include income deprivation affecting children, older people, and working-age adults, employment deprivation, education and skills deprivation, health deprivation and disability, and crime deprivation:

1. Income Deprivation Affecting Children Index (IDACI) - This index measures the proportion of children aged 0-15 living in income deprived families. The denominator is the total number of children aged 0-15 in each Lower Super Output Area (LSOA).
2. Income Deprivation Affecting Older People Index (IDAOPI) - This index measures the proportion of older people aged 60+ living in income deprived households. The denominator is the total number of older people aged 60+ in each LSOA.
3. Income Deprivation Affecting Working Age Adults Index (IDAWA) - This index measures the proportion of working-age adults (16-64) living in income deprived households. The denominator is the total number of working-age adults (16-64) in each LSOA.
4. Employment Deprivation Index (EDI) - This index measures the proportion of the working-age population (16-64) who are out of work and who want to work, and the availability of jobs in the local area. The denominator is the total number of working-age adults (16-64) in each LSOA.
5. Education, Skills and Training Deprivation Index (EST) - This index measures the level of deprivation related to education, skills and training opportunities. The denominator is the total number of residents aged 16 or over in each LSOA.
6. Health Deprivation and Disability Index (HDDI) - This index measures the level of deprivation related to health and disability. The denominator is the total number of residents of all ages in each LSOA.
7. Crime Deprivation Index (CDI) - This index measures the level of deprivation related to crime and the fear of crime. The denominator is the total number of residents of all ages in each LSOA.

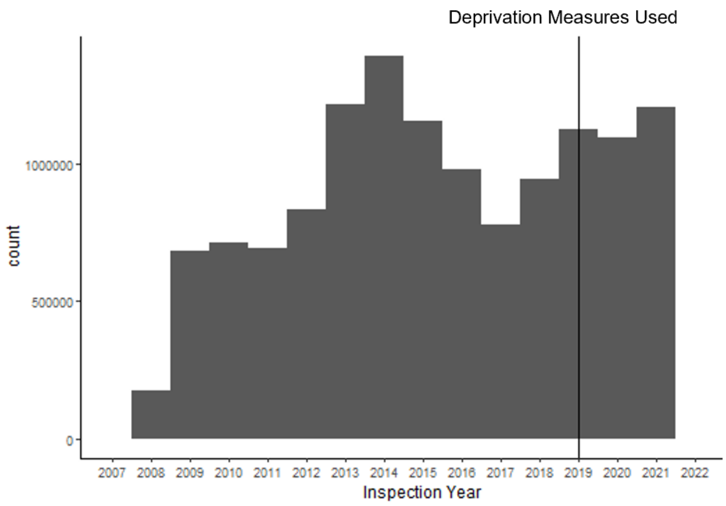


Figure 3-8 Temporal Juxtaposition of Deprivation Measures

The data for the most recent English Indices of Deprivation (2019) were collected between 2016 and 2019. The previous edition of the indices (2015) used data from 2012 to 2015. The collection of data for the indices typically takes several years because it involves gathering information from a wide range of sources, including national surveys, administrative data from government agencies, and local authorities. Once the data have been collected, they are analysed and aggregated at LSOA level to produce the different indices of deprivation. The ONS uses the UPRN Directory to link and integrate data from various sources, including administrative data from government agencies and survey data, to produce small area statistics and indices of deprivation.

Levels of surrounding income deprivation / affluence are of particular interest in this analysis for a number of reasons. Firstly, there are several ways that income deprivation can directly impact housing stock. Persistent levels of neighbourhood deprivation can result in long-term neglect of the housing stock – whether the housing is owned by private or social landlords (Atkinson and Kintrea 2002). This neglect may take many forms but chiefly common housing upgrades such as loft insulation, double glazing or the upgrading of the heating system – which require significant investment even for those with means – may not occur. Conversely, it may be that case that institutional or social landlords are able to prioritise energy efficiency improvements for residents taking advantage of cost savings through bulk improvement programmes in ways that might give those who are most deprived an advantage relative to slightly more affluent neighbours.

The effects of affluence may be similarly counter-intuitive. Clearly those with more disposable income will have more options available to them when it comes to improving the energy efficiency of their home, but it is far from clear whether this will always translate to investment in the building rather than simply turning the heating up higher as it's easier to afford a higher bill. Furthermore, it's likely that large, detached homes with extensive external surface areas are going to be more challenging to make energy efficient than smaller flats or terraced houses surrounded by other properties regulating temperatures in winter and summer.

3.4.4 Geodemographic Area Classifications

The ONS produces a number of Area-level Geodemographic Classifications at different spatial scales. These classifications take Census and other data and cluster spatial units according to their dominant characteristics. At the finest grained geographic scale, the Output Area Classification (OAC) characterises different types of neighbourhoods, dividing the UK into 7 supergroups, 21 groups and 52 subgroups, each with distinct characteristics such as income, education level, employment status, housing type, etc. The last iteration of OAC was released after and based on data within the 2011 Census.

The OAC can be used to think about energy efficiency of homes in different neighbourhoods by enabling clusters of dwellings to be grouped according to similar types of demographic characteristic. For example, areas with a high proportion of owner-occupied homes in affluent and well-educated neighbourhoods (such as OAC groups 1 and 2) may be more likely to have energy-efficient homes due an awareness of the resources and incentives available to homeowners or a greater environmental consciousness, but this may vary across urban and rural areas. In contrast, areas with a high proportion of privately rented housing occupied by recent immigrants in deprived neighbourhoods (such as OAC groups 6 and 7) may have lower levels of energy efficiency due to lack of financial resources, knowledge of initiatives or and ability to invest in their homes.

At higher levels of spatial granularity such as at the local authority level, area classifications can be useful for contextualising overall patterns observed at these levels. While we should be cautious of making erroneous ecological inferences, this can still be a useful exercise where population characteristics can vary quite considerably between

3.5 Data Filtering for Extreme Values

3.5.1 Extreme Value Treatment

Extreme Value Edits					
Conditions:	**<100**		**SAP = 0**		
Current Energy Efficiency	4 247	**0.03%**	6	**0.00%**	Low values are considered invalid, and high values are capped at 101
Environmental Impact	8 865	**0.05%**	7	**0.00%**	
Conditions:	**> 277m2**		**< 6m2**		Extreme values are capped at their nearest threshold.
Floor area	166 633	**0.98%**	18 401	**0.11%**	

Table 3-7 Extreme Value Treatment

Each EPCs is issued for a specific property, taking into account an approx. measure of the floor area to produce two main measures: the environmental impact (an estimate of C02 emissions) and the energy efficiency (an estimate of running cost). Most scores for both measures should fall between 0 and 100, but errors do exist. As is shown in Table 3-7, a small number of properties exist with scores of over 100, or, less commonly, zero. These extreme values are excluded from our analysis.

Other errors exist where variables are either missing or extreme. A common error is where age is unknown as the surveyor is unable to provide an estimate following an assessment visit (Table 3-8). Less commonly built form is unknown, floor area is vast or miniscule or tenure is unknown. Where such errors or omissions occur, we exclude these from our analysis

Dropping Condition	Instances	Sample
	Uncensored:	16 984 281
Unknown Age Band	2 159 300	14 824 981
Unknown Built Form	146 039	14 678 942
Park home' Property Types (too few)	6 880	14 672 062
Floor Area above 379m2 (99% percentile)	50	14 672 012
Floor Area below 10m2 (.01% percentile)	41 132	14 630 880
Unknown Tenure	429 852	14 201 028
Energy Efficiency SAP Scores = 1	22 046	14 178 982
	General Sample:	**14 178 982**
Lacking any English index of deprivation	1 215 468	12 963 514
Energy Efficiency SAP Scores over 100	943	12 962 571
Unassigned Local Authority	4717	12 957 854
	GISRUK Analysis Sample:	**12 957 854**

Table 3-8 Sample Censorship

4 ANALYSIS

4.1 COHORT PROFILE: THE HOUSING STOCK

It goes without saying that the housing stock of England and Wales is hugely diverse, but what does this diversity look like and how does it vary across the various attributes described in the previous section? And, crucially, how does it vary across different local authorities, in different parts of the country? In this section we carry out a baseline-setting descriptive analysis in order that a nuanced profile of the building stock can be understood. We will explore various interactions, for example between property type (e.g. flat, house etc.) and built form (e.g. different types of terrace and detached morphologies) and try to disentangle the relationship between energy efficiency ratings (an estimate of running cost) and environmental impact scores (an estimate of CO2 emissions).

In any analysis, having a sense of 'what matters' is important for comparative purposes. Often what matters is whatever is significantly above or below some sort of expected value. In statistics this might be something like two standard deviations above or below a population mean. Here, rather than adopting a purely statistical approach such as looking at the extremes of a frequency distribution, we adopt a policy perspective and will focus on the band "C" energy efficiency threshold. As we mentioned in the background section of this report, band C is the threshold that all rental properties will be expected to me (bar exemptions) by 2030. Having a clearer understanding of the characteristics of band C properties and their geography, will be important for identifying both where most attention for retrofitting of energy efficiency measures is required but also where, potentially, the supply of private rental properties might be affected if landlords decide to withdraw from the market due to the costs of upgrading their properties.

4.1.1 Morphology, Age and Tenure

Figure 4-1 and Figure 4-2 begin to give a feel for the shape of the England and Wales housing stock as represented in the EPC database. Houses are the dominant morphology with some 4.25 million terraced and 3.3 million semi-detached. Some 1.8 million are detached houses, which is broadly equivalent to the number of attached (terraced) flats. A much smaller number of bungalows and non-standard flat and maisonette morphologies make up the rest of the stock.

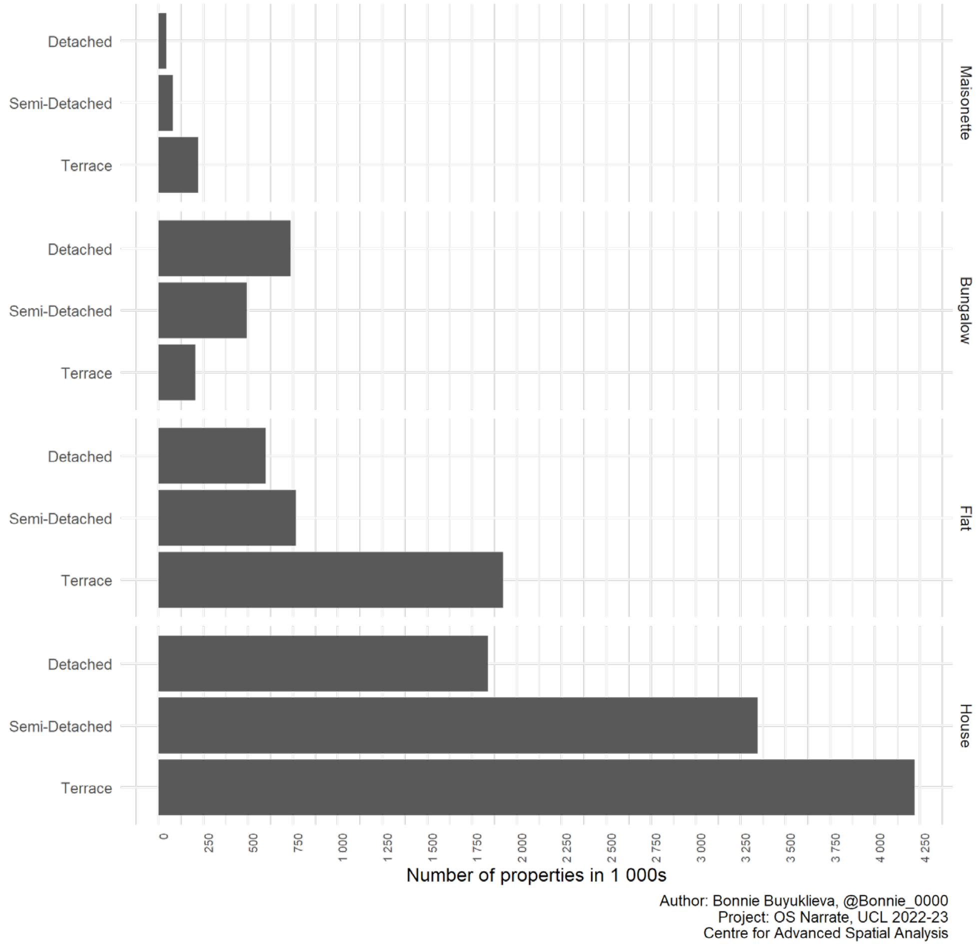


Figure 4-1 Morphology as a combination of Proper Type and Built Form

A final informative slice of the EPC dataset disaggregates by morphology and tenure. Here we can observe that the majority of properties in the dataset are owner-occupied, reflecting the shift towards home ownership precipitated by Margaret Thatcher's 'Right-to-Buy' policy which commenced in the 1980s and which has seen the transfer of social housing into mainly the owner occupation tenure, but increasingly in recent years, into the private rental sector – by some estimates up to around 40% of those homes originally transferred to owner occupation (Murie 2016). Figure 4-2 below shows how some 54% of the properties in the dataset are owner occupied, most of these houses and terraced, with a significant number semi-detached and detached. For socially and privately rented properties, houses are still the most important morphology, although flats play a much more important role than they do in the owner occupation tenure.

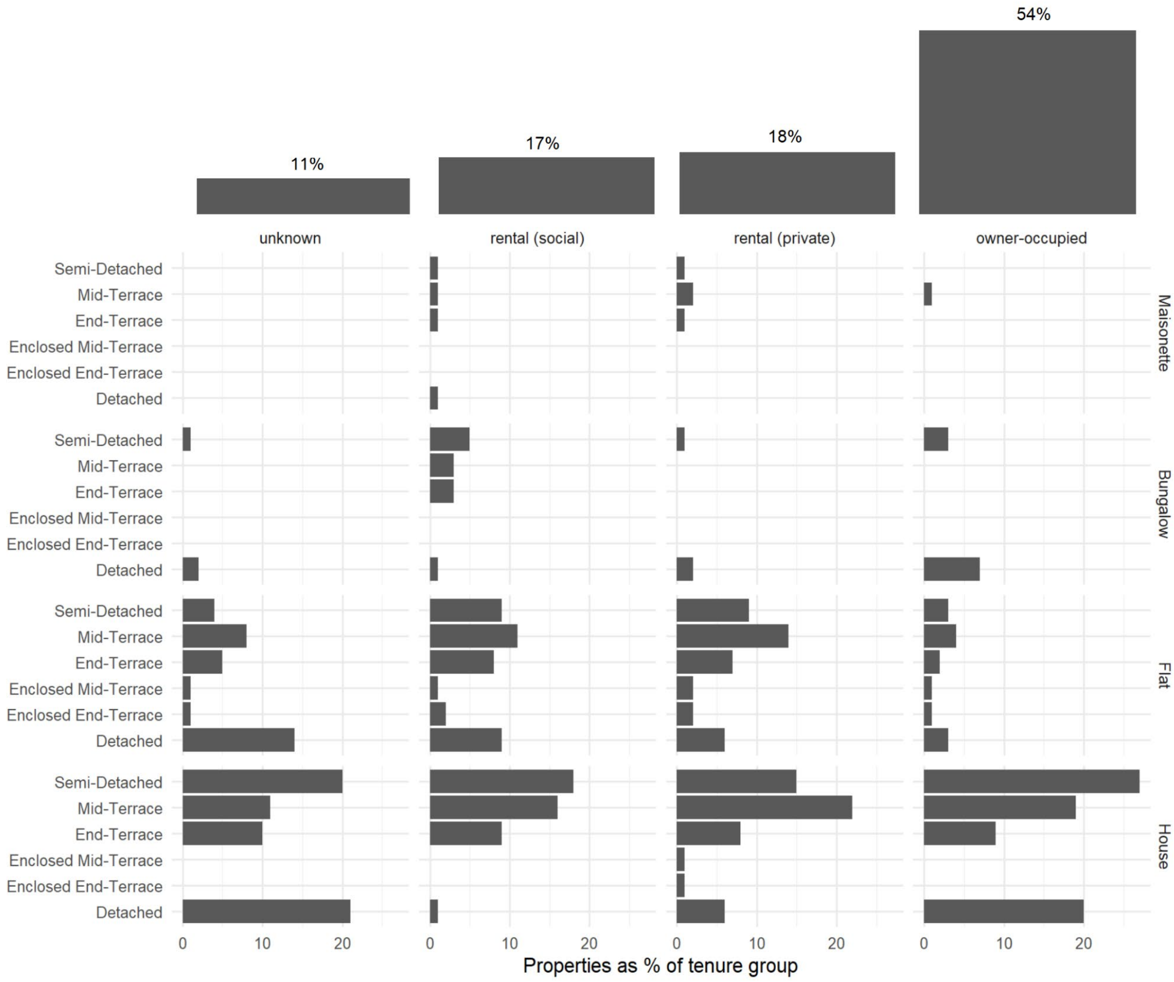


Figure 4-2 Morphology Breakdown

Slicing the stock another way, Figure 4-3 shows when these houses of different morphologies were built. Most terraced houses existing today were built over 100 years ago in the band either prior to 1900 or between 1900 and 1929. Aside from a small post-War uptick in terraced house building propagating through into the stock existing today, the existence in the dataset of this morphology type decreases every year following the 1900 to 1929 peak. Semi-detached housing saw its development peak in the immediately pre- and post- second world war period and this is represented in the numbers of properties represented in the EPC dataset. High numbers of semi-detached properties built in the 1950s and 1960s as the post-war reconstruction continued are still represented in the housing stock. Detached houses are more evenly spread in terms of their age profile, with an indication of a declining trend in building from the 1970s onwards. Similarly, flats of all types (detached, semi-detached and terraced) appear in the EPC dataset relatively consistently across the different age cohorts, again, with a small decline in absolute numbers since the 1970s.

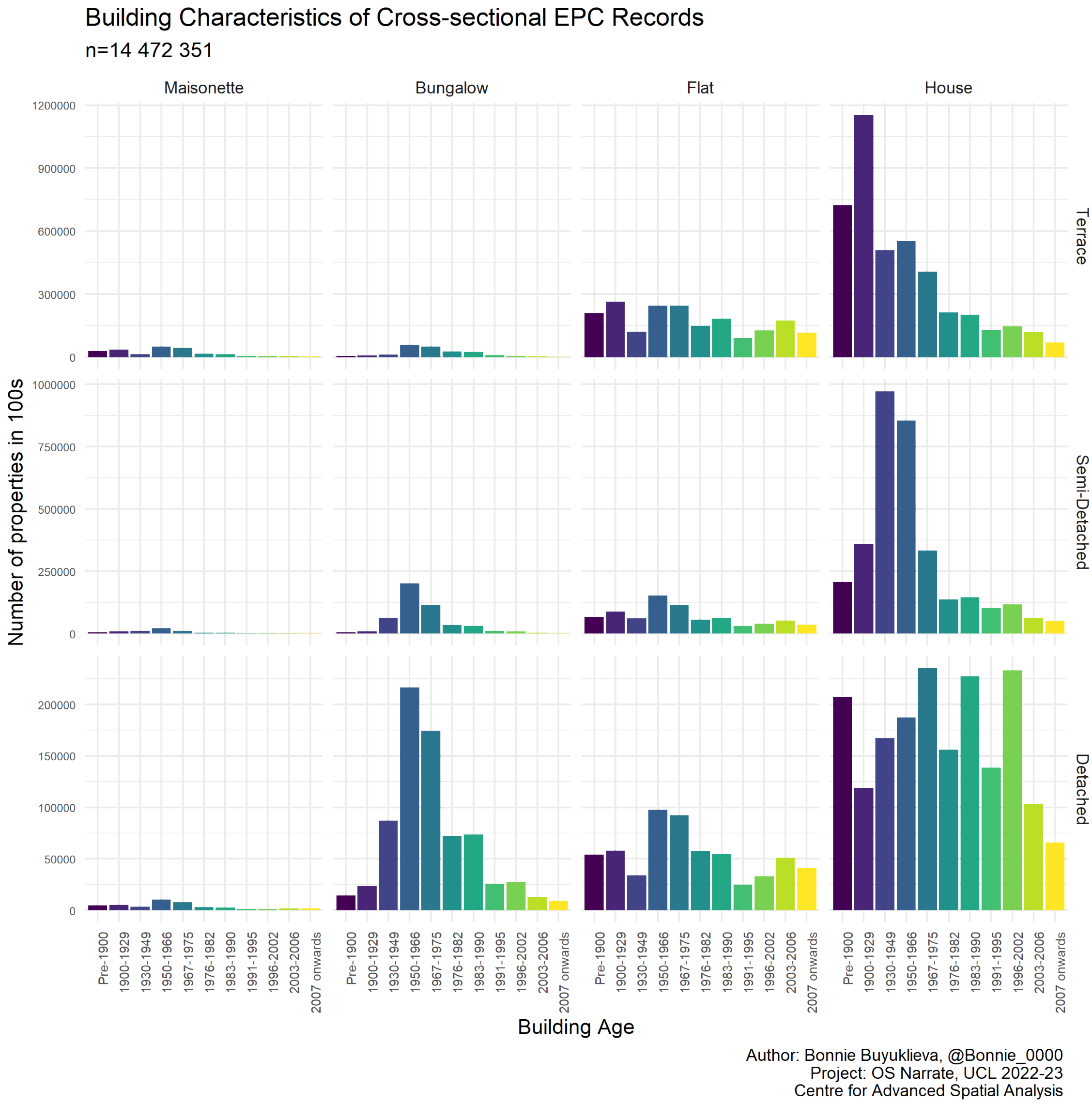


Figure 4-3 Morphology by Age

4.1.2 Property Attributes Relative to Energy Performance.

While Figure 4-1, Figure 4-2 and Figure 4-3 give an indication of the national distribution of housing types relative to morphology, age and tenure, Figure 4-4 shows how these properties are distributed relative to the different energy performance bands and, crucially, band C. Currently, the mean and median EPC rating is in band 'D' with a sharp rise in properties at the bottom of the 'E' grade at 39 points. This spike in the distribution likely reflects the current requirement for rental properties to achieve at least the 'E' letter score. Figure 4-4 demonstrates the scale of the huge challenge of shifting the housing stock to Band C when such a large proportion of dwellings are currently well below this standard.

4.1.2.1 Energy Performance by Morphology, Age and Tenure

Breaking this overall energy performance distribution down by morphology (Figure 4-5) we can see that flats have the best energy efficiency, increasing probability of external walls as we move through, terraced, semi-detached and detached properties, translating to poorer overall performance. That said, flats also display the most variance with a fairly high interquartile range and some particularly poor performing outliers. Semi-detached houses display the least variance in energy performance, but display a mean of somewhere around 65 – below the threshold of 69 which would indicate a performance in band C. Detached houses display the highest variance in performance, which, given the huge variety of types is not surprising. Nor is their position as the worst performing morphology, on average.

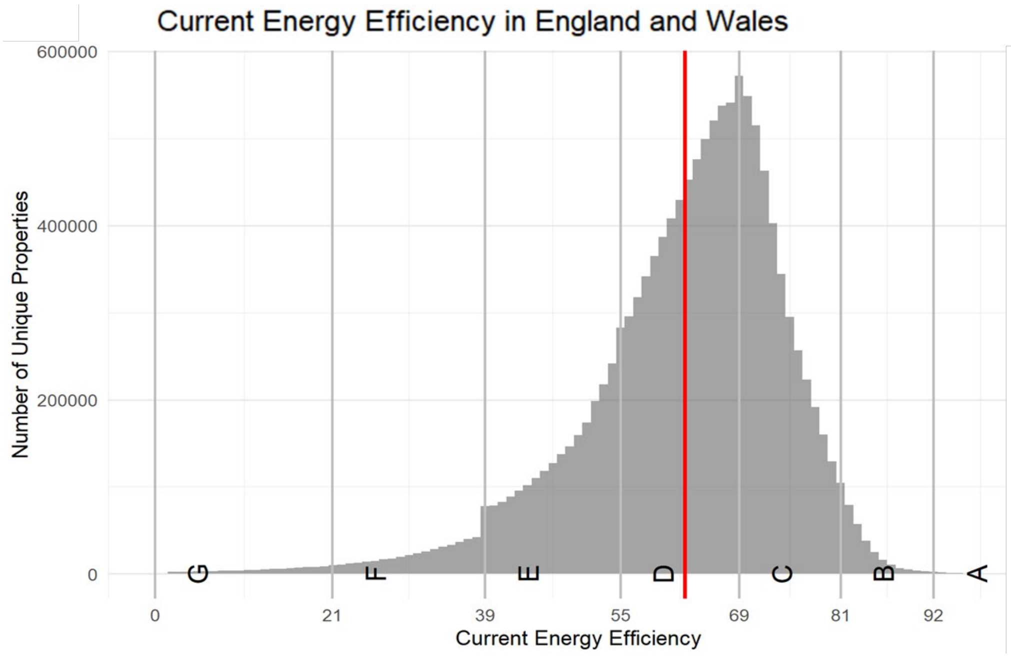


Figure 4-4 Current Energy Efficiency Distribution

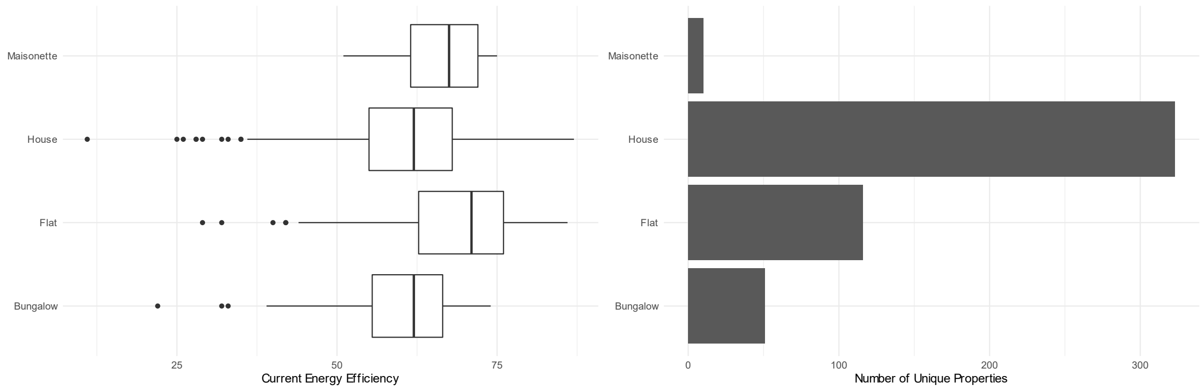


Figure 4-5 Efficiency by Morphology

Taking Age next (Figure 4-6 and Figure 4-7), we can observe the huge influence that when a property was built has on its likely energy performance. There are two main features to note. Firstly, it's clear that the more recently a property has been built, the more likely it is to be more energy efficient. As building regulations have slowly become more stringent over time in relation to the 'u-values' (a measure of energy transfer through materials) associated with key points of heat loss such as through roofs and windows, houses have become less 'leaky'. The mean energy efficiency of properties in the dataset built after 2007 is over 81 – the threshold for band B performance. Most properties built since the year 2000 fall within at least band C, however, the second main feature to note is that the kurtosis (peakiness) of the energy performance distribution reduces prior to the millennium and the variance increases as the age of properties increases. The increase in variance is mainly reflective of the difference levels of upgrade and retrofitting present within the different age cohorts. It is also indicative of the challenge that is presented with the stock that exists in England and Wales as the effort required to upgrade properties built prior to the 1960s (i.e. the majority of the stock in the country) will be immense. Hardly any properties built prior to 1966 are currently found in band B, with a minority proportion in band C.

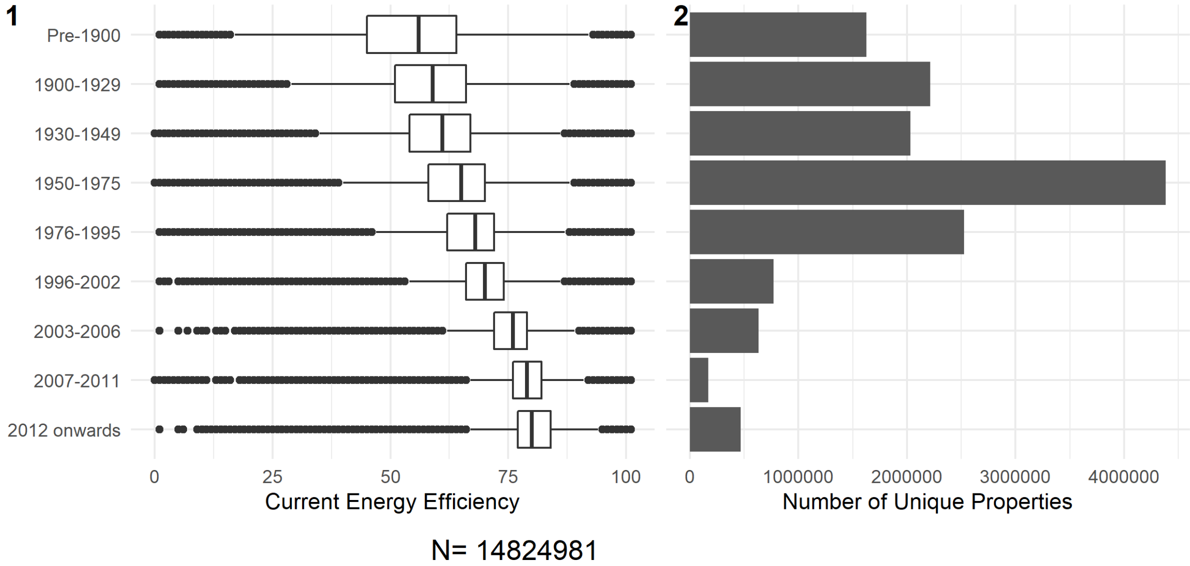


Figure 4-6 Efficiency by Building Age

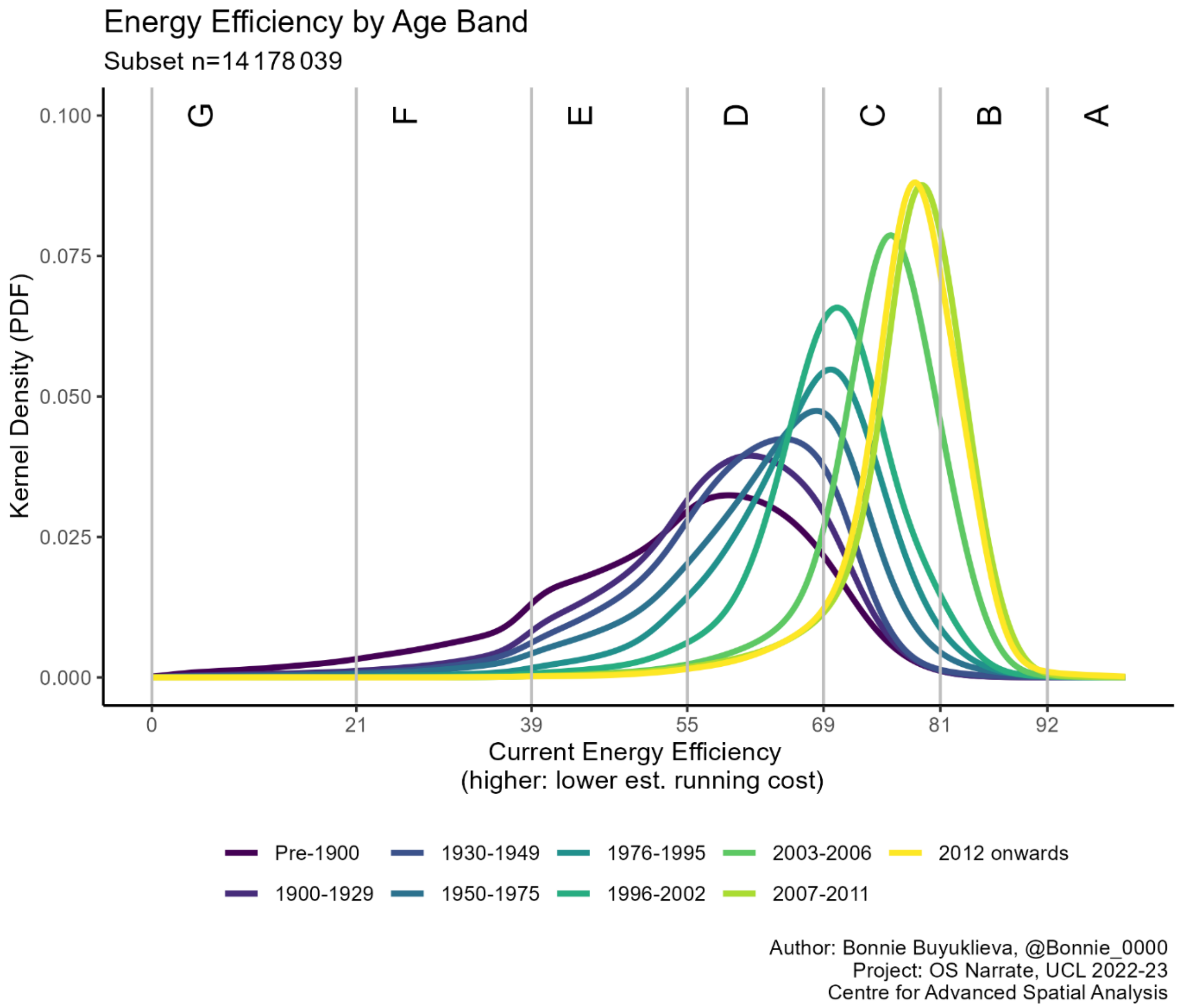


Figure 4-7 Probability Distribution by Age

Finally, we can break energy performance down by Tenure (Figure 4-8). Here we focus just on the band of acceptability – band C. The stark differences between the tenures is clear with over 50% of social housing being rated at least in band C. This compares to only 25% of owner-occupied housing. Housing owned and rented out by private landlords manages to get to around 30% being in band C or above. Of course, the disaggregation by morphology and age is not present in this basic aggregate graph. Figure 4-9 unpacks this a little by cross-tabulating all band C properties by age, tenure and morphology. Here we can see that at least some of the relative poor performance in owner occupied properties is down to the majority of properties for this group being older houses. Social renting, on the other hand, has a higher proportion of newer flats. While private rental properties feature more flats, it's also interesting to note that the private rental stock is, on the whole, proportionally older than both the owner occupied and socially rented stock. As such, private sector landlords – if we assume their main goal is rent-seeking profitability – may be even more disinclined to improve the energy efficiency of their properties where the properties are generally older and therefore much harder (more expensive) to bring up to standard.

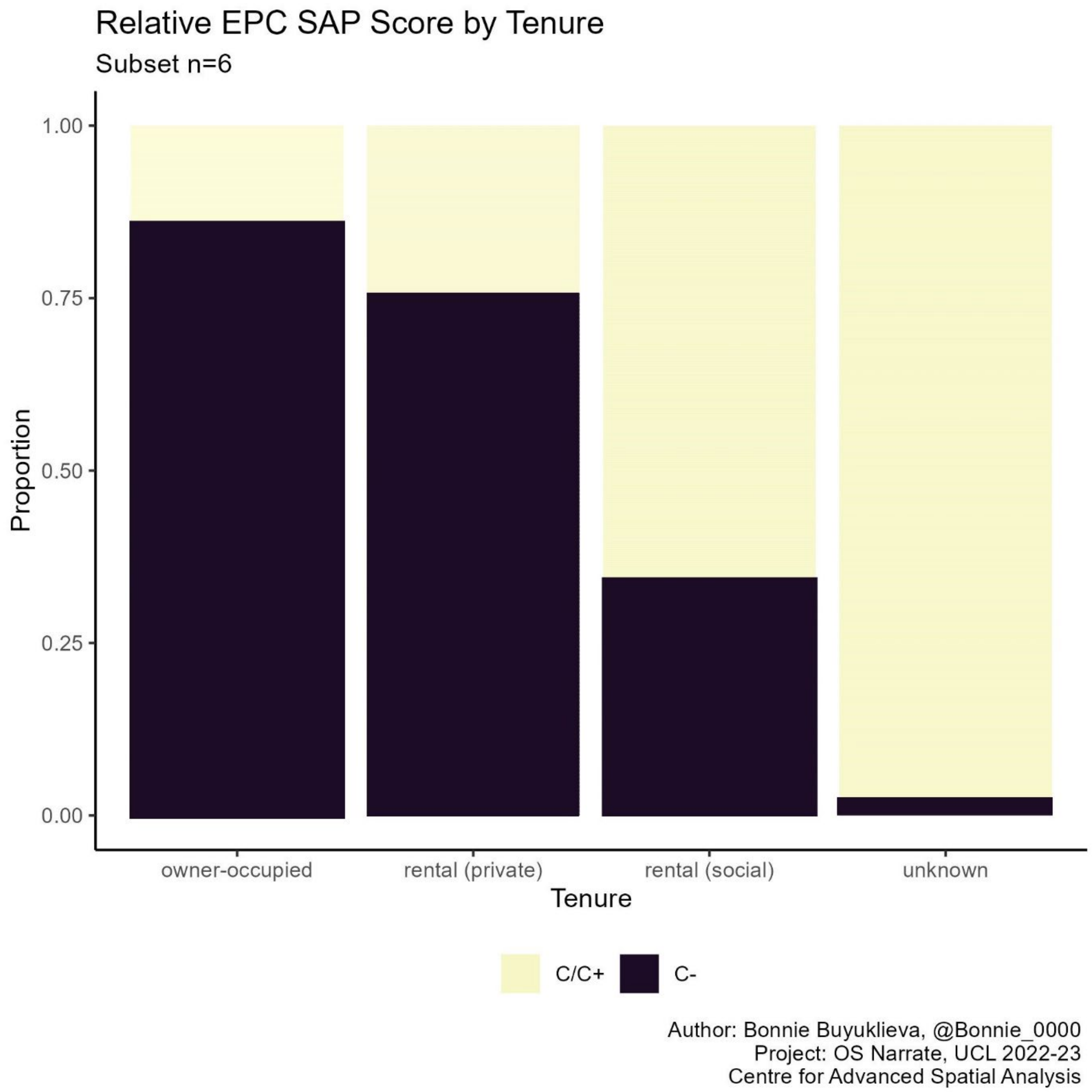


Figure 4-8 Performance by Tenure

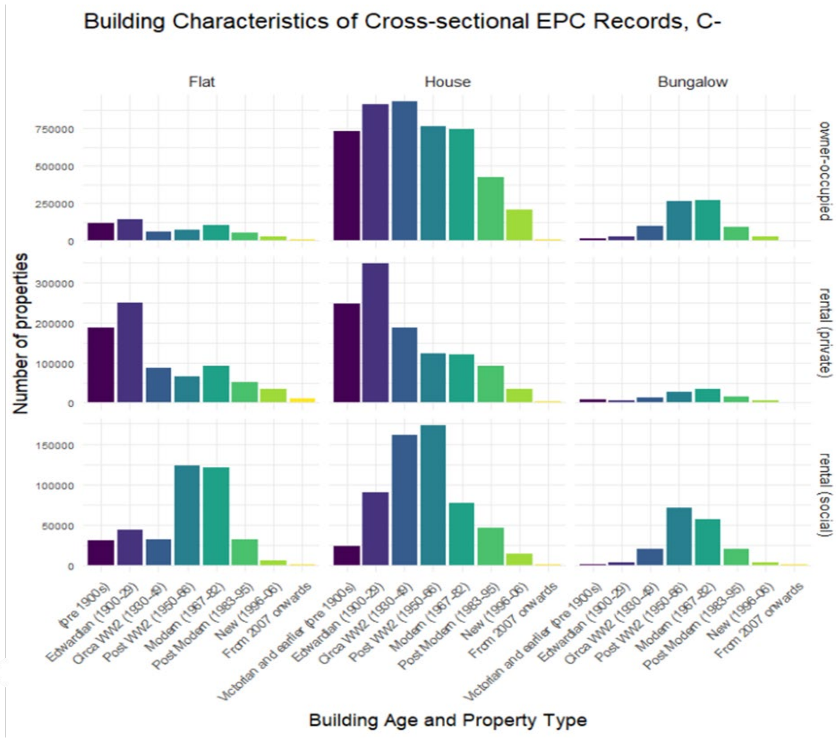


Figure 4-9 Relative performance by morphology and tenure

4.1.3 Efficiency vs Impact

Up to this point, we have focused our attention on the Energy Efficiency dimension of the EPC dataset, but as noted earlier the certificates also include a measure of Environmental Impact. The two, while in some cases are related, are not necessarily always aligned. Figure 4-10 below depicts all properties in the EPC dataset with values and bands for Energy Efficiency along the x-axis and Environmental Impact along the y-axis.

There is some information loss in the figure as represented by the histograms at the top and far right of the plot which show that most properties fall between bands B and E on both measures, the majority of those falling in the blue boxes which occur where the band is the same for either measure. What the plot is useful for conveying, however, is the relative proportions of properties that fall in one band for energy efficiency and another band for environmental impact. Of course, most properties fall within a single band of each other but there are others where bands differ by more than one – for example, the quadrant to the right of the graph where properties enjoy an Energy Efficiency B rating, but and environment impact rating of B. These properties – and others highlighted by red in the graph – might include relatively modern properties which are well insulated with energy efficient lighting but might be fuelled by more polluting fuels such as oil or wood-burning stoves. They might also be larger properties which may be relatively efficient for their size, but which nevertheless may use a lot of fuel and generate more by way of CO^2 emissions.

The green portion of the graph represents properties which score better along the environmental impact axis, but worse for energy efficiency. We note that more properties fall in this green portion of the graph than those in the red. At the extreme, these properties could be characterised by those which are heated by a ground or air source heat pump, but have single glazing or be lacking insulation. Where most houses in the UK are heated by gas boilers and have gas central heating, they might score better in terms of environmental impact than solid fuel. Similarly, houses heated by district heating or electricity could fair better than gas, but all could have varying levels of insulation, lighting efficiency or glazing performance and thus lead to quite different energy efficiency scores relative to their environmental impact. Furthermore, the EPC rating incorporates a cost element which, prior to the recent huge increases in wholesale gas prices, would have meant electrically heated properties would have on the whole, scored worse than those heated by gas (Palmer 2020).

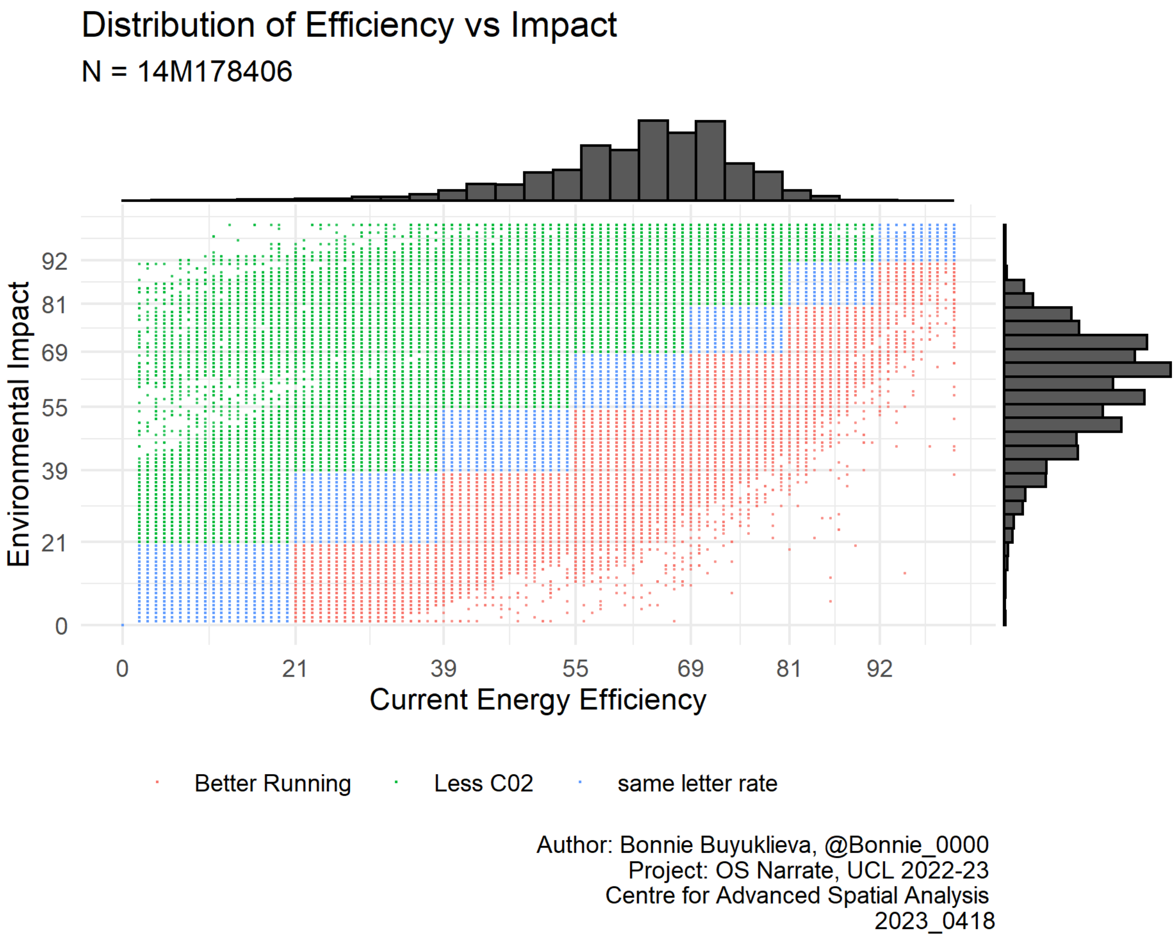


Figure 4-10 Distribution of Efficiency vs Impact

Figure 4-11 and Figure 4-12 below disaggregate this plot by both building age and morphology – both variables revealing how age and morphology influence this, sometimes, asymmetric relationship between energy efficiency and environmental impact. Taking age first, with yellow and light green (most modern) properties clustering mainly around bands C and B along the energy efficiency axis, but spread over A to E along the Environmental Impact Axis, it's clear to see that newer buildings are more likely to exhibit greater variation across their CO2 emissions than their overall energy efficiency. Some of the reason for this will be down to the ways that CO2 emissions and overall energy efficiency are calculated in the SAP methodology. As Palmer (2020, 5) notes "Dwelling Emission Rate and EPC rating includes the offsetting effect of any photovoltaic panels and so you can achieve a very high EPC rating on a dwelling with an average fabric performance by adding a modest amount of PV generation" and as the emission rate for electricity reduces as more renewables are added into the UK generation mix, "the emissions associated with a dwelling which uses gas (e.g. for heating and hot water) will far outweigh the emissions saving from generating electricity". As such, we can see the environmental impact rating varying far more than the energy efficiency rating for newer buildings, which are able to offset poor fabric with the use of more energy efficient fuels.

We can see similar trends across morphology where in Figure 4-12 where newer properties correlate with flats (in light yellow). Interestingly, at the extremes of the inequalities at the lower-right (better energy efficiency, worse environmental impact) and upper left (worse energy efficiency, better environmental impact) we see signals of certain morphologies being more prevalent. In the lower portion of the graph, for example, the are clusters of red and orange, indicating groups of semi-detached houses and bungalows interspersed with some terraced housing and flats (yellow and light blue). These groups near the edge of the cluster – many post-war in their construction age – perform some two bands worse in their environmental impact than they do in their Energy Efficiency. They are likely to be those buildings which have a slightly better performing fabric but are heated with more polluting fuels such as oil or gas central heating or perhaps still have open fires which are used. In contrast, in the upper portion of the graph, we have those dwellings with a better environmental impact but worse energy efficiency – mainly detached and semi-detached houses, often older, but heated electrically, perhaps with storage heaters and economy seven hot water cylinder.

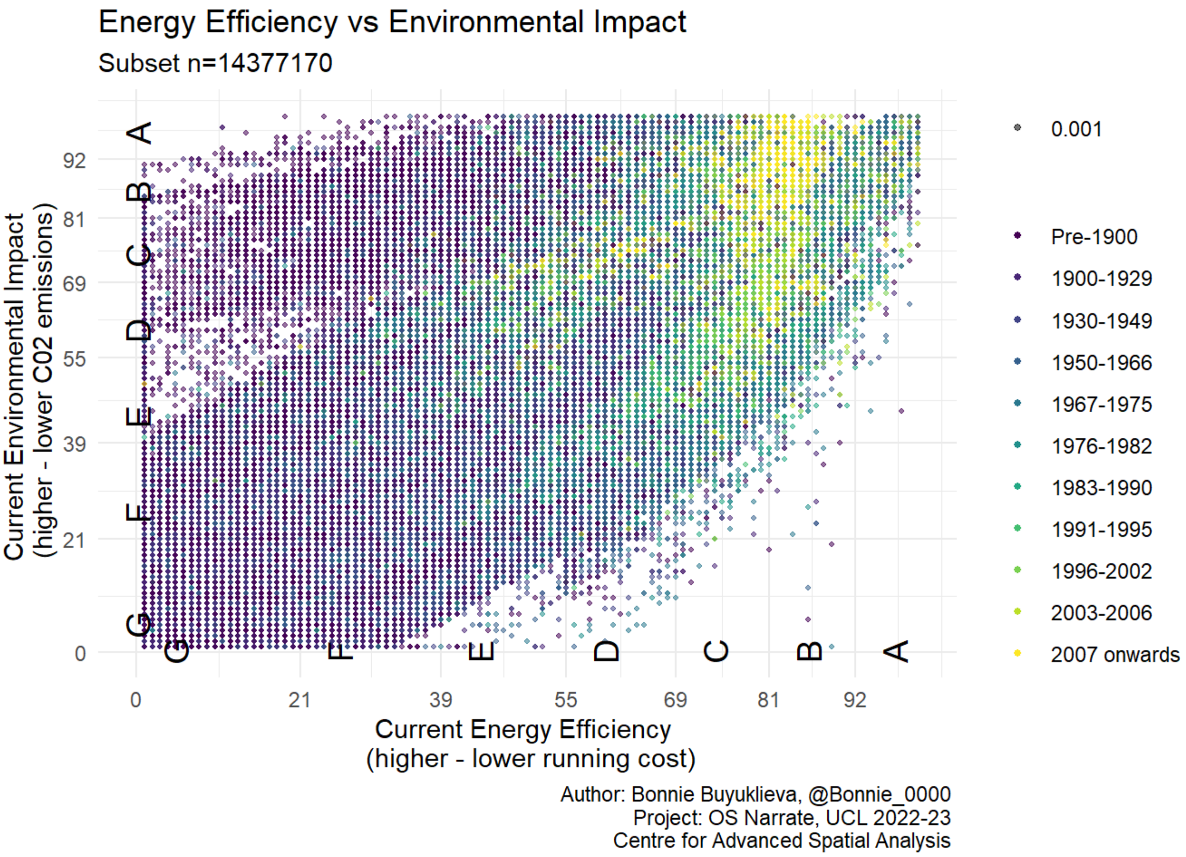


Figure 4-11 Energy Efficiency vs Environmental Impact by Property Age Cohort

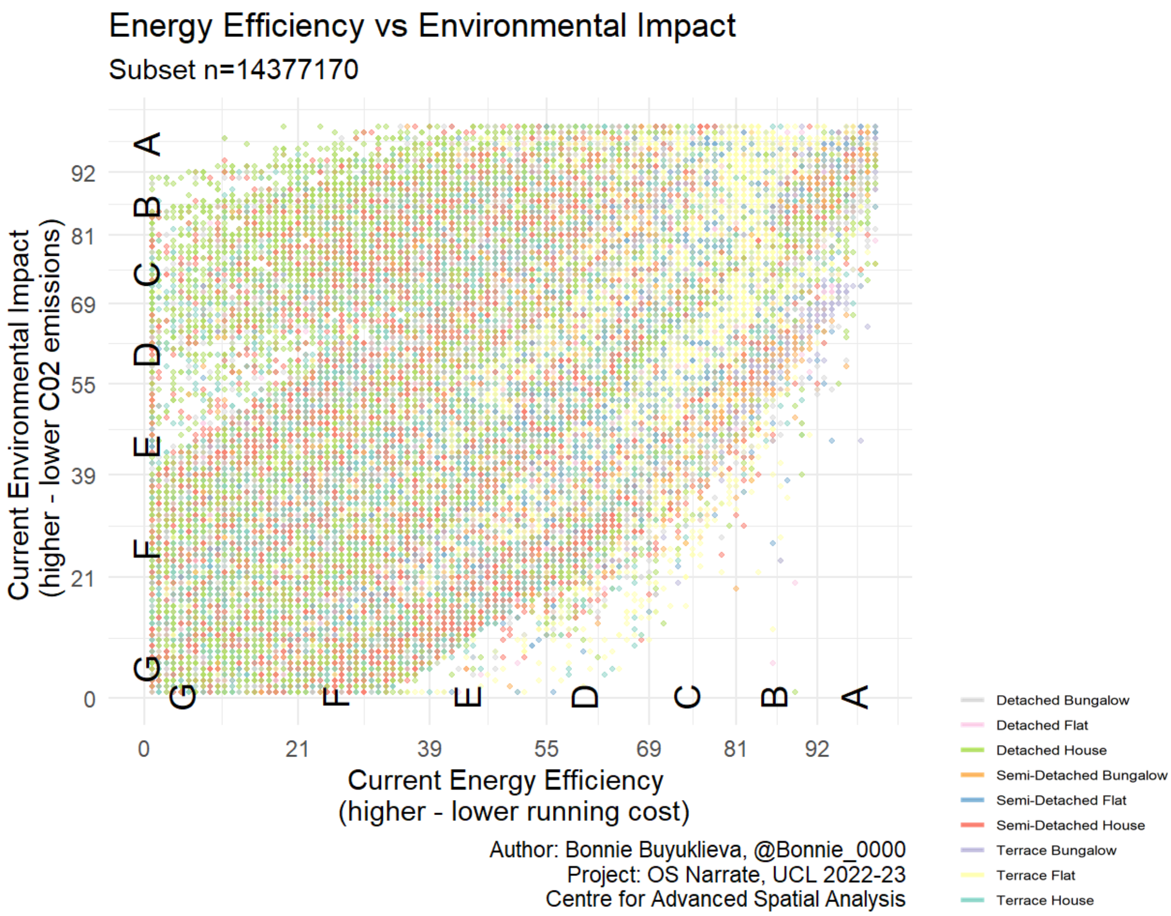


Figure 4-12 Energy Efficiency vs Environmental Impact by Property Type

Disaggregating this efficiency vs impact profile further, other patterns emerge. For example, signals emerge in the data which suggest that for those who are income deprived (Figure 4-13 below), it's unlikely that they will be living in detached or semi-detached housing which have better environmental impact, but worse energy efficiency – they are more commonly found either in slightly better performing (near the upper right of the graph) socially rented accommodation (Figure 4-14), in accommodation which is performing equally as poorly both in terms of impact and efficiency (the diagonal) or in the case of quite a number in accommodation which is performing worse in its environmental than its energy efficiency. It is also the case that properties in urban areas are more likely to have similar energy efficiency and environmental impact ratings than those in rural areas (Figure 4-15) – something likely related to the more consistent availability of mains gas and energy and the wider adoption efficiency retrofitting technologies such as double glazing and insulation.

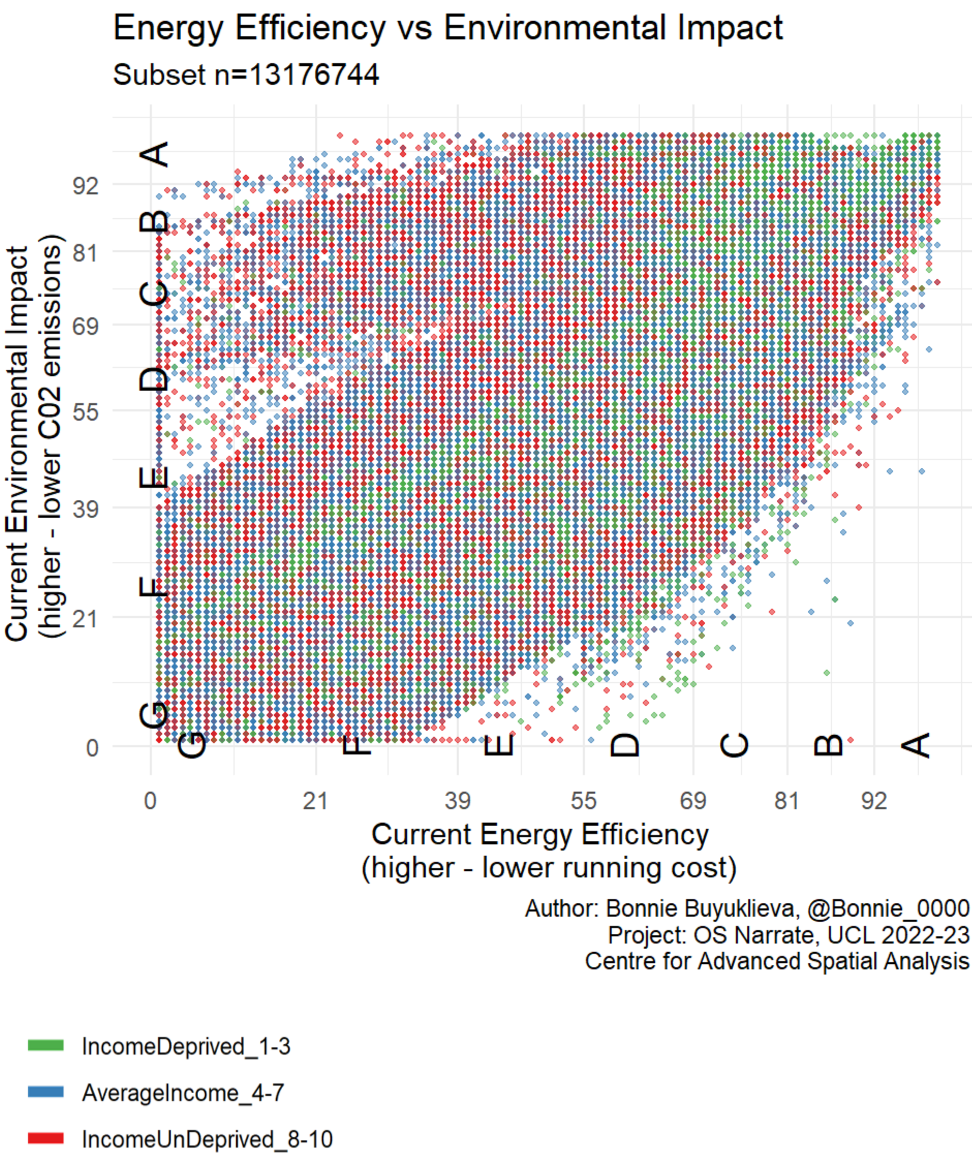


Figure 4-13 Energy Efficiency vs Environmental Impact by Income Deprivation Decile

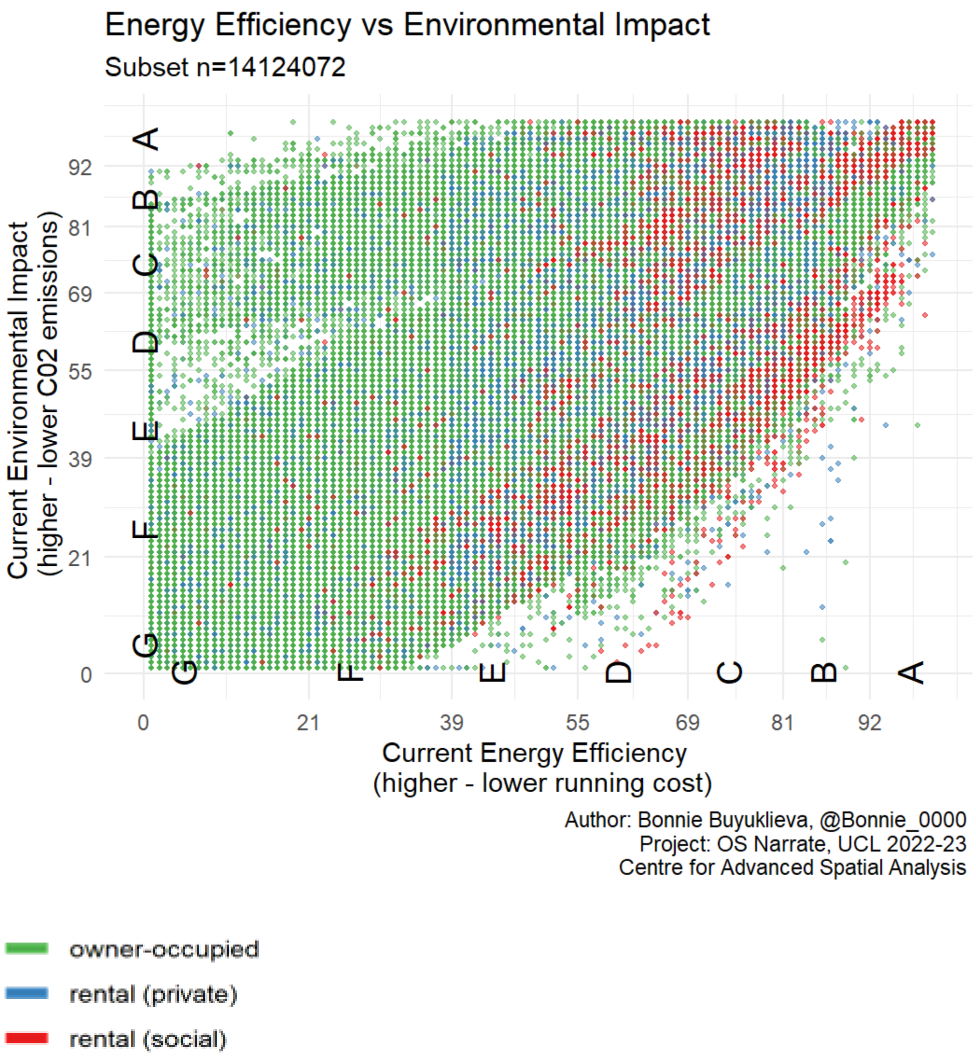


Figure 4-14 Energy Efficiency vs Environmental Impact by Tenure

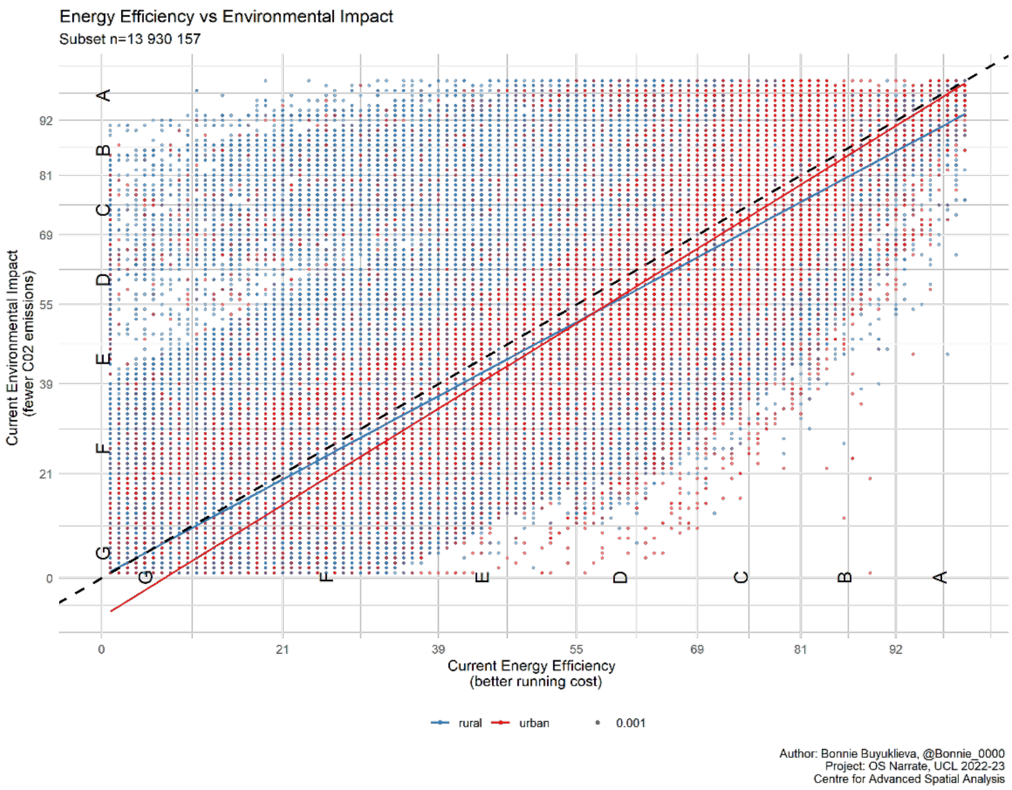


Figure 4-15 Energy Efficiency vs Environmental Impact by Urban / Rural

4.2 GEOGRAPHY OF RESIDENTIAL BUILDING ENERGY PERFORMANCE

4.2.1 Best and Worst Performing LADs

Table 4-1 presents the best and worst performing Local Authority Districts (LADs) in England and Wales. It's notable that 4 of the top 5 are in London with areas in Wales and the South West performing worse. A fuller picture across the entire country is shown in Figure 4-16. Here a clear geography can be observed across LADs with Inner London and areas the South and East of the Country performing best both in terms of Energy Efficiency and Environmental Impact. The Worst performing areas can clearly be seen in Wales, Cornwall, the North Norfolk Coast and in parts of Yorkshire and the North West.

To give some context to these patterns in light of some of the earlier analysis, Figure 4-17 shows the modal morphology type in each Local Authority, while Figure 4-18 shows the average floor area of properties. Clearly, urban areas with smaller flats explain some of the better average energy performance in the south and around parts of Inner London, however, this relationship doesn't hold everywhere. Cities outside of London such as Leeds, while dominated by smaller flats, tend to have on average worse energy performance.

		Local Authority	Median EPC	Total Certificates
	1	Tower Hamlets	76	111636
	2	City of London	73	5473
	3	Hackney	71	82381
	4	Salford	71	95308
Top	5	Southwark	71	100098
	335	Isle of Anglesey	60	21835
	336	Eden	60	16807
	337	Ceredigion	58	22109
	338	Gwynedd	57	34780
Bottom	339	Isles of Scilly	49	691

Table 4-1 Energy Efficiency by LA

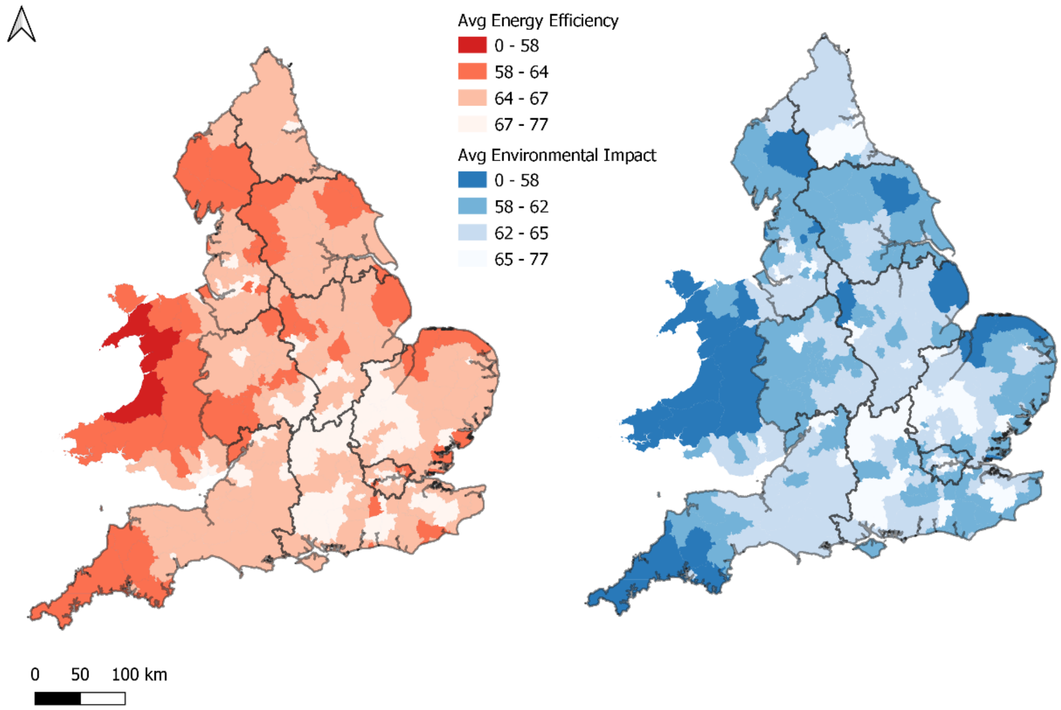


Figure 4-16 Local Authority Level Energy Efficiency and Environmental Impact in England and Wales

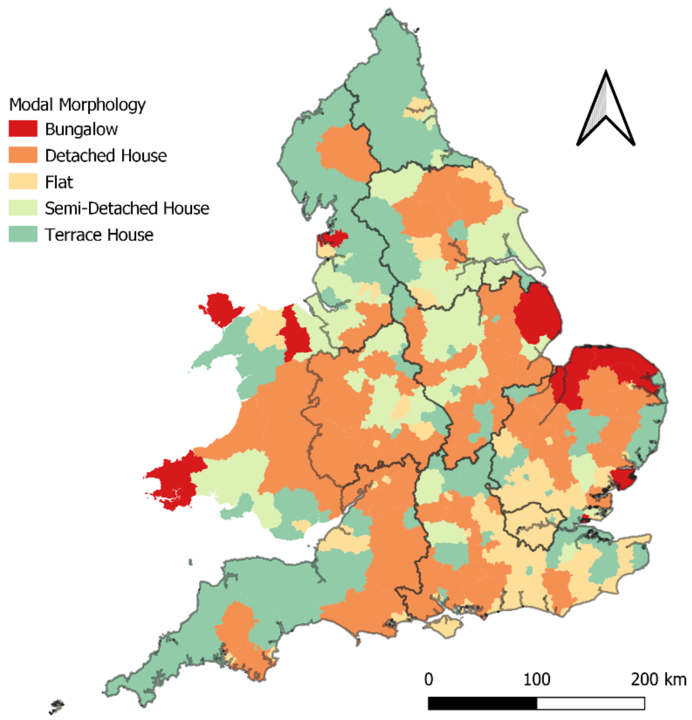


Figure 4-17 Local Authority Level Modal Residential Property Morphology, England and Wales

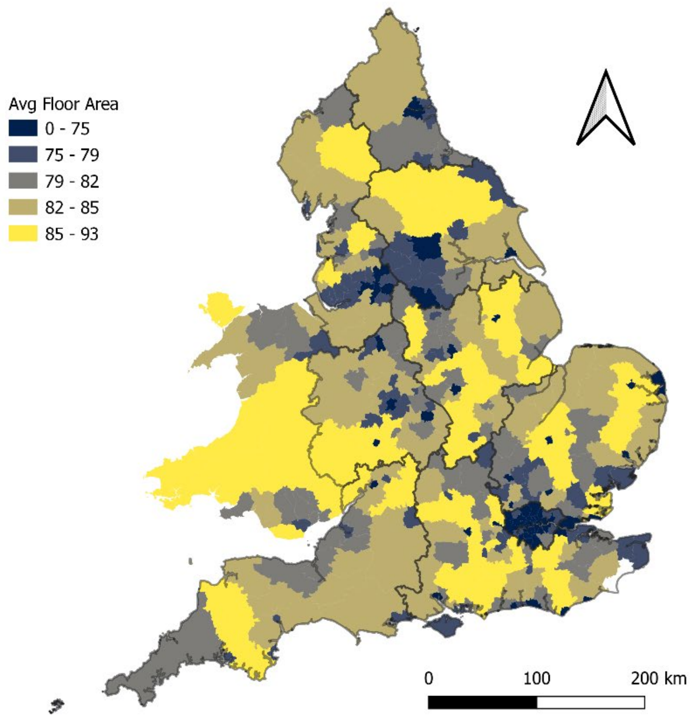


Figure 4-18 Local Authority Level Average Floor Area

4.2.2 Urgent Rental Upgrades

The ecological fallacy warns that patterns observed at the aggregate level should not necessarily be attributed to observations at a finer level of spatial granularity. Within areas that are apparently performing better on average, significant numbers of problem properties can still be found. The government's Net Zero Strategy includes a recommendation for higher minimum standards on homes to meet EPC Band C by 2035. More binding, legislation under Minimum Energy Efficiency Standards will require all rental properties to upgrade from grade E to grade C in the next few years, but in some local authorities, there are large numbers of privately rented dwellings in need of significant upgrade and in places this need can become as high as 1 in 3 properties. These local authorities are highlighted in Figure 4-19 below.

Figure 4-19 Urgent Rental Upgrades, England and Wales

4.3 THE SOCIO-SPATIAL CONTEXT

4.3.1 Explaining and Predicting EPC Scores

The preceding analysis begins to suggest some of the factors that are influencing residential building energy efficiency and environmental impact in different parts of the country with clear geographies emerging for efficiency and the variables which might either influence it directly. These variables such as tenure or social deprivation interact positively or negatively with the pressing need to improve much of the stock in the country – potentially helping or hindering this transition. Turning our attention to Energy Performance and leaving Environmental Impact for the time-being, in order to try and understand more clearly the relative importance of these different factors, we can model the associations which emerge in the data at property level across the entire dataset.

In our baseline model, we examine the energy efficiency of all domestic properties in England in our dataset (at the individual property level) as a function of a series of fixed effect (explanatory variable) characteristics. Wales is left out of this analysis for now as we make use of the English Indices of Deprivation We then further explore the model residuals to measure whether properties in a local authority are either over- or under-performing relative to these baseline features. Our model (1) – where all variables are categorical except for size – is as follows:

$$E.Efficiency = Intercept + \beta_1\ age + \beta_2\ type + \beta_3\ tenure + \beta_4\ log(floor\ area) + \beta_5\ localAuthority + \varepsilon \quad (1)$$

In the second part of this exercise we use the residuals of the base model (effectively variations within each local authority) to ask: how can we explain the prediction error after controlling for the characteristics of the local building stock? This time we examine how property-level alterations and area-level characteristics capture the divergence between expected and actual energy efficiency. To summarise these, we look at the proportion of the variance in residuals which is explained by each factor.

4.3.2 Base Model

Fitting a standard linear model to our dataset, we can explain almost one third of the variance in energy performance by accounting for the age, type, tenure and local authority location. Table 8 documents the model coefficients (estimates), standardised coefficients, related standard errors and p-values. Standardised coefficients allow for meaningful comparison between variables measured on different scales and can reveal which independent variables are having a greater influence on the dependent (energy efficiency) variable. Figure 4-20 maps the coefficient (intercept) values for each local authority dummy variable used in the base model. As dummy variables, these are all values relative to a contrast category – in this case, Tower Hamlets, the best performing local authority in the dataset.

We can see from Table 4-2 that age has the most influence (comparing standardised t-statistic values with other variables), with newer properties exhibiting much better energy performance and those built prior to 1900 having a more influential negative impact on energy performance than any other variable - a reflection in large part of the success of regulation through building standards. More recent buildings perform on average much better, but interestingly, those properties built between 2007-2011 appear to perform better than the more modern baseline classification (2012 onwards) – it is difficult to say why this might be, however it's likely that mix of properties could play a role here, particularly if flats were the dominant building type constructed between 2007 and 2011.

After age, tenure is the next most important variable, with those living in social housing (relative to owner occupation) faring considerably better in energy performance. Privately rented units tend to be more energy efficient than owner occupied dwellings, however, there is the confounding factor that many private rental properties tend to be flats. Dwelling type also is an important factor, with flats (with fewer external faces and hence lower heat loss) performing the best. The most inefficient homes tend to be larger detached houses and bungalows with those with fewer external walls (semi-detached and terraced) performing much better. Overall floor area is also significant with the most efficient homes tend to be smaller, newer and socially rented flats - especially those built after 2006. The worst performing stock is owner-occupied, then private and social rent. This may mirror how these tenures are regulated. Size remains important in these models even though the dependent variable is energy efficiency and incorporates size to some extent (i.e. energy use per square metre). Larger properties have lower energy efficiency even accounting for their size.

The two Maps in Figure 4-21 Local Moran's I for Local Authority Dummy Coefficients highlight the spatial clustering of these values and the significance of this clustering through localised Moran's I statistics. Moran's I essentially measures the correlation between the value in one local authority with those in immediately surrounding (in our case, Queen's Case Neighbouring) local authorities. The maps highlight clusters of local authorities with characteristics which negatively influence energy efficiency and those which positively influence it (relative to the best overall performing local authority). It's clear that clusters of poor performance (with poor performing LADs neighbouring other poor performing LADs) can be found in the far South-West, the Welsh Borders, East Anglia and the North West – all predominantly rural areas. Clusters of Relative good performance are found in North-Central London, around Manchester and Newcastle / Sunderland in the North East.

Base Model:
Construction Age + Dwelling Type + Tenure + log(Floor Area) + Local Authority (LA)

	adj.R2	RSE	rsd.median	terms
Model Summary:	0.32	9.83	1.52	332

	Term	Coefficient estimate	Standardised coefficient (t-statistic)	p.value	std.error
1	**Intercept**	81.5	1447.5	0	0.1
	Construction Age (β1)				
	Reference: Built from 2012 onwards (newest)				
2	2007-2011	0.9	27.5	0	0
3	2003-2006	-1.4	-58.6	0	0
4	1996-2002	-5.8	-246.1	0	0
5	1976-1995	-9.4	-440.4	0	0
6	1950-1975	-13.4	-635	0	0
7	1930-1949	-16.3	-744.5	0	0
8	1900-1929	-19.3	-890.1	0	0
9	pre-1900	-22.4	-1008.1	0	0
	Dwelling Type (β2)				
	Reference: Flat/Maisonette (highest scoring EPC)				
10	Terraced House	-1.3	-148.1	0	0
11	Semi-Detached	-3.5	-347.4	0	0
12	Detached	-5.9	-451.7	0	0
13	Bungalow	-5.7	-481.6	0	0
	Tenure (β3)				
	Reference: Owner Occupied (majority group)				
14	Privately Rented	0.4	55.5	0	0
15	Socially Rented	4.5	561.6	0	0
	Floor Area (β4)				
16	Total Floor Area (log10)	-0.6	-65.9	0	0

Note: Local authority fixed effects are shown in Table 2

Table 4-2 Model 1, Base model Results

Local Authority (β5)

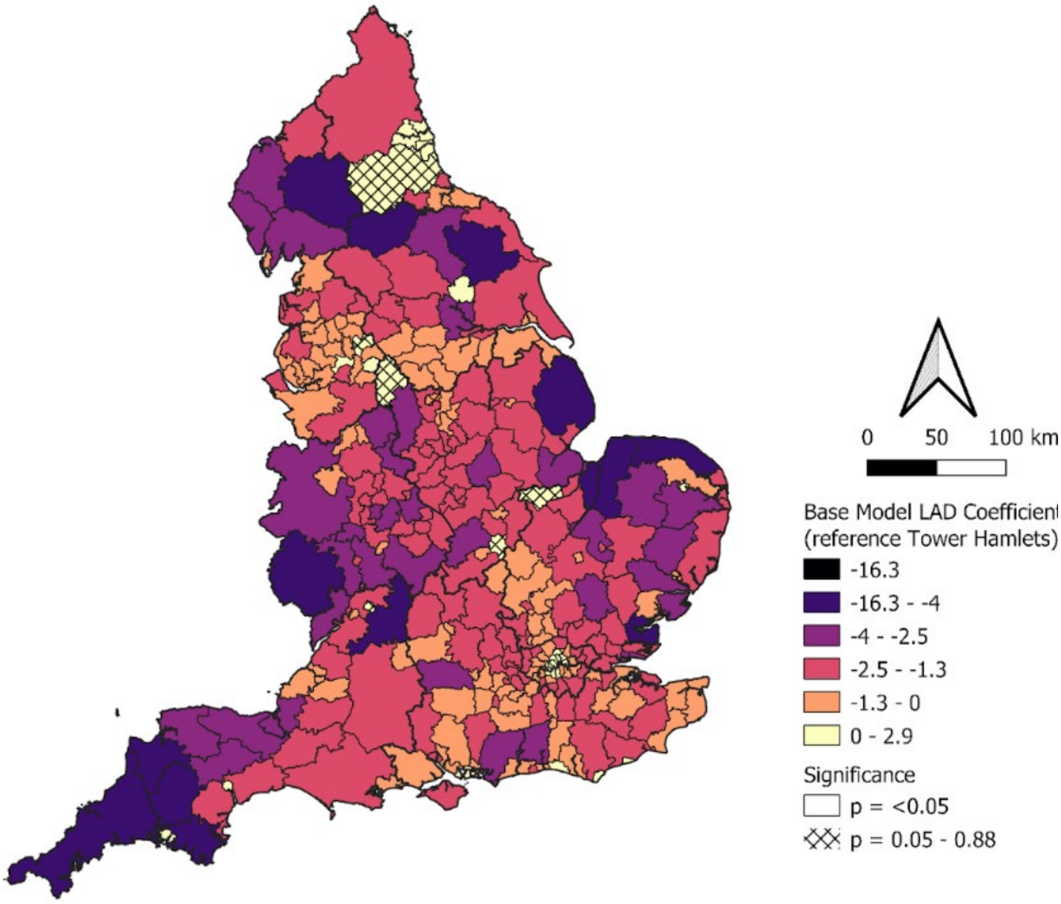


Figure 4-20 Model 1 Local Authority Dummy Coefficients

See map for coefficient estimates.
Estimate summaries are provided below:

	Region	*est.range*	*median*	*mean*	*SD*	*n ($p < 0.05$)/n*
17	North East	2.4	-0.2	-0.42	0.9	1/12
18	London	5.4	-0.6	-0.48	1.5	1/32
19	North West	7.2	-1.0	-1.31	1.3	1/39
20	South East	4.6	-1.1	-1.17	0.8	1/67
21	Yorkshire and The Humber	6.2	-1.5	-1.82	1.5	0/21
22	East Midlands	4.1	-1.9	-1.77	0.9	3/40
23	East of England	5.2	-1.9	-1.9	1.1	2/45
24	West Midlands	3.7	-2.0	-2.18	0.9	0/30
25	South West	16.7	-2.1	-2.74	3.1	1/30

Table 4-3 Summary of LA Fixed Effects by Region

4.3.3 Spatial Autocorrelation of Local Authority Dummy Coefficients

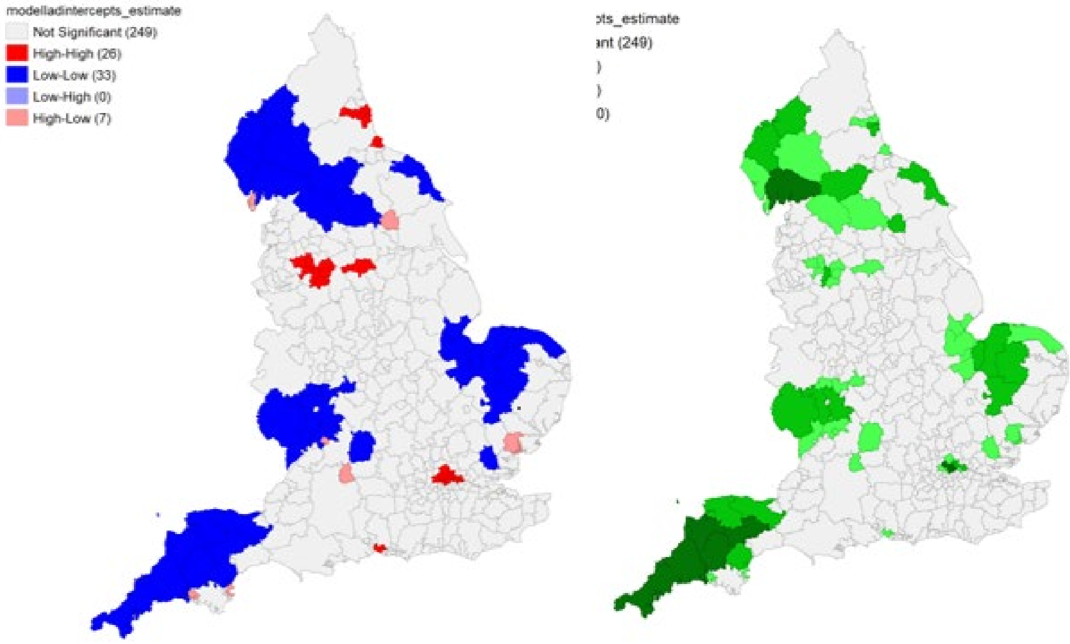


Figure 4-21 Local Moran's I for Local Authority Dummy Coefficients

4.3.4 Residual Analysis

Our base model (1) is a starting point and suggests that after accounting for some of the main dwelling-level and locational influences on energy efficiency, with only around 30% of the variation accounted for there are a large number of homes performing better or worse than expected. These residual properties warrant some further investigation. From a policy perspective, there are some aspects of a property or its wider neighbourhood environment that are more addressable than others. For example, it's relatively easy to switch an individual property from gas to electricity as its main source of heating, but much less straightforward – although perhaps desirable for reasons beyond energy efficiency – to uplift income deprivation experienced by the residents in an area. We might term switching fuel as easy an 'intervention' factor, whereas being in an urban or rural area something more immutable.

Figure 4-22 below maps the average residual value from Model 1, aggregated to Local Authority level. There is a clear geography to these residuals with negative residuals (properties with lower [worse] Energy Efficiency ratings than the model would predict), accounting for the influence of age, type, tenure, floor area and local authority). Properties within boroughs in Central London, in particular, Islington, Hackney and Hammersmith and Fulham perform worse than expected, alongside Harlow in Essex, Eastleigh in Hampshire, Norwich, Lincoln and Sunderland. Most of these areas fair quite well in terms of overall energy performance, so are showing underperformance relative to a fairly good baseline. The areas with more positive average residuals tend to be those which are on average, doing quite poorly already (the West Country, North Norfolk etc.).

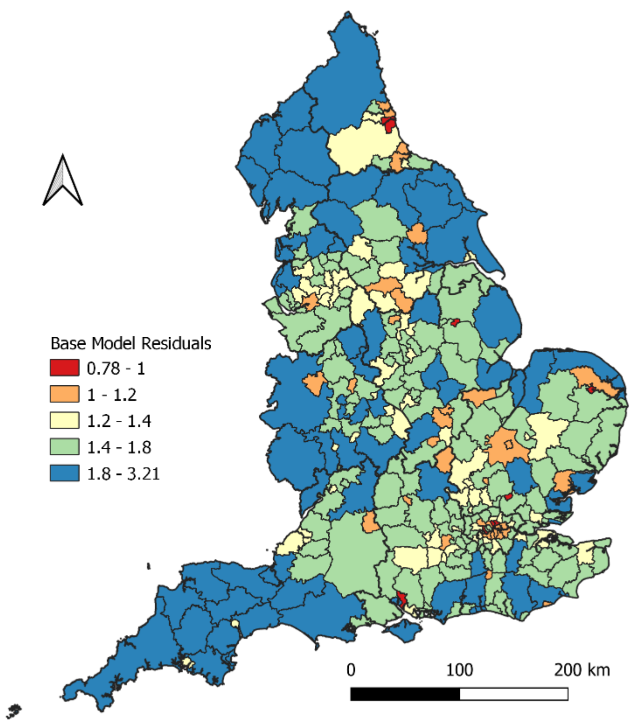


Figure 4-22 Model 1, Base Model Residual Values

These residuals can be modelled as a function of some additional property and neighbourhood level variables as in Equation 2 below, with the outputs of the model displayed in Table 10.

$$Residual = \beta_0 + \beta_1\ FuelType + \beta_2\ TransactionType + \beta_3\ Glazing + \beta_4\ SAPVersion + \beta_5\ UrbRur + \beta_6\ UrbRul + \beta_7\ IncomeDep + \varepsilon \quad (2)$$

Looking at easy intervention-related factors, a home's primary fuel type captures a large amount of the prediction error. Relative to homes heated with mains gas in our sample (84% of all homes), those with no information provided on fuel type usage (30%) are expected to be almost three rating bands (30pts) off in their estimate. Similarly, those heated with solid fuel, LPG or renewable combustible fuel – those that are more likely 'off grid' – certainly for gas – contribute to a lot of the measurement error. A property's glazing is less informative than the reason for issuing the EPC certificate (transaction type), although given the poor performance of private rental properties on the whole, this is perhaps not as surprising as it first appears. Houses with Triple Glazing are likely to contribute to quite a lot of positive over performance in energy efficiency – some 7.4 points better on average, although those with single glazing having a slightly less detrimental effect than one would expect. Compared to 'sales', most other reasons (e.g. for a survey, with a new build, private and social rent issue) tend to have a slightly larger misestimation (all under 2 pts). Only EPCs issued for assessment (6.5%) – usually for subsidised improvement programmes – tend to have a wider residual range of over 5 pts suggesting a great mix of homes putting themselves forward in the different programmes. The SAP methodology (with its climatic regions provided in the appendix) does not account for much residual variance.

Regional effects are slightly confusing as they are probably capturing a lot of the local authority level positive and negative effects. However, being in an urban area, relative to a rural area, is likely to have only a small negative effect on the size of the residual error. Similarly, income has only a small effect on error – as wealth increases (within each authority, measured purely in terms of declining Income Deprivation) it has a small positive influence on residual error.

Residual Model:
Fuel Type + Transaction Type + Glazing + SAPVersion + SAPRegion + Urban/Rural + Income Deprivation

	adj.R2	**RSE**	**rsd.median**	**terms**
Model Summary:	0.19	9.83	0.8	34

Term	**Coefficient estimate**	**Standardised coefficient (t-statistic)**	**p.value**	**std.error**
Intercept	-2.95	-2.27	0.02	1.3
Fuel Type (β1)				
Reference: Mains Gas				
bioGas	-0.63	-1.6	0.11	0.39
electricity	-9.27	-1121.13	0	0.01
LPG	-21.19	-595.5	0	0.04
oil	-7.77	-489.53	0	0.02

oRenewable	-3.59	-3.06	0	1.18
oRenewCombust	-21.9	-7.1	0	3.08
solid fuel	-16.11	-435.42	0	0.04
unspecified	-29.23	-614.86	0	0.05
Transaction Type (β2)				
Reference: Sale				
rental	1.29	202.85	0	0.01
srental	0.08	9.8	0	0.01
new	1.59	9.56	0	0.17
assessment	-5.18	-498.24	0	0.01
survey	1.87	54.56	0	0.03
Glazing (β3)				
single glazing	-1.44	-38.86	0	0.04
triple glazing	7.41	118.43	0	0.06
double glazing	3.73	324.7	0	0.01
secondary glazing	1.07	38.86	0	0.03
SAP Version (β4)				
versionSAP09	-1.21	-0.93	0.35	1.3
versionSAP12	1.54	1.18	0.24	1.3
SAP Climate Group (Region) (**β5**)				
climate_grp10 – NE England	0.06	4.49	0	0.01
climate_grp11 – East Pennines	-0.12	-13.39	0	0.01
climate_grp12 – East Anglia	0.65	61.02	0	0.01
climate_grp2 – SE England	0.26	23.43	0	0.01
climate_grp3 – Southern Eng	0.49	38.85	0	0.01
climate_grp4 – SW England	1.87	124.39	0	0.02
climate_grp5E – Severn Eng	0.78	64.5	0	0.01
climate_grp6 – Midlands	0.09	10.2	0	0.01
climate_grp7E – West Pennines	-0.1	-11.1	0	0.01
climate_grp8E – NW England	0.8	30.18	0	0.03

climate_grp9E – Borders Eng	-0.1	-6.07	0	0.02
Urban / Rural (β6)				
Urban	-0.39	-48.56	0	0.01
Income Deprivation (β7)				
Deprivation Decile	1.2	36.97	0	0.03

Table 4-4 Residual Regression Analysis

	Region	*SD*	*median*	*range*
1	South West	10.90	1.81	125
2	West Midlands	10.10	1.73	118
3	North West	9.80	1.56	118
4	East of England	9.70	1.46	116
5	East Midlands	9.70	1.51	116
6	Yorkshire and The Humber	9.70	1.45	120
7	South East	9.70	1.53	120
8	London	9.40	1.30	113
9	North East	9.10	1.34	115

Table 4-5 Summary of Base Model Residuals by Region

4.3.5 Geodemographic Analysis of Local Authority Coefficients

In order to add one final explanatory layer to this analysis it is useful to explore the coefficient estimates for the local authority dummy variables in the base model. As is shown in Figure 4-22, there is a clear geography to these coefficients which represent, relative to the Tower Hamlets base level (the Local Authority with, on average, better performing properties) how much worse other local authorities perform. So, for example, we expect properties in the South West to be up to 16.4 energy efficiency points lower than in Tower Hamlets. The residual analysis in the last section hits at a small socio-economic effect in operation, but is it possible to go further and use additional demographic data to predict some of this Local Authority Level variation?

Earlier in the data section we outlined some of the national geodemographic classifications available from the Office For National Statistics. Here we make use of the national 2011 Local Authority Classification[4] sub-groups (Figure 4-23) to see if the demographic composition of these Local Authorities can provide any further clues as to their relative performance. In order to explore this we fit a simple bivariate linear model with only the classification subgroup as the predictor:

$$LocalAuthorityBeta = \beta_0 + \beta_1 \; subgroup + \varepsilon \quad (3)$$

The results of this model are shown below in Table 4-6

4 https://www.ons.gov.uk/methodology/geography/geographicalproducts/areaclassifications/2011areaclassifications

Coefficients	Estimate[1]	SE[2]
(intercept)	-1.33***	0.253
SubGroup		
Affluent rural (reference category)	—	—
Ageing Coastal Living	-0.96**	0.357
City Periphery	-0.26	0.357
Country Living	-0.88**	0.291
Ethnically Diverse Metropolitan Living	0.08	0.323
Expanding Areas	0.72	0.366
Industrial and Multi-ethnic	0.4	0.339
Larger Towns and Cities	0.92**	0.317
London Cosmopolitan	2.4***	0.375
Manufacturing Legacy	0.5	0.323
Mining Legacy	0.6	0.416
Older Farming Communities	-2.1***	0.326
Prosperous Semi-rural	-0.85	0.466
Prosperous Towns	0.14	0.32
Rural-Urban Fringe	0.16	0.33
Rural Growth Areas	-0.32	0.317
Seaside Living	0.36	0.466
Service Economy	0.78	0.4
Sparse English and Welsh Countryside	-1.5***	0.334
University Towns and Cities	0.90*	0.416
Urban Living	0.12	0.334
R^2	0.547	
Adjusted R^2	0.516	
No. Obs.	308	

[1] *p<0.05; **p<0.01; ***p<0.001

[2] SE = Standard Error

Table 4-6 Model 3 Outputs

The results of this model paint a fascinating picture with almost 55% of the variation in relative energy efficiency performance accounted for by these different geodemographic groups. Relative to the reference category – Affluent Rural[5] (which covers areas such as Winchester, the Vale of the White Horse and South Cambridgeshire – a cluster with above average numbers of detached houses, higher education qualifications and those who work in high-skilled jobs and which performs relatively well for energy efficiency despite the dominance of the detached stock and the rural location with high positive residual values in Model 2) – we see a collection of statistically significant local authority categories which are worth commenting upon.

Firstly, London Cosmopolitan – a small cluster of Local Authorities in Central London which has over representation of flats, over representation of social renting, large under-representation of owner occupation, high levels of good qualifications and, conversely, unemployment, as well as large ethnic minority populations, people in their 20s and 30s, and those born outside of the UK – shows the strongest positive influence on relative energy efficiency performance, relative to an already fairly well performing reference group.

At the other end of the scale, Older Farming Communities – found in the parts of the country with much worse energy performance from Model 1, for example down in the South West, the Welsh Borders and the North – is characterised by an over-representation of detached houses and bungalows which are owner occupied, and over-representation of those aged over 45, 65 and 90+, those who are well educated, but who rely on cars to get around and are employed in hospitality and agriculture. These areas – to which we can also add Sparse English and Welsh Countryside (and with a very similar demographic profile as it's in the same supergroup) fair much worse than the reference group.

These findings – while in many ways not revealing anything new, do add some demographic colour to the patterns already revealed in the earlier modelling.

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5 https://www.ons.gov.uk/methodology/geography/geographicalproducts/areaclassifications/2011areaclassifications/penportraitsandradialplots

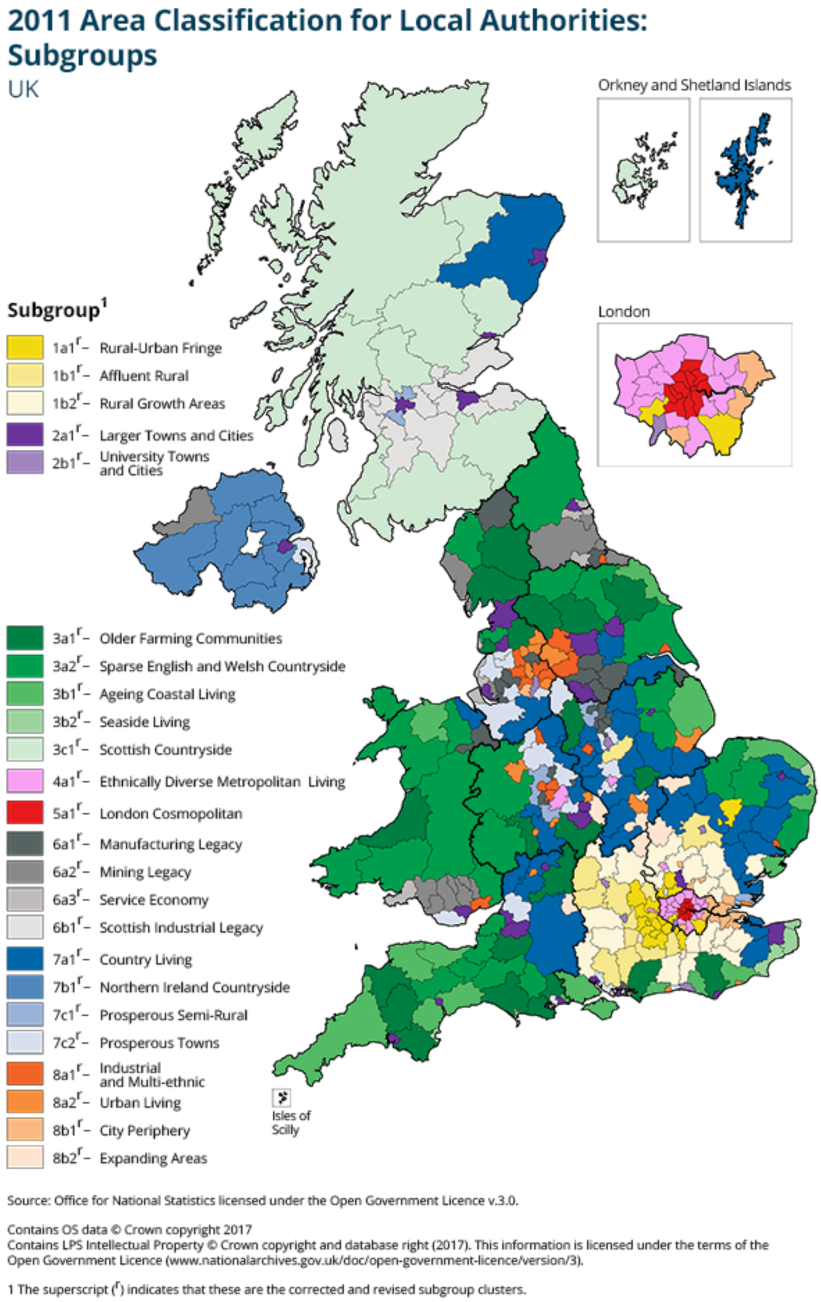

Figure 4-23 ONS 2011 Local Authority Classification

4.3.6 Potential Analysis Limitations

Hardy and Crew (2019) estimate at least 27% of all EPC entries lodged between 2008 and 2016 contain some kind of error. They estimate that up to 30% of EPCs could be placed in the wrong band, with flats and maisonettes, in particular, exhibiting higher error rates. Using a list of sixteen assumed errors nested into six error groups, which they create with nine columns of the EPC database (Hardy and Glew, 2019, tbl. 2), they find errors such as large discrepancies in the 'Built Form' column and flat entries ('Property Type' = flat). Spatially, there are high errors recorded for central London, with almost 80% of records assumed to contain incorrect information in the Royal Borough of South Kensington and Chelsea (Hardy and Glew, 2019, fig. 5). A limitation of their method is that it is not validated on the ground with actual site visits. It also yields high error rates that suggest spatial autocorrelation with the distribution of denser property types such as flats and maisonettes.

4.3.7 Modelling Discussion

This analysis has revealed a number of important features of the residential building energy performance landscape of England. In our baseline model we were able to account for almost 1/3 of the variation in energy efficiency ratings using just information on building age, type, tenure, size and location. Older, larger, detached, owner occupied dwellings located in rural local authorities – particularly in places like the South-West of the Country, the Welsh Borders, North Norfolk and the far North of England, were the worst performing. Modern, socially rented flats located in big cities, particularly London, but also places like Manchester and the North-East around Newcastle and Sunderland were the best performing properties.

When we examined the residuals from the model, aggregated to local authorities – those areas where properties existed that, on the whole, performed better than we would have expected given these physical and locational characteristics, we see a slight reversal in the pattern with over performance tending to be in those local authorities with worse relative performance – particularly in places like the South-West. What this shows is that in these places, we can find some properties which actually perform quite well. At the other end of the scale, we find under-performing properties – relative to the model average – in some of the best overall performing local authorities – Central London and some other regional cities. Given the size of our dataset and the heterogeneity in the stock, this is perhaps not too surprising. More surprising were the additional factors influencing these residuals. Our second model looked at whether there was anything else either at building level or in the wider neighbourhood social geography which might be acting to push properties into either over or under-performance relative to the baseline model. We looked at variables such as main Fuel type, transaction type, glazing at the property level and then at how urban or rural the area surrounding the property was as well as income deprivation from the English Indices or Deprivation. We found that Fuel type has a large influence, accounting for quite a large portion of the variation in residuals, with other property level characteristics such as transaction type and glazing being more important than some of the location factors such as rurality or income deprivation – which explain very little of this variation.

In thinking about the reasons behind these observations, it's reasonable to conclude that – certainly in relation to the relatively low influence of the urban / rural divide and income deprivation – that much of the influence of these socially orientated variables, is actually captured by the local authority level dummies in the base model. Every local authority has a unique social profile and location which interacts with the property mix within. The final modelling exercise in this analysis brought additional geodemographic dimensions to these local authority dummies and showed that, for example, in the poorly performing rural local authorities, we find that many of these owner-occupied detached houses are inhabited by older people who are white and born in the UK. On the whole people inhabiting these local authorities are better educated than average, but are completely reliant on cars and have an over representation in occupations traditionally associated with the countryside – farming, forestry etc.

5 CONCLUSIONS

We embarked upon this piece of research with a series of broad aims and specific objectives. Firstly, a primary functional aim was to demonstrate the value of geo-located residential property energy performance certificate data in understanding the national challenges involved in shifting to a net-zero emitting residential system. Through a detailed analysis of some 18 million residential properties, it's clear that the country has a long journey ahead if even the relatively modest ambition of moving more houses into performance Band C over the next decade or so. Through the recent addition of UPRNs to the EPC data set, we have been able to geolocate and analyse the geography of this challenge which has provided a more nuanced perspective than the high-level policy documents which have to date predominated in the discourse around a national shift to net-zero.

There is a clear urban / rural geography to the problem of residential energy efficiency with urban areas more likely to fair better with smaller, more efficient, newer homes; more of which are socially rented – a key factor emerging from our analysis as social landlords evidently either preside over newer stock or are more concerned with upgrading and maintaining their older properties so that they are more energy efficient. Central London in particular fairs very well, however a dichotomy exists where alongside a generally better performing stock, in the private rental sector there is an acute need to upgrade a large number of poorly performing properties. Central and North London in particular is a hot-spot for dwellings which fall well below Band C – a standard which will come into force soon as a requirement for all landlords wanting to rent their properties. This may have multiple implications which could lead to, either through targets not being met and the political consequences thereof, or more problematically, landlords leaving the marking and making the availability of rental properties which are already in short supply even more constrained.

Indeed, while on average performing better, the most extreme cases of low domestic energy performance are in urban areas, notably in areas where we expect high inequality. Therefore, more complex and location-specific interventions will be needed to effectively address residential energy performance in these areas. These interventions will be complex because they might require landlords and owners to make improvements who might be without the capital to fund them and who could be in danger of leaving the market entirely without the right incentives in place. This highlights the importance of addressing social and spatial inequalities as a component of the UK Geospatial strategy and will require central government to work closely with local authorities if changes are to be affected within the timescales currently aimed for.

Energy performance can be defined and therefore addressed in different ways across local authorities. The evidence from our analysis is that the physical factors of a home have a more direct impact on its EPC score than its social and local contexts, but they cannot be treated entirely separately. Property age is by far the most associated with a building's energy performance and while it clearly links directly to the fabric of the building it may also reflect constraints on improvements due to historic conservation or older owner-occupation by individuals who may have moved into and made their last major home upgrade decades ago. It is also important to note that homes with theoretically higher running costs might not actually cost more to run if these are not used at full capacity (e.g. an older, shrinking household using only some of their home). There are gaps in the relationship between estimated and actual usage that can be best addressed with further geospatial linkage and insight.

The spike in efficiency Band E properties and the higher average performance of the privately rented sector (compared to owner-occupation) suggests we have an opportunity to encourage improvement to the building stock through regulation. One way we can align upgrade and market incentives is to promote specific upgrades. Our findings suggest that promoting upgrades in glazing would have less of an impact than future-proofing a home's main source of fuel.

Geographies of domestic energy efficiency are inevitable and need to be considered for the making of impactful policy. Furthermore, older homes – houses built before the mid-1970s – perform less well. These are often owner-occupied, the majority of the recorded stock and most likely to score below 69 (band 'C'). The real volume challenge that faces the country in its shift to many more energy efficient homes, is in rural areas. Particularly more remote rural areas in the South West, on the coastal fringes, particularly in Norfolk, on the Welsh Borders and in the far North of England in places like Cumbria. These homes are low density but numerous. In these areas, people tend to own their own houses, but are generally later on in their lives and evidently so far and so perhaps in the future. less open to undertaking the expensive changes that would be required to upgrade their properties. Our analysis suggests that these demographic factors are present, important, and will need to be overcome if real country-wise, extensive improvements are to be made.

5.1.1 Implications for Policy Design

We set out in the introduction that our intention was to adopt a whole system approach to this piece of work and to contribute to our understanding of the system, the theory surrounding it and methods we could use to understand it further; rather than to attempt the more complicated Policy, Design and subsequent analysis of Wilson's systems thinking framework. While in many ways offering much more spatial nuance than before, this work represents, still a relatively high-level overview. In our analysis we were able to examine at the property level and at a very fine level of spatial granularity, for the first time.

It is clear from this work that the geography of energy efficiency – and indeed environmental impact which we touched upon only really as a comparison point to energy efficiency distributions – that a lot more work can be carried out and will need to be carried out in order that Local Authority-specific successful policy making is made. We have shown, for example, the dichotomous situation in places like London which on the whole enjoy good energy performance across most of the residential stock, but where acute problems in the private rental sector are on the horizon. The data we have used are extensive and highly detailed both in terms of their spatial granularity and their attribute information. We recommend that deeper local analyses are conducted in order that the best future policy decisions can be made.

5.1.2 Future Work

A natural next step from the analysis is to augment with additional modelling to examine the hierarchical effects of geography (neighbourhoods nested within local authorities and regions) and the role of property prices and other property level variables within the EPC dataset that we did not analyse to their full extent in this work. Future efforts could be directed at estimating the scale of the energy efficiency challenge in homes that do not yet have an EPC or exploring the repeat entries in the database which may evidence where improvements have been made to properties and what characterises the social and spatial dimension of those upgrading properties. This could potentially offer useful clues about who might be most easily targeted to get the national upgrade programme underway. Another recommendation in the future is to consider a wider spectrum of social variables to extend the observations on tenure and deprivation discussed in the outputs of this project. A new census has taken place and slowly data from it are coming online which could offer new opportunities in this work. These directions for future work will be impactful in the context of passing on the cost of residential upgrades..

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7 APPENDIX

7.1 REPOSITORY

https://github.com/Bonnie-Buyuklieva/OS-Narrate

7.2 INVALID UPRNS

Address	UPRN	ubdc_UPRN	INSPECTION_DATE
2 bowley house, rectory lane ox20 1uf	100120972330	100120965812	12 February 2020
2 bowley house, rectory lane ox20 1uf	100120972330	100120972330	04 September 2017
5, eglinton hill se18 3pg	100023243402	10010264920	27 July 2019
5, eglinton hill se18 3pg	100023243402	100020960244	28 May 2009
7, ramsey road pe27 5rf	100090114656	100090114656	24 November 2017
7, ramsey road pe27 5rf	100090114656	10012050741	04 October 2008
apartment 2, the old vicarage, 2 brackley road, eccles m30 9lg	10070743737	10007887002	11 March 2019
apartment 2, the old vicarage, 2 brackley road, eccles m30 9lg	10070743737	10070743737	21 April 2009
flat 1, albert court, park street ws11 0es	10014216656	10014216656	30 June 2014
flat 1, albert court, park street ws11 0es	10014216656	10008162667	03 October 2008
flat 12 college house, 188, college road, saltley b8 3tq	100071487365	100071487365	15 February 2019
flat 12 college house, 188, college road, saltley b8 3tq	100071487365	10093330457	15 December 2008
flat 4, albert court, park street ws11 0es	10014216659	10014216659	12 March 2019
flat 4, albert court, park street ws11 0es	10014216659	10008162670	03 October 2008
flat 7 zoe court, 26, kirtleton avenue dt4 7pt	100040667974	100040667914	21 January 2019
flat 7 zoe court, 26, kirtleton avenue dt4 7pt	100040667974	100040667974	21 January 2009

7.3 CHANGING LADS

LAD11CD	LOCAL_AUTHORITY_LABEL	LOCAL_AUTHORITY	LAD11NM	POSTCODE.EPC_raw	N
E07000007	Buckinghamshire	E06000060	Wycombe	HP11 1GX	6
E07000050	Dorset	E06000059	North Dorset	SP8 4TW	23
E07000050	Dorset	E06000059	North Dorset	SP8 4QS	49
E07000205	East Suffolk	E07000244	Suffolk Coastal	IP12 2TA	37
E06000028	Bournemouth, Christchurch and Poole	E06000058	Bournemouth	BH2 6AU	23
E06000029	Bournemouth, Christchurch and Poole	E06000058	Poole	BH21 1RR	7
E07000201	West Suffolk	E07000245	Forest Heath	IP28 7JW	22
E07000006	Buckinghamshire	E06000060	South Bucks	SL2 3AP	2
E07000048	Bournemouth, Christchurch and Poole	E06000058	Christchurch	BH23 4JZ	5
E07000112	Folkestone and Hythe	E07000112	Shepway	CT19 6BU	30
E07000205	East Suffolk	E07000244	Suffolk Coastal	IP5 2YJ	18
E07000206	East Suffolk	E07000244	Waveney	NR32 4JX	11
E07000112	Folkestone and Hythe	E07000112	Shepway	CT20 1LY	23
E07000049	Dorset	E06000059	East Dorset	BH21 5NA	2
E07000048	Bournemouth, Christchurch and Poole	E06000058	Christchurch	BH23 2BJ	3
E06000028	Bournemouth, Christchurch and Poole	E06000058	Bournemouth	BH6 3PW	59
E07000049	Dorset	E06000059	East Dorset	SP6 3ER	19
E07000004	Buckinghamshire	E06000060	Aylesbury Vale	MK18 2HQ	2
E09000012	Haringey	E09000014	Hackney	N4 2ZT	68

This is a sample from 62 629 examples, from 604 374 instances of incorrect LAD assignment.

7.4 SAMPLE EPC FORM

Energy Performance Certificate (EPC)

17 Any Street, District, Any Town, B5 5XX

Dwelling type:	Detached house	**Reference number:**	0919-9628-8430-2785-5996
Date of assessment:	15 August 2011	**Type of assessment:**	RdSAP, existing dwelling
Date of certificate:	13 March 2012	**Total floor area:**	165 m²

Use this document to:

- Compare current ratings of properties to see which properties are more energy efficient
- Find out how you can save energy and money by installing improvement measures

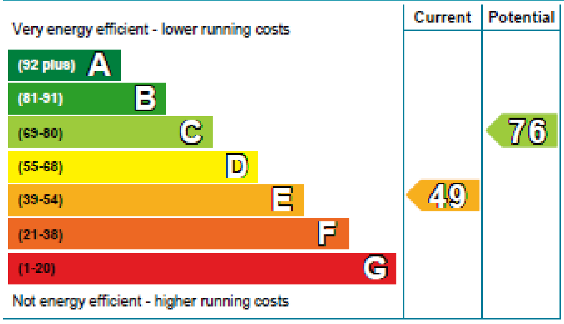
Estimated energy costs of dwelling for 3 years	**£5,367**
Over 3 years you could save	**£2,865**

Estimated energy costs of this home

	Current costs	Potential costs	Potential future savings
Lighting	£375 over 3 years	£207 over 3 years	**You could save £2,865 over 3 years**
Heating	£4,443 over 3 years	£2,073 over 3 years	
Hot water	£549 over 3 years	£222 over 3 years	
Totals:	**£5,367**	**£2,502**	

These figures show how much the average household would spend in this property for heating, lighting and hot water. This excludes energy use for running appliances like TVs, computers and cookers, and any electricity generated by microgeneration.

Energy Efficiency Rating



The graph shows the current energy efficiency of your home.

The higher the rating the lower your fuel bills are likely to be.

The potential rating shows the effect of undertaking the recommendations on page 3.

The average energy efficiency rating for a dwelling in England and Wales is band D (rating 60).

Top actions you can take to save money and make your home more efficient

Recommended measures	Indicative cost	Typical savings over 3 years	Available with Green Deal
1 Increase loft insulation to 270 mm	£100 - £350	£141	✔
2 Cavity wall insulation	£500 - £1,500	£537	✔
3 Draught proofing	£80 - £120	£78	✔

See page 3 for a full list of recommendations for this property.

To find out more about the recommended measures and other actions you could take today to save money, visit **www.direct.gov.uk/savingenergy** or call **0300 123 1234** (standard national rate). When the Green Deal launches, it may allow you to make your home warmer and cheaper to run at no up-front cost.

Summary of this home's energy performance related features

Element	Description	Energy Efficiency
Walls	Cavity wall, as built, partial insulation (assumed)	★★★☆☆
Roof	Pitched, 75 mm loft insulation	★★★☆☆
Floor	Solid, no insulation (assumed)	–
Windows	Partial double glazing	★★☆☆☆
Main heating	Boiler and radiators, mains gas	★★★☆☆
Main heating controls	Programmer, room thermostat and TRVs	★★★★☆
Secondary heating	None	–
Hot water	From main system	★★★☆☆
Lighting	Low energy lighting in 17% of fixed outlets	★★☆☆☆

Current primary energy use per square metre of floor area: 298 kWh/m² per year

The assessment does not take into consideration the physical condition of any element. 'Assumed' means that the insulation could not be inspected and an assumption has been made in the methodology based on age and type of construction.

Low and zero carbon energy sources

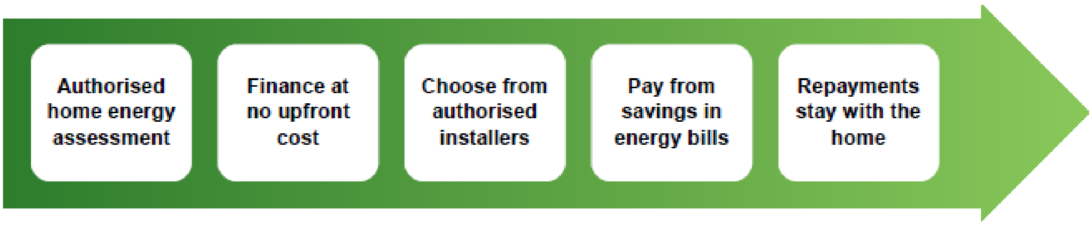
Low and zero carbon energy sources are sources of energy that release either very little or no carbon dioxide into the atmosphere when they are used. Installing these sources may help reduce energy bills as well as cutting carbon. There are none provided for this home.

Opportunity to benefit from a Green Deal on this property

When the Green Deal launches, it may enable tenants or owners to improve the property they live in to make it more energy efficient, more comfortable and cheaper to run, without having to pay for the work upfront. To see which measures are recommended for this property, please turn to page 3. You can choose which measures you want and ask for a quote from an authorised Green Deal provider. They will organise installation by an authorised installer. You pay for the improvements over time through your electricity bill, at a level no greater than the estimated savings to energy bills. If you move home, the Green Deal charge stays with the property and the repayments pass to the new bill payer.

For householders in receipt of income-related benefits, additional help may be available.

To find out more, visit **www.direct.gov.uk/savingenergy** or call **0300 123 1234**.



Recommendations

The measures below will improve the energy performance of your dwelling. The performance ratings after improvements listed below are cumulative; that is, they assume the improvements have been installed in the order that they appear in the table. Further information about the recommended measures and other simple actions you could take today to save money is available at **www.direct.gov.uk/savingenergy**. Before installing measures, you should make sure you have secured the appropriate permissions, where necessary. Such permissions might include permission from your landlord (if you are a tenant) or approval under Building Regulations for certain types of work.

Measures with a green tick ✓ are likely to be fully financed through the Green Deal, when the scheme launches, since the cost of the measures should be covered by the energy they save. Additional support may be available for homes where solid wall insulation is recommended. If you want to take up measures with an orange tick ✓ be aware you may need to contribute some payment up-front.

Recommended measures	Indicative cost	Typical savings per year	Rating after improvement	Green Deal finance
Increase loft insulation to 270 mm	£100 - £350	£47	E 51	✓ (green)
Cavity wall insulation	£500 - £1,500	£179	D 59	✓ (green)
Draught proofing	£80 - £120	£26	D 60	✓ (green)
Low energy lighting for all fixed outlets	£50	£43	D 61	
Replace boiler with new condensing boiler	£2,200 - £3,000	£339	C 74	✓ (green)
Solar water heating	£4,000 - £6,000	£34	C 75	✓ (orange)
Replace single glazed windows with low-E double glazing	£3,300 - £6,500	£41	C 76	✓ (orange)

Alternative measures

There are alternative measures below which you could also consider for your home.

- External insulation with cavity wall insulation
- Biomass boiler (Exempted Appliance if in Smoke Control Area)
- Air or ground source heat pump
- Micro CHP

Choosing the right package

Visit **www.epcadviser.direct.gov.uk**, our online tool which uses information from this EPC to show you how to save money on your fuel bills. You can use this tool to personalise your Green Deal package.

Directgov
Public services all in one place

Green Deal package	Typical annual savings
Loft insulation	**Total savings of £587**
Cavity wall insulation	
Draught proofing	
Condensing boiler	
Electricity/gas/other fuel savings	£0 / £587 / £0

You could finance this package of measures under the Green Deal. It could **save you £587 a year** in energy costs, based on typical energy use. Some or all of this saving would be recouped through the charge on your bill.

About this document

The Energy Performance Certificate for this dwelling was produced following an energy assessment undertaken by a qualified assessor, accredited by AAA Energy Assessors Ltd. You can get contact details of the accreditation scheme at www.aaa.co.uk, together with details of their procedures for confirming authenticity of a certificate and for making a complaint. A copy of this EPC has been lodged on a national register. It will be publicly available and some of the underlying data may be shared with others for the purposes of research, compliance and direct mailing of relevant energy efficiency information. The current property owner and/or tenant may opt out of having this information disclosed.

Assessor's accreditation number: AAA_123456
Assessor's name: John Smith
Phone number: 030 5555 1234
E-mail address: john.smith@isp.net
Related party disclosure: No related party

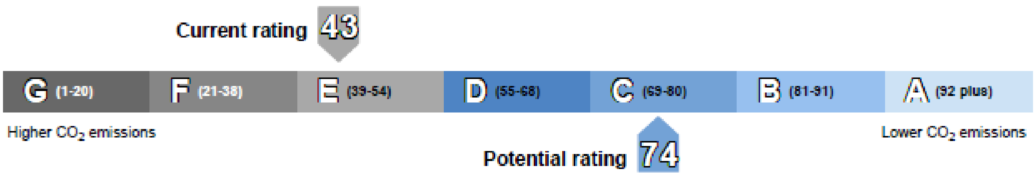
Further information about Energy Performance Certificates can be found under Frequently Asked Questions at **www.epcregister.com**.

About the impact of buildings on the environment

One of the biggest contributors to global warming is carbon dioxide. The energy we use for heating, lighting and power in homes produces over a quarter of the UK's carbon dioxide emissions.

The average household causes about 6 tonnes of carbon dioxide every year. Based on this assessment, your home currently produces approximately 9.5 tonnes of carbon dioxide every year. Adopting the recommendations in this report can reduce emissions and protect the environment. If you were to install these recommendations you could reduce this amount by 5.5 tonnes per year. You could reduce emissions even more by switching to renewable energy sources.

The environmental impact rating is a measure of a home's impact on the environment in terms of carbon dioxide (CO_2) emissions. The higher the rating the less impact it has on the environment.



Your home's heat demand

For most homes, the vast majority of energy costs derive from heating the home. Where applicable, this table shows the energy that could be saved in this property by insulating the loft and walls, based on typical energy use (shown within brackets as it is a reduction in energy use).

Heat demand	Existing dwelling	Impact of loft insulation	Impact of cavity wall insulation	Impact of solid wall insulation
Space heating (kWh per year)	22,154	(1179)	(4535)	N/A
Water heating (kWh per year)	2,792			

Addendum

This dwelling may have narrow cavities and so requires further investigation to determine which type of cavity wall insulation is best suited.