DEPARTMENT OF COMPUTER SCIENCE

Tool for Assessing Heat Pump Readiness for Dwellings in the UK using Energy Performance Certificate Data

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Abstract

The UK became the first major economy to pass net zero emissions into law, with the amendment to its Climate Change Act of 2008, targeting greenhouse gas emissions to net zero by 2050. This bold move in the fight against climate change aims to completely decarbonise the economy, targeting our industries, transport, fuel and power supplies and the heating of buildings. All present significant challenges in doing so and in this project we focus on the heating of buildings aspect, specifically the transformation of the UK's housing stock, replacing traditional gas fired boilers with low carbon heat pump technology. The UK remains very early on its heat pump adoption curve, with current uptake rates far below target. This report explores the possible factors behind this and the challenges faced in achieving the required adoption levels.

This project aims to aid this adoption by providing an informative tool to assess levels of 'heat pump readiness' for dwellings in England and Wales, through the use of Energy Performance Certificates. This is carried out at an individual dwelling, postcode and district level, allowing for comparisons to be drawn and the identification of potential 'zones', where the installation of heat pumps may be particularly ideal, or zones with relatively poor energy (efficiency) performance, which may require various insulation improvements to aspects such as roofing, walls and windows before being 'heat pump ready'.

- I spent many hours collecting material and learning about Energy Performance Certificates and the role of Heat Pumps in decarbonising the UK's housing stock
- I wrote approximately 2000 lines of source code in the creation of a Web Application, compromising of Python for the back-end and HTML + CSS + Javascript for the front-end.
- I calculated a 'heat pump readiness' (HPR) rating derived from an Energy Performance Certificate for a dwelling

Dedication and Acknowledgements

I wish to thank my supervisor Ruzanna Chitchyan, for the guidance and support she provided throughout the project and members of the Centre for Sustainable Energy, who took the time to give me feedback on my work and offer advice going forward. I must also acknowledge the unwavering support and dedication shown by my parents over the past 20 years, who have enabled me to achieve all that I am proud of.

Declaration

I declare that the work in this dissertation was carried out in accordance with the requirements of the University's Regulations and Code of Practice for Taught Programmes and that it has not been submitted for any other academic award. Except where indicated by specific reference in the text, this work is my own work. Work done in collaboration with, or with the assistance of others, is indicated as such. I have identified all material in this dissertation which is not my own work through appropriate referencing and acknowledgement. Where I have quoted or otherwise incorporated material which is the work of others, I have included the source in the references. Any views expressed in the dissertation, other than referenced material, are those of the author.

Ben Browne, Wednesday 3$^{\text{rd}}$ May, 2023

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Ethics Statement

- “This project did not require ethical review, as determined by my supervisor, Ruzanna Chitchyan”;

Supporting Technologies

- I used the Pandas, Geopandas and Numpy libraries to support the pre-processing of data
- I used Matplotlib, Bokeh and mpld3 for data visualisation and the plotting of maps
- I used the Flask micro web framework and Jinga template engine to create a Pythonic Web Application
- The web application was hosted and deployed on PythonAnywhere, accessible at https://www.heatpumpready.xyz/
- The codebase can be browsed at https://github.com/benbrowne7/EPCProject
- The EPC OpenDataCommunities API was used to request EPC certificates, accessible at https://epc.opendatacommunities.org/domestic/search

Notation and Acronyms

GGE	:	Greenhouse Gas Emissions
EPC	:	Energy Performance Certificate
HPR	:	Heat Pump Readiness
HP	:	Heat Pump
ASHP	:	Air Source Heat Pump
GSHP	:	Ground Source Heat Pump
COP	:	Coefficient of Performance
SPF	:	Seasonal Performance Factor
CSE	:	Centre for Sustainable Energy

Chapter 1

Introduction

1.1 Motivation

Climate Change remains a high priority global challenge, at the forefront of policy makers decisions, with particular responsibility falling to those governing more developed nations, equipped with the workforce and financing opportunities to drastically decrease their contributions to climate change, primarily through the reduction of greenhouse gas emissions (GGE) throughout the economy and infrastructure. In the most recent AR6 Climate Change 2023 report by the IPCC [25] it is described how, 'Human activities, principally through emissions of greenhouse gases, have unequivocally caused global warming, with global surface temperature reaching 1.1°C above 1850–1900 in 2011–2020', with global greenhouse gas emissions continuing to rise from 'unequal historical and ongoing contributions arising from unsustainable energy use, land use and land-use change, lifestyles and patterns of consumption and production across regions, between and within countries, and among individuals'. The impacts and dangers of unchecked greenhouse gas emissions are clear, with many climate related risks being assessed as higher (vs AR5 [2014]) and high confidence in projected long-term impacts being up to 'multiple times higher than currently observed'[25]. The 2020's therefore represent a critical decade in laying the foundations for a sustainable future and to mitigate the large, compounding adverse impacts associated with higher global warming levels.

The UK has recognised the gravity of the situation, becoming the first major economy to pass net zero emissions into law, targeting GGE (85% being CO2 emissions [8]) to net zero by 2050 compared with the previous target of at least 80% reduction from 1990 levels.[1] The UK has already made significant progress towards its goals, with GGE almost halving from 1990 levels [20]. To maintain this trend it's imperative our industries, transport, fuel and power supplies and the heating of buildings are continued to be decarbonised through technological advancements and substantial funding through both fiscal and private investments.

The tool focuses on the 'Heat and Buildings' aspect of the Net Zero Strategy published by HM Government in October 2021 [20]. The heating for homes and work-spaces contributes to 'almost a third of UK carbon emissions', with the 'Heat and Buildings Strategy' [19] outlining that to meet net-zero **'virtually all heat in buildings will need to be decarbonised'**. This will be achieved via improving the energy efficiency of the UK's housing stock and accelerating the transition away from fossil fuel heating, towards low carbon heating via the electrification of heat through heat networks and hydronic heat pumps. The idea of replacing natural gas in the grid to low-carbon produced hydrogen is also under consideration, but is unproven and not yet regarded as a serious option for the decarbonising of the UK's housing stock.

Heat Pumps, on the other hand, are a proven, scalable option for decarbonising heat and continue to become more affordable to consumers as the technology matures. This project, specifically, uses Energy Performance Certificates (EPC's) for domestic properties to assess a property's 'heat pump readiness', at an individual, postcode and local authority district level, in the form of a tool available on the web, a metric not included in current EPC's. The shortcomings of basing such a 'readiness' rating on these EPC parameters are detailed later in this report 4, as in their current form, EPC's have numerous criticisms and potential inaccuracies.

[1] https://www.gov.uk/government/news/uk-becomes-first-major-economy-to-pass-net-zero-emissions-law

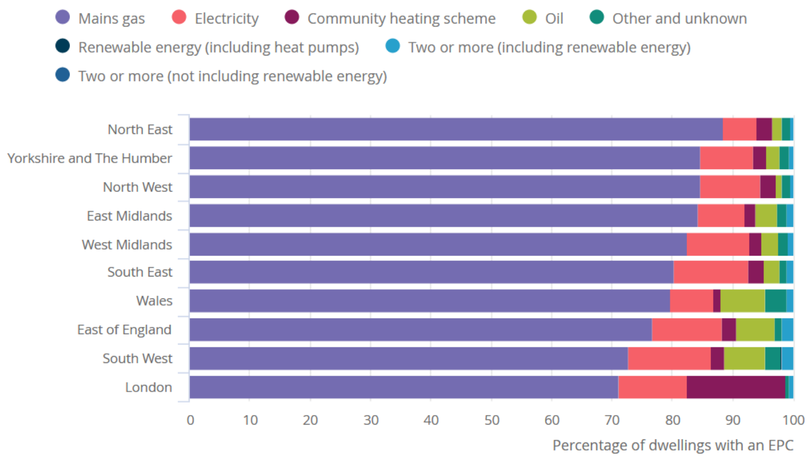


Figure 1.1: Main fuel type used in central heating, English regions and Wales, up to March 2022 [15]

Heat pumps are an established technology, with the first functioning heat pump built in 1856 [39], but falling costs paired with increased efficiencies and adaptation for domestic properties have positioned them as crucial in the UK's strategy to decarbonise the heating of our buildings, with aims to reach 600,000 hydroponic heat pump deployments a year by 2028 [19]. Their importance in fulfilling our ambitious net-zero targets cannot be understated and I believe this tool can play a small role in this, by helping to address some of the challenges rapid adoption of heat pumps faces. Figure 1.1 gives us an idea of how early the UK is on this adoption curve, with 80% of dwellings in the UK with an EPC still using mains gas to fuel central heating [15]. The scale of this adoption over the upcoming decades will partially determine the UK's ability to sufficiently reduce its emissions in line with targets, whilst improving thermal comfort and decreasing utility costs for households, benefits which are unknown or overlooked by many. However, as described in 'UK Housing: Fit for the Future, 2019' [5], GGE reductions from UK housing have stalled and heat pump uptake is low 'symptomatic of low awareness, financing constraints, concerns around disruption and difficulty in finding trusted installers with the right skills'. Recent statistics suggest uptake rates remain low, with only 412 heat pumps per 100,000 people, ranking 20th out of the 21 European nations considered.[2]

Clearly, current uptake rates fall well below targets and present a *significant* challenge in sufficiently increasing their adoption at a national level. It is further noted in [5] how there 'is not enough use of local and urban planning to make progress on climate change mitigation or adaptation'. My tool aims to aid local planning regarding heat pump uptake by providing insight into 'candidate' areas, areas with a high average 'heat pump ready' (HPR) rating, or higher than average energy efficiency ratings for the local authority district. The Individual user is also considered, providing a summary of important EPC information, a individual HPR rating for the dwelling, comparisons between dwellings of the same postcode and eligibility check for the Boiler Upgrade Scheme.[3]

1.2 Intended Aims and Contributions

The following constitute as the **intended aims and contributions of the tool and report**:

A1 An outlining of the current state of heat pump adoption in the UK and the challenges faced

A2 Informing households of the state of their energy performance, allowing comparisons between peers and the requirements in qualifying for related government grants (Boiler Upgrade Scheme)

A3 The usage of Energy Performance Certificates to assess a dwellings 'heat pump readiness' (HPR Rating) and the limitations of doing so

A4 Data visualisation to allow policy makers and officials to assess the energy performance of areas, including their 'heat pump readiness', whilst allowing for comparisons between areas

[2]https://www.theecoexperts.co.uk/heat-pumps/top-countries
[3]https://www.gov.uk/apply-boiler-upgrade-scheme/check-if-youre-eligible

A5 User friendly interface, with insights and information easy to obtain

1.3 Upcoming Sections of the Report

In Background and Related Work chapter 2 I explore the origins and intended purposes of the Energy Performance Certificate, as well as its criticisms and uses by others; then provide a brief technical overview of heat pumps before summarising the current state of their adoption in the UK and the challenges faced in accelerating this adoption in the years to come. In the Existing Tools section 2.3 we detail existing tools and software relating to EPCs and heat pumps.

In the Project Execution chapter 3, a high level overview of tools architecture and framework is discussed, the methodology and justification for the calculation of the 'heat pump readiness' rating, before focusing on different functionalities of the tool in turn, how they were implemented and how they contribute to the overall aims of the project.

In Critical Evaluation and Further Work 4 first I discuss the evolution of the project and any major changes made throughout its development, then I discuss the merits and shortcomings of the conclusions drawn from the tools functionalities; in their usefulness to users, accuracy and reliability. Additional factors not considered in the tools 'assessment of heat pump readiness' are explored, alongside ways in which the tool could incorporate these factors and the potential benefits of doing so.

Finally the Conclusion chapter 5 summarises the work completed, reaffirming the aims and objectives of the project and the extent to which these have been fulfilled.

Chapter 2

Background and Related Work

2.1 Energy Performance Certificates

As this project draws heavily on the information provided by Energy Performance Certificates (EPC's) it is important to gain a deeper understanding of how they are produced, potential drawbacks in their methodologies and their overall purpose and effectiveness.

2.1.1 EPC Origins and Use

The inception of EPC's can be traced back to the Energy Performance of Buildings Directive (EPBD, 2003) which became law in January 2006 [42], one of the first collective efforts to reduce CO2 emissions from buildings in Europe, which at the time were estimated to account for approximately 40-50% of CO2 emissions [42]. The EPBD had 3 main aspects: 'to provide a valid methodology for calculating the energy performance of buildings', 'to provide application of minimum requirements on the energy performance of new buildings and large existing buildings that are subject to major renovation' and 'to inform purchasers and tenants of the energy efficiency of a property when set against a national benchmark value'. Thus, EPC, an asset rating, is required in the UK whenever a building is constructed, sold, let or assessed for certain funding schemes.

EPCs exist for both domestic and non domestic dwellings, with the related display energy certificate (DEC) for public buildings. This project focuses specifically on the domestic EPC.

Figure 2.1 details some of the processes behind EPC generation and the various ways in which they can be used. Specifically the project utilises the 'EPC provides information on potential improvements' and 'EPC data used to gain knowledge of building stock' uses, to provide related insights to users in the form of a tool.

In order to meet the requirements set out in the EPBD, a National Calculation Methodology was developed, namely, the Standard Assessment Procedure (SAP) for new dwellings and the Reduced Data Standard Assessment Procedure (RdSAP 2012) for existing dwellings. The 'Reduced Data' aspect of the RdSAP methodology refers to the use of a 'set of assumptions about the dwelling based on conventions

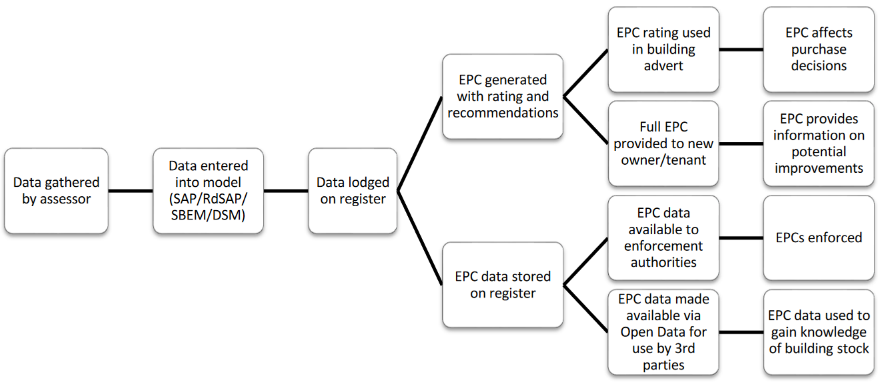


Figure 2.1: Process for generation and use of EPCs [12]

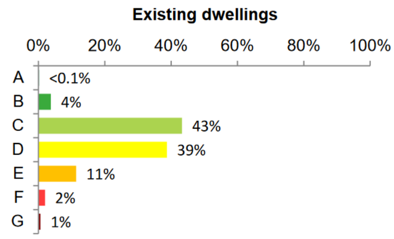


Figure 2.2: Energy efficiency ratings: existing properties, England, Jan to March 2022 [13]

and requirements at the time it was constructed'.[1] These assumptions imply that EPC's for *existing dwellings are likely less accurate* than those for new dwellings, with the most accurate EPC's attributed to new dwellings assessed after June 2022, produced using the updated SAP 10.2 methodology.

SAP works by 'assessing how much energy a dwelling will consume when delivering a defined level of comfort and service provision' [42]. Information about a building, such as wall type and levels of insulation are fed into the SAP algorithm, which then makes assumptions about the thermal properties of the *building fabric*, *occupancy* and *behaviour* to calculate the theoretical heat loss of the property [22].

SAP quantifies a dwellings performance in terms of:

- energy use per unit floor area
- a fuel-cost-based energy efficiency rating (the SAP Rating)
- emissions of CO2 (the Environmental Impact Rating)

The SAP (EPC) rating ranges from A (most efficient) to G (least efficient), with its integer counterparts units in £/kWh/m2. Figure 2.2 shows the distribution of this rating for existing dwellings in England, the majority being rated either D or C.

The EPC itself consists of over 90 features and improvement recommendations ranging from loft insulation to solar photovoltaic panels, alongside associated estimated costs. The features include a unique property identification key 'lmk-key', details on the properties location, form, age and various other details such as estimated CO2 emissions, estimated costs for heating/lighting and feature specific descriptions and ratings. An example of a full EPC is included in the Appendix A

This project primarily uses the fuel-cost-based energy efficiency rating along with its sub components that assess the energy efficiencies of various features of the dwelling (i.e., loft insulation), in order to calculate a 'Heat Pump Ready' rating.

The EPC dataset used organises the certificates by Local Authority District (LAD) and so is worth outlining their definition. Local Authority Districts or Local Government Districts are a level of sub-national division of England used for the purposes of local government, the equivalent in Wales being 'principle areas' or counties. Structural changes to these local governments in England are not uncommon consisting of merges and abolishments of LADs. These changes posed a small challenge when comparing between LADs, as discussed in section 3.2.1.

EPCs are used to set energy efficiency standards, such as the Minimum Energy Efficiency Standard (MEES), which applies to domestic private rented properties. MEES currently requires a minimum EPC rating of E, rising to a C by 2030 [23]. Figure 2.2 shows the distribution of EPC ratings across England, currently only 47% of existing dwellings are rated C or above. In order to meet the 2030 MEES, property owners will need to make efficiency improvements; often via wall or loft insulation upgrades.

Figure 2.3 shows how these installations, under government schemes, have decreased in frequency over recent years, *a trend that must be reversed*. Increasing the rate of these installations will also be important in accelerating the rate of heat pump adoption, with eligibility for the Boiler Upgrade Scheme 2.3.3 relying on no outstanding wall and loft insulation recommendations alongside a valid EPC (<10 years since date of certification).

2.1.2 EPC Criticisms

There are, however, a range of criticisms regarding EPC methodology and their accuracy, with a comprehensive overview detailed in [33].

[1] https://www.gov.uk/guidance/standard-assessment-procedure

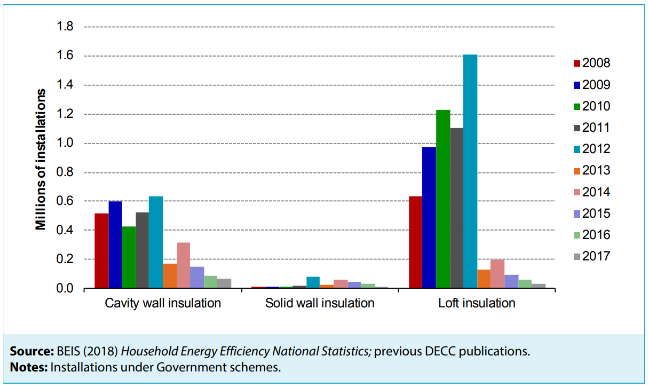


Figure 2.3: Insulation Installations under Government Schemes [5]

It is argued that 'for homeowners and consumers to make meaningful comparisons and informed decisions regarding home improvement upgrades and ultimately improve the building stock of a country, EPC ratings must be consistent and rigorous'. However, research carried out by D. Jenkins [26], indicates the level of quality and outputs from a SAP/RdSAP can be variable, with **multiple assessors evaluations of the same property often producing markedly different results** and therefore, variable recommendations as to how the properties energy performance can be improved. These conclusions are echoed by A. Hardy and D. Glew [22], who estimate the proportion of EPCs containing errors to be between 36% - 42%, with many errors caused by EPC assessors disagreeing on building parameters such as floor type, wall type and built form. Consequently, they found the energy efficiency rating of EPCs to 'typically change by 4 points due to errors' [22]; research by D. Jenkins found EPC ratings to have even greater levels of uncertainty, with an average difference of 11.1 points for similar properties [26]. If EPC stated recommendations are unreliable and misguided this could lead to unnecessary energy efficiency improvement investments that could otherwise have been put towards low carbon solutions, i.e., heat pumps, or if suitable recommendations are overlooked, could result in **sub-optimum operating efficiencies** of subsequent heat pump installations. This is a realistic concern, with the English Housing Survey Energy Report 2020-21 [14] finding that, of surveyed owner occupiers (including shared owners) who had remembered seeing an EPC with energy efficiency recommendations (1.2 million households), 57% mentioned that an energy efficiency improvement measure mentioned by their EPC had been carried out by themselves or someone in their household.

Countering this, research suggests in relation to number or types of energy efficiency measure adopted, there has been little to no statistical significance detected between groups with and without an EPC [30]. Regardless, it is clear that EPC's alone can only play a small role in raising the minimum energy standards inline with MEES and boosting domestic heat pump adoption.

The theoretical approach to EPC methodology, whilst allowing for comparisons to be more easily drawn between properties, a feature of the 'heat pump ready' tool 3.2.5, it does not necessarily reflect energy costs in reality or, therefore, the most effective improvement measures, which has implications for public trust in the EPC as an information source [33]. S. Organ continues by suggesting an approach which **combines theoretical information with actual energy prices and consumption** (ie., smart meters), as having the potential to 'increase usefulness, relevance and foster trust'. Such an EPC would allow for more meaningful comparisons to be drawn using the tool, having a greater influence in increasing a dwellings real energy performance, as it could be argued that decreasing energy consumption and its associated costs through behavioural adjustments is more appealing than expensive, one-time upgrades for home owners. The advantages of the combination of theoretical EPC information, with actual recorded data for dwellings, for the tool, is discussed further in section 4.4.

2.1.3 Positive Role of EPC

EPC's have been used in studies to analyse and predict certain properties of a dwelling. For instance, [16] investigates the **relationship between EPC rating and transaction (sale) prices** in England, using over 333,000 dwellings sold at least twice in the period from 1995 to 2012. Using hedonic regression in conjunction with an augmented repeat sales regression, they found a *positive relationship between the energy efficiency rating of a dwelling and the transaction price per square metre.* It would appear,

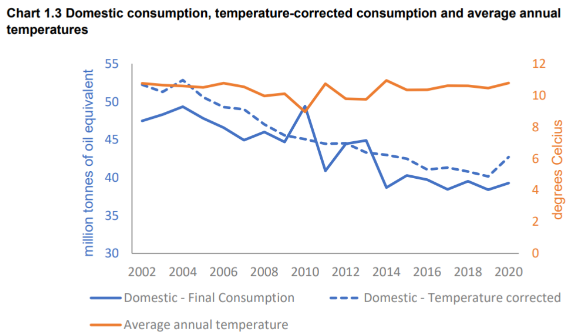


Figure 2.4: Domestic Energy Consumption [41]

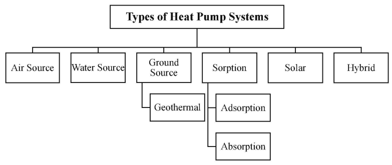


Figure 2.5: Types of Heat Pump [17]

according to these results, that the EPC has fulfilled some its purpose in 'informing purchasers and tenants of the energy efficiency of a property when set against a national benchmark value (EPC)' and achieving market transformation through this. It was concluded that dwellings in the A and B bands sold for a 5% premium; all else equal and those in band C for a 1.8% premium, albeit with considerable variation in those effects across property type and region.

Although this project has used EPC's to assess different variables (heat pump readiness), it is important to understand that EPC's are recognised by potential home buyers, with the energy efficiency of a dwelling providing incentive to pay more; all else equal.

2.2 Heat Pumps

Temperature adjusted domestic energy usage peaked at approximately 53 tonnes of oil equivalent in the early 2000s, shown in Figure 2.4 and has been trending downwards since, which we can attribute to gradual improvements in the energy efficiencies of dwellings, appliances and levels of public perception regarding climate change and the need to curtail energy usage. Covid-19 restrictions and the 'stay at home' policies have resulted in the first yearly uptick in domestic energy consumption for 15 years but this is an outlier in an otherwise encouraging trend. As outlined in the UK Governments Heat and Buildings Strategy [19] in 2019, this energy use in buildings accounted for 23% of UK emissions, with homes specifically accounting for **17% of emissions**, the vast majority from heating.

2.2.1 Heat Pumps Brief Technical Overview

To meet our goals of net-zero by 2050, decreasing our net energy use in homes is not enough, the heating of our homes must be completely decarbonised and electrified, through the mass adoption of heat pumps. The advantage of heat pumps over traditional heating methods lies in their ability to extract heat from a *low temperature source* (such as ambient air) and supplying it to a *high temperature sink* (internal space or domestic hot water), whilst *consuming high grade energy* (electricity) [21].

There are currently various categories of heat pump technology on the market, shown in Figure 2.5. The most common in the UK are air source (ASHP) and ground source (GSHP) heat pumps, with the number ASHPs in operation 5x higher than the number of GSHPs in 2019.[2] A Canadian study shows GSHPs have rather consistent performance throughout the year unlike ASHPs, whose performance is highly location specific [37]. It was also found that GSAHPs (ground source to air) perform better in colder climates than ASHPs due to a higher COP in lower temperatures and had better greenhouse gas emission savings when compared against direct electric heating (70% vs 40% reduction for GSHP and

[2]See https://www.statista.com/statistics/740491/heat-pumps-in-operation-uk/

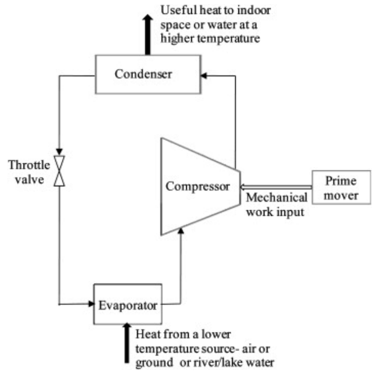


Figure 2.6: Typical Heat Pump Cycle

ASHP respectively). Despite the relative performance advantages of GSHPs, ASHPs are the most widely installed in the UK, due to their quicker installation times, lower initial costs and significantly lower space requirements; with the average GSHP requiring 'between 600 and 1200 square meters of land'[3]. It's these footprint requirements that make them 'unsuitable for retrofit in urban and metropolitan areas' [4] and therefore unsuitable for the majority of the UKs housing stock.

Figure 2.6 shows the heat pump cycle. Heat from the lower temperature source is extracted via a fan (ASHP) or heat collector (GSHP) from a source; heat is then used in the evaporator to evaporate the refrigerant. This gaseous refrigerant is then compressed, raising its pressure and temperature and this generates high-grade heat which is then used to heat indoor spaces or water within a heat distribution network. In the process, the refrigerant cools and condenses and is then passed through a throttle/expansion valve to decrease its pressure before the cycle begins again. Thus, heat pumps operate using the *reverse refrigeration cycle* and so also have the capability for cooling [21].

The performance of a heat pump is expressed in terms of its Coefficient of Performance (COP):

$$COP = useful\ heat\ output\ (kW)/\ power\ consumed\ (kW)$$

With COPs reaching over 4 in ideal conditions, heat pumps can operate at a very high efficiency, resulting in lower carbon emissions and savings in primary energy consumption when deployed at scale. (The related Seasonal Performance Factor (SPF), aims to represent the average annual performance in a given location, based on the average outdoor temperatures throughout the year [39].) There are various studies supporting these claims, such as studies for the Italian and Chinese energy systems [2] [44] and more focused case studies in California [3] where heat pumps were identified as a key component in decarbonising the heating sector, reporting **up to 50% emission reductions.** It is important to note that the performance of a heat pump and therefore emission reductions potential, is **strongly influenced by ambient conditions of the heat pump, the installation, and the building characteristics** [4], as well as **user behaviour and preferences.**

2.2.2 Heat Pump Adoption

This potential in domestic heat pumps has been recognised for some time, with papers published over a decade ago exploring the factors affecting their uptake [38] and potential life cycle effects and implications for the UK [21].

At the time, results showed that heat pumps had greater environmental effects than gas boilers due to the use of electricity, despite savings in CO2 emissions, with [21] concluding that 'it is doubtful whether heat pumps can contribute to a more sustainable domestic energy supply in the UK', but that 'results suggest that the *environmental sustainability of all heat pump systems improves with the greater penetration of renewables in the electricity mix*'. Since the publication of the report, significant progress has been made regarding low-carbon electricity generation, with 48.5% generated from low carbon sources in 2022 vs less than 20% in 2010[4], a trend that is only poised to continue, with targets to completely decarbonise the power sector by 2035[4], subject to security of supply.

Heat Pumps potential for energy savings in the UK's existing building stock was modelled by J. Rosenow and P. Guertler [36], who estimated heat pumps 'current technical potential' (not regarding

[3]https://rabrown.co.uk/faq/how-much-space-do-i-need-for-the-ground-source-heat-pump-collector/
[4]https://www.nationalgrid.com/stories/energy-explained/how-much-uks-energy-renewable

their cost effectiveness) reduction in household energy consumption by 2035 as a percentage of energy consumption in 2015, to be 24%, with another potential 27% savings coming from general energy efficiency improvements. They also model potential energy savings under 'cost-effective' scenarios, where rates of deployment are informed by historical deployment and follow a traditional S-curve trajectory for market diffusion. In this scenario only 12% of heat pumps 'current technical potential' by 2035 is achieved, equating to only 2.7 million heat pumps. This is evidence that the UK is **behind the curve on heat pump adoption** and that the current uptake trajectory will be insufficient in successfully decarbonising the housing stock by 2050, where a 'large share of this technical potential will need to be delivered.'

Regardless, the potential of heat pumps in reducing emissions has boosted their importance in recent years, with policy makers of various countries recognising their potential towards a sustainable future, evidenced by incentives towards their adoption, such as the UKs £450m 3 Year Boiler Upgrade Scheme (BUS)[5], replacing the Domestic Renewable Heat Incentive[6] (RHI) scheme and £60m Heat Pump Ready Programme to provide funding for pioneering heat pump technologies. The new BUS funding provides grants of **up to £5000** contributing to the cost and installation of an air source heat pump and **up to £6000** for ground source heat pumps. This new scheme differs to the old RHI by providing funds for upfront costs vs subsidising electricity costs when generated though heat pumps.

The BUS has recently been extended until 2028 after criticism of the scheme by Members of the House of Lords environment and climate change committee, for failing to meet goals with only roughly 1/3 of the schemes annual budget used since its launch in May 2022, equating to 9,981 voucher redemption's as of 31st March 2023[7] (figures updated montly). The committee said that public awareness of low-carbon heating solutions was 'very limited' and that promotion of the scheme had been 'inadequate', also blaming a shortage of heat pump installers, 'insufficient independent advice for homeowners' and the misleading messages of 'presenting hydrogen as a serious option for home heating for the short and medium term' in negatively affecting take-up of established LCS for heating such as heat pumps[8].

This criticism highlights that despite the support of fiscal policy, significant challenges remain in achieving the level of heat pump adoption required, evidenced by the UKs lacklustre uptake rates with only 42,779 installations in 2022, **one of the lowest rates in Europe**, a far cry away from the 600,000 a year goal by 2028[9]. One of the main barriers in heat pump adoption in the UK is the discrepancy between the running costs of gas and electricity, not isolated to the UK, with studies in the EU also identifying the price ratio between alternative energy sources and electricity, investment costs as well as installation costs as major barriers in the European heat pump market [34].

Research by J.M de Waardt [11] summarises various studies on the factors influencing residential heat pump adoption and concludes that 'age, income, educational level, construction year, size of living area, and urban area' are the most important influencing factors.

Other more unique challenges to retrofitting the UKs housing stock include space requirements, planning regulations required in installing new low carbon heating systems [7], as well as ensuring infrastructure can support the additional electricity demand via connected substations and that the **stability of the national grid is maintained** [7]. It is also important to consider the life cycle effects of gas boilers on low-carbon heating system uptakes, with the average life cycle of a gas boiler up to 15 years, giving rise to a delay in technology switches, even if the owner is aware or willing to upgrade to a LCS in the future. Figure 2.7 shows the number of heat pumps in operation in the UK from 2013-2019 [40], with the **average %y/y increase in the number operational heat pumps at 15%**. Assuming this rate of increase remains constant (a rate which becomes increasingly more difficult to maintain as the market becomes more saturated), there will be approximately 18 million heat pumps over the UK, in operation by 2050 against a projected 27m+ households in England alone [32]. This implies a maximum of 2/3 of homes equipped with heat pumps, despite net-zero requiring 'virtually all heat in buildings to be decarbonised' [19] or '27.2 million heat pumps by 2050', as set out in the Climate Change Committees' Sixth Carbon Budget [6], assuming no other low-carbon heating solutions achieve mass adoption in this time frame (hydrogen boilers). This mass adoption would also require a **drastic increase in the number of qualified heat pump installers**, with research suggesting that widely promoted 50,000 installers required to meet the government's ambitious annual heat pump installation target of 600,000, **may be**

[5] https://www.ofgem.gov.uk/environmental-and-social-schemes/boiler-upgrade-scheme-bus
[6] https://www.ofgem.gov.uk/environmental-and-social-schemes/domestic-renewable-heat-incentive-domestic-rhi
[7] https://www.ofgem.gov.uk/publications/bus-monthly-scheme-update
[8] https://www.theguardian.com/environment/2023/feb/22/450m-boiler-upgrade-scheme-failing-deliver-heating
[9] https://www.newscientist.com/article/2328095-uks-slow-heat-pump-efforts-will-take-600-years-to-meet-2050-target/

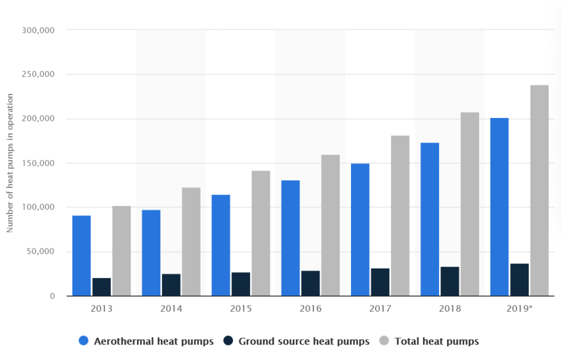


Figure 2.7: Annual Amount of Heat Pumps in Operation in the UK 2013-2019 [40]

three times lower than the number required, at an estimated 142,500 trained installers, of which, 87,000 would need to be newly trained heat pump installers, rather than up skilled gas safe installers [10].

Clearly, there currently exists a *disconnect* between the UK's targets and real-time uptake rates and much more must be done to address the numerous discussed structural and infrastructural barriers, as well as consumers economical concerns over switching to heat pumps and overall public acceptance and awareness regarding the environmental and cost benefits of heat pump technology, an understanding that can often be lacking, even in developed societies [24]. Without addressing these concerns urgently, the UK will likely fall short of its ambitious heat pump targets and by extension, net-zero by 2050 as a result.

More localised, targeted schemes, such as the 'Clean Heat Streets' project in Oxford[10], aim to address some of these concerns. This particular trial is led by a consortium consisting of Samsung, Oxford City Council, University of Oxford and other supporting partners, who were awarded £3.2m through the Net Zero Innovation Portfolio (NZIP), as part of the Governments Heat Pump Ready funding programme. Rose Hill is the area to be trialled, aiming to connect the community to local installers, helping to remove the barriers and costs from the current heat pump installation process, whilst testing the robustness of the local electricity network when faced with a sudden increase in demand. Ultimately the project aims to create a more *streamlined* approach to installations through establishing a **network of skilled installers and supply chains**, as well as saving time, money, and resources; all key barriers to heat pump adoption. The advantages of such an approach are already apparent, with the costs of installation around a third less than a typical installation (£7k-£13k), paired with the £5k BUS grant, taking the final cost down to £2.6k. If trial projects such as this can be shown to be effective in boosting local heat pump installation numbers, then similar projects, only larger in scale and number, could form an important part of the UK's aims of fully decarbonising its building's heat and accelerating heat pump adoption.

2.3 Existing Tools

2.3.1 Heat Pump Tools

Tools to aid heat pump adoption include size, costs and design specification calculators. Cost Calculators, specifically regarding ASHPs, provide estimated running costs or installation costs.

Great Homes' 'Air Source Heat Pump Running Costs Calculator'[11], takes actual annual gas usage for the home supplied by the user and by making assumptions on typical gas boiler and heat pump efficiency (Seasonal Performance Factor SPFH2) alongside user adjustable gas/electricity prices, calculates a likely heat pump electricity demand and subsequent annual running costs estimation for the home as output. Figure 2.8 shows the inputs/outputs of the tool.

It is a relatively simple tool to operate, requiring little user specific inputs and outputs information useful to a user trying to gain a better understanding of the potential benefits of switching to a low-carbon system for heating over traditional gas boilers. It also highlights the consequences of the currently elevated

[10] https://www.oxford.gov.uk/news/article/2383/oxford_to_trial_neighbourhood_heat_pump_scheme_in_rose_hill
[11] https://great-home.co.uk/air-source-heat-pump-running-costs-calculator/

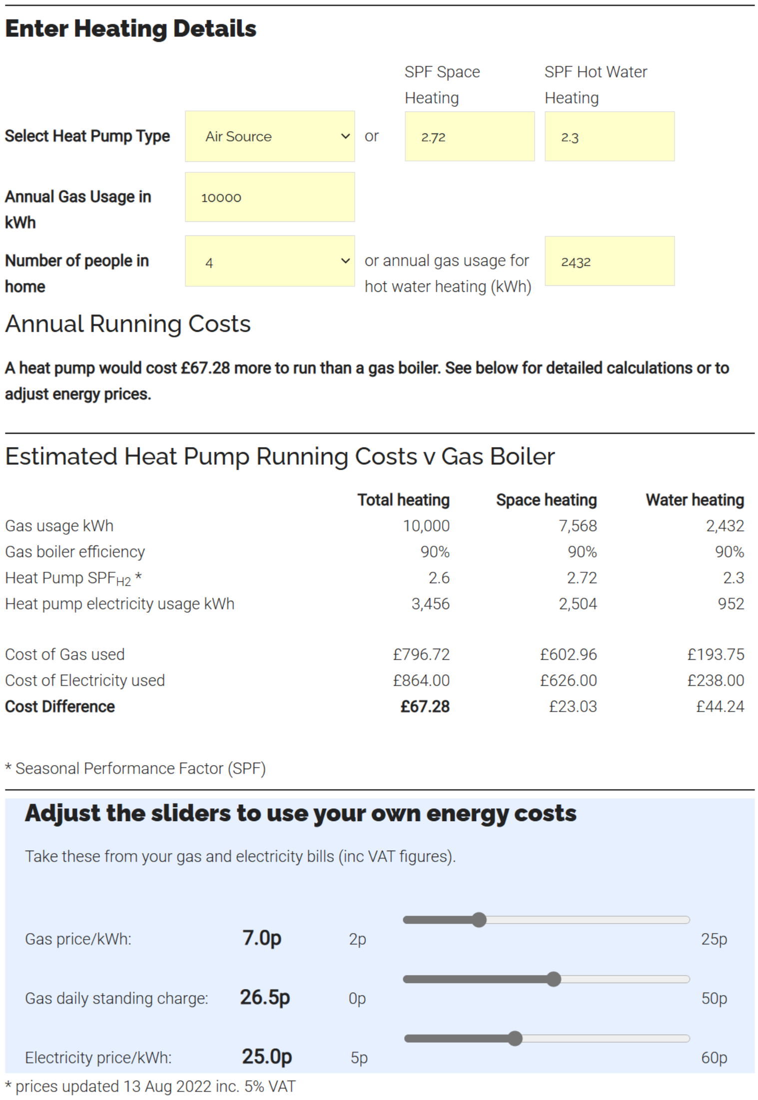


Figure 2.8: Example Heat Pump Running Costs Estimator

electricity costs; inputting average annual gas usage (12,000 kWh), estimated by Ofgen[12], with the tools default gas/electricity prices/kWh (as of 13th August 2022), total heating running costs for an ASHP are estimated to be £80 higher or at a 9% premium compared to a gas boiler. Being able to compare the running costs of a heat pump against an existing gas boiler makes the tool *superior* to its competitors, which only provide heat pump cost estimates.

Calculators such as those from nesta[13] and theecoexpert[14] provide the means of estimating the install cost of an ASHP. Theecoexperts' tool only has input for the size of the home (number bedrooms) but also allows the user to request a heat pump quote, which gets an appropriate provider in contact with the user. Nestas' tool provides cost estimates 'based on statistical modelling of installations recorded by MCS', with fields such as location, type of property, age and size taken into account. The MCS database contains information about past heat pump installations including the hardware installed, the kind of home it's installed into and the amount paid, so results in a more accurate estimation for the user.

MCS Certified, an industry-led and nationally recognised quality assurance scheme for low-carbon technologies provides a multitude of tools to aid heat pump deployment. For consumers they have a 'Find a Contractor' page[15] that, given a product to install and region/location returns a list of MCS certified contractors, with certification details, services offered and contact details. The tool also has a 'Registered for Boiler Upgrade Scheme' which directly filters contractors by those who are registered to install heat pumps and/or biomass boilers under the Boiler Upgrade Scheme, a useful feature for those wanting to find quality assured installers under the BUS.

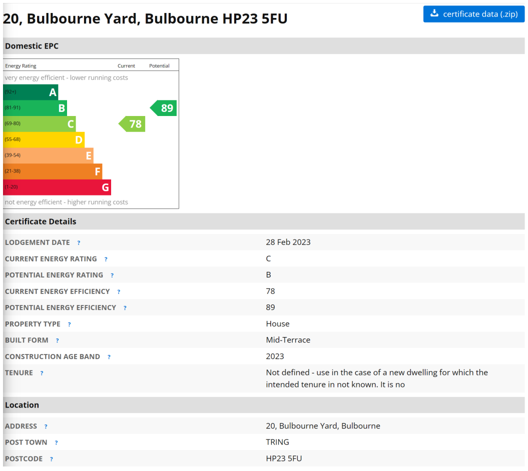
MCS also has a 'Heat Pump Calculator', a spreadsheet providing a method to carry out the design calculations required by MIS 3005 (Heat Pump Standard). The process involves conducting a room by room heat loss survey, in order to properly size the required heat pump. The MCS (Microgeneration Certification Scheme) is required to be able to claim any government grant (BUS).

MCS also provides a 'Heat Pump System Performance Estimation Template' (HPSPE), a spreadsheet that provides a method for calculating the electricity consumption of a heat pump when delivering a given annual heat/hot water demand at a given flow temperature, also comparing to any existing heating source. Potential uncertainties of such a prediction are identified, categorised as 'Fixed', 'Variable' or 'Random', examples include energy assessment via the EPC, ambient temperatures and user behaviours respectively. The combined effect of these factors on energy consumption and running costs makes overall predictions difficult but states an accuracy of '+/-25-30% would not be unreasonable in many instances[16].' These tools, along with the Heat Pump Standard - Design (MIS 3005-D) and the Heat Pump Standard - Installation (MIS 3005-I) specifications for MCS contractors can be found at[17].

2.3.2 EPC Tools

EPC certificates can be browsed at[18], with filters by location, property type, floor area and energy rating. The certificate data can be downloaded or viewed in full as shown in Figure 3.3. A developer API, incorporated into the site, allows for requesting individual EPCs or multiple, filtered by location/energy band/dates/floor areas or a combination, with a maximum return result of 10,000 records for a single request. The API supports various Accept headers to alter the response format, which includes CSV, Excel, JSON and Zip. The API requires a registered account, with all requests to the API authenticated to the account using HTTP Basic Auth. Individual Domestic recommendations can be acquired through a separate API using a unique 'lmk-key' found on each EPC, this API is incorporated into the tool for this project. Certificates can also be found using the GOV.uk[19], which displays key EPC information, recommendations, estimated energy uses for space/water heating and details such as assessor and accreditation scheme contacts.

[12]https://www.ofgem.gov.uk/information-consumers/energy-advice-households/average-gas-and-electricity-use-explained
[13]https://www.nesta.org.uk/project-updates/a-calculator-to-estimate-the-cost-of-a-heat-pump/
[14]https://www.theecoexperts.co.uk/heat-pumps/air-source-heat-pump-cost-calculator
[15]https://mcscertified.com/find-an-installer/
[16]https://mcscertified.com/wp-content/uploads/2022/05/MCS_031_MCS$_{H}eat_{P}ump_System_Performance_Estimate_Issue-$3.0_290422.$xlsm$
[17]https://mcscertified.com/standards-tools-library/
[18]https://epc.opendatacommunities.org/domestic/search
[19]https://find-energy-certificate.service.gov.uk/find-a-certificate



20, Bulbourne Yard, Bulbourne HP23 5FU

certificate data (.zip)

Domestic EPC

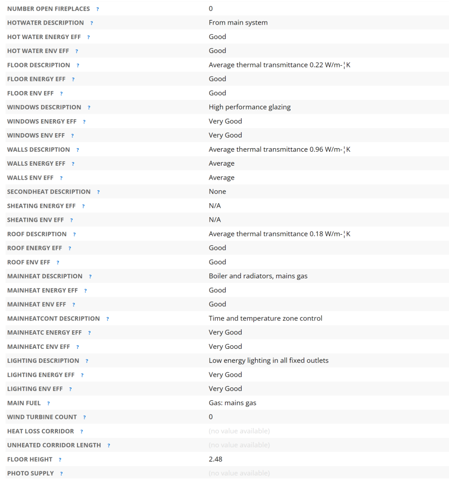
Certificate Details

LODGEMENT DATE ?	28 Feb 2023
CURRENT ENERGY RATING ?	C
POTENTIAL ENERGY RATING ?	B
CURRENT ENERGY EFFICIENCY ?	78
POTENTIAL ENERGY EFFICIENCY ?	89
PROPERTY TYPE ?	House
BUILT FORM ?	Mid-Terrace
CONSTRUCTION AGE BAND ?	2023
TENURE ?	Not defined - use in the case of a new dwelling for which the intended tenure in not known. It is no

Location

ADDRESS ?	20, Bulbourne Yard, Bulbourne
POST TOWN ?	TRING
POSTCODE ?	HP23 5FU

(a) EPC 1



NUMBER OPEN FIREPLACES ?	0
HOTWATER DESCRIPTION ?	From main system
HOT WATER ENERGY EFF ?	Good
HOT WATER ENV EFF ?	Good
FLOOR DESCRIPTION ?	Average thermal transmittance 0.22 W/m-¦K
FLOOR ENERGY EFF ?	Good
FLOOR ENV EFF ?	Good
WINDOWS DESCRIPTION ?	High performance glazing
WINDOWS ENERGY EFF ?	Very Good
WINDOWS ENV EFF ?	Very Good
WALLS DESCRIPTION ?	Average thermal transmittance 0.96 W/m-¦K
WALLS ENERGY EFF ?	Average
WALLS ENV EFF ?	Average
SECONDHEAT DESCRIPTION ?	None
SHEATING ENERGY EFF ?	N/A
SHEATING ENV EFF ?	N/A
ROOF DESCRIPTION ?	Average thermal transmittance 0.18 W/m-¦K
ROOF ENERGY EFF ?	Good
ROOF ENV EFF ?	Good
MAINHEAT DESCRIPTION ?	Boiler and radiators, mains gas
MAINHEAT ENERGY EFF ?	Good
MAINHEAT ENV EFF ?	Good
MAINHEATCONT DESCRIPTION ?	Time and temperature zone control
MAINHEATC ENERGY EFF ?	Very Good
MAINHEATC ENV EFF ?	Very Good
LIGHTING DESCRIPTION ?	Low energy lighting in all fixed outlets
LIGHTING ENERGY EFF ?	Very Good
LIGHTING ENV EFF ?	Very Good
MAIN FUEL ?	Gas: mains gas
WIND TURBINE COUNT ?	0
HEAT LOSS CORRIDOR ?	(no value available)
UNHEATED CORRIDOR LENGTH ?	(no value available)
FLOOR HEIGHT ?	2.48
PHOTO SUPPLY ?	(no value available)

(b) EPC 2

Figure 2.9: EPC Data Fields

2.3.3 Heat Pump Adoption Modelling

Nesta, in partnership with the Energy Saving Trust, worked on a project that used Energy Performance Certificates to predict heat pump uptake[20]. Information about MCS-certified heat pump installations were derived from the MCS Installations Database[21], whose access is granted to those with a valid MCS Certification Body. Through a combination of supervised machine learning (ML) and statistical modelling they attempted to learn how heat pump uptake varies depending on different property characteristics. Using this, they then built models to predict the pattern of future heat pump uptake by considering the geographical distribution of properties with these characteristics. They found that, historically, heat pump adoption has been positively correlated with **property size**, whether a property is **detached**, and whether the property is located in an area **without access to the gas grid** or an area where the residents have **comparatively high incomes**.

During data preprocessing, using Principle Component Analysis to perform dimensionality reduction, the number of EPC features used with reduced to 24. Figure 2.10 displays the coefficient importance of each EPC feature in determining 'Current Heat Pump Status' and 'Future HP Status'.

In predicting a dwellings *current* heat pump (HP) Status, it was found that a **'electric' heating fuel was a strong indicator** of a heat pump installations, the reverse holding for 'gas' heating fuel. Heat Pumps were found to be more likely in owner-occupied houses and bungalows and social housing related to green deals and rarer in lower income areas and older properties on the gas grid.

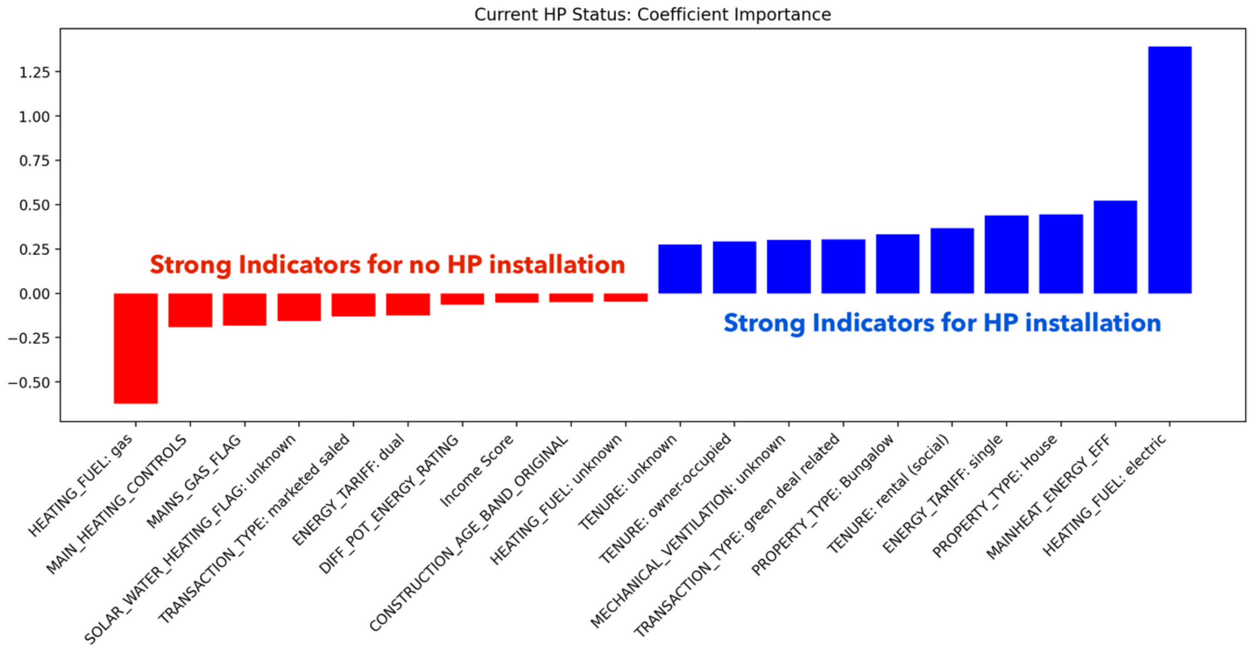
In predicting a dwellings *future* HP status, the strongest indicators were the property types house and bungalow, followed by (semi-)detached houses and social housing. The strongest negative indicators were properties on the gas grid and/or with gas as heating fuel, as well as low income, old and private rental properties. When predicting whether a property without a heat pump would have one installed by the end of 2021, on a dataset with 20% properties with a heat pump and 80% without, a Linear Support Vector Classifier (LSVC) model achieved the results in table 2.1. A lower recall than precision score indicated the model was better at predicting instances of no heat pump, which is due to the in-balanced data set, only able to match 1% of EPC records to an MCS heat pump installation. The model was taken further to predict % heat pumps in a postcode (or % increases) for a target year, postcodes that adopted significantly more or less heat pumps than expected could also be identified[22]. However, setup of this model proved complex and so evaluation of the tool was limited to the written report 22.

A 'Nearest Neighbour Search' model, operating at a household/postcode level was built on the assumption that postcode areas that might adopt heat pumps, but have not already, might be identified through sharing similar characteristics with those that have. Such a model allowed for geographic analysis of which groups are more or less prevalent across regions of the UK[22].

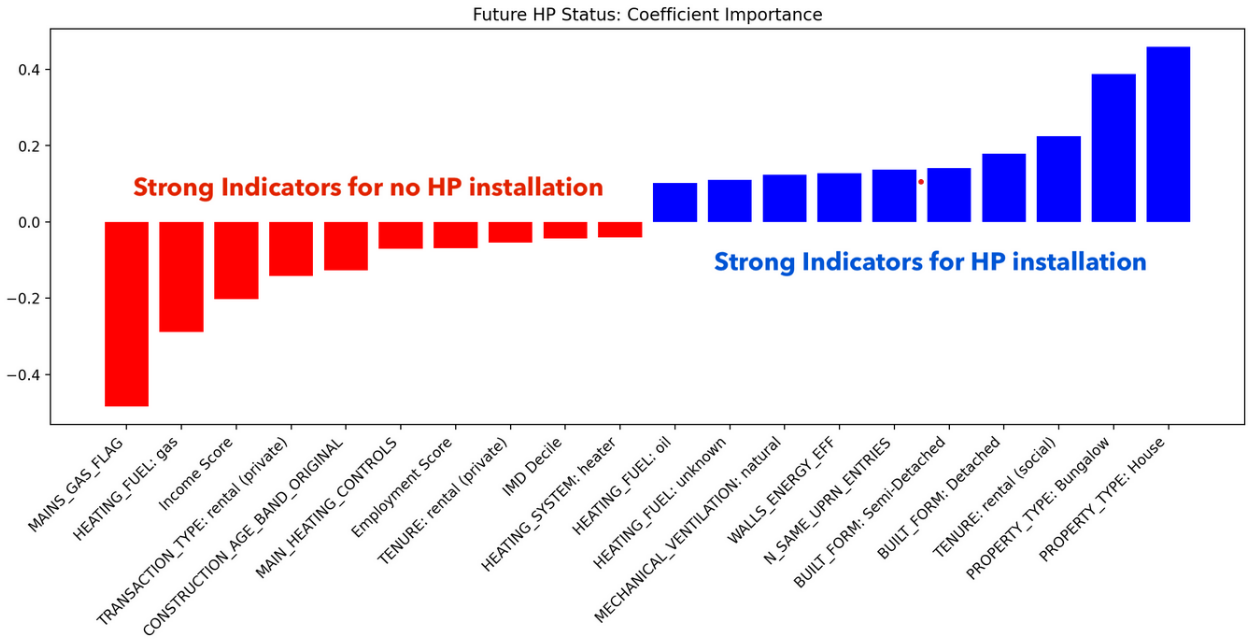
[20] https://www.nesta.org.uk/project-updates/using-energy-performance-certificates-predict-heat-pump-uptake/
[21] https://certificate.microgenerationcertification.org/
[22] https://github.com/nestauk/heat_pump_adoption_modelling/blob/dev/outputs/reports/EST_Supervised_Model.md

Metric	Train	Test
Accuracy	0.88	0.88
Precision	0.72	0.71
Recall	0.64	0.64
F1-Score	0.68	0.68

Table 2.1: LSVC for predicting heat pump status in 2021 22



(a) Current Heat Pump Status



(b) Future Heat Pump Status

Figure 2.10: Coefficient Performance of EPC Features in Predicting HP Status 22

Table 2.2: Table Summarising the current functionality and issues addressed regarding the previously discussed tools

Tool	Issue Addressed / Function	Aim Contributed To
Nesta Cost Calc	Estimate HP Installation Costs	None
Great Homes Cost Calc	Estimate HP Running Costs	None
TheEcoExperts Cost Calc	Estimate HP Installation Costs Finds Accredited Installers	None
MCS `Find A Contractor'	Finds Accredited Installers	None
MCS Heat Pump Calc	HP Size Calculator	None
MCS HPSPE	Estimate HP Electricity Consumption	A2
Open Data Communities	Find/Filter EPCs	A2
Nesta HP Uptake	Predicting the Current and Future Status of Heat Pumps in Homes using Statistical and ML Models	A1 A4

2.3.4 The Current and Open Issues Addressed

Table 2.2 summarises the current issues addressed by the discussed existing tools and identifies, if any, which of the project aims 1.2 they align with. Table 2.3 gives some examples of some of the open issues regarding EPC and Heat Pumps, the project aims they would align with and whether the tool/report is aiming to contribute towards them.

The majority of the tools discussed aim to aid homeowners interested in the upgrade to heat pumps by informing them of potential installation costs, running costs and suitable accredited installers in the area. A tool assessing the actual suitability of their home for a heat pump however, does not appear to exist and is something my tool aims to fulfil.

Although Nestas' work in predicting heat pump adoption 2.3 and identifying areas with characteristics similar to areas with high heat pump uptake rates (Nearest Neighbour Search) is in line with some of my project aims, such as the 'Identification of Potential Heat Pump Ready Areas' A4, its relatively challenging requirements for doing so (configuring an AWS account and setting up conda environments) means the insights are difficult to obtain and not easily accessible to the public or the less technologically able. Other than the report and documentation I was unable to properly setup and test the project. My tool aims to provide similar insights, through simple data visualisation techniques on an easily accessible web application.

Table 2.3: Table Summarising Potential issues to be addressed regarding EPCs and Heat Pumps

Open Issues / Function	Project Aim	Contributing Towards?
Determining Eligibility for the Boiler Upgrade Scheme	A2	Yes
Rating of a Dwellings Heat Pump Readiness	A3	Yes
Identification of Potential `Heat Pump Ready' Areas	A4	Yes
Comparing Energy Performance Between Areas and Individual Dwellings	A2 A4	Yes
Assessing an Areas Grid Capacity In Supporting Heat Pump Adoption	A4	No
Tool for Determining a Reliability/Rating for Accredited MCS Heat Pump Contractors	NA	No

Chapter 3

Project Execution

3.1 Project Overview

The Methodology used during the projects development and evaluation was the **Design Science (Engineering Research) Methodology**[1]. Section 3.2 details the data-sets used and how they were incorporated into the project, justification behind the methodology for calculating the Heat Pump Readiness (HPR) rating, then each part of the application described in turn; its functionality, implementation details, justification on decisions made during its development and how it contributes to satisfying the projects aims A1:A5 set out in 1.2. Chapter 4 conducts a critical evaluation of the too, its shortcomings and ways it could be improved.

The Tool, at a high level (Figure 3.1[2]), is a Python (version 3.8) based Web Application hosted on pythonanywhere.com using a python virtual environment, accessible at `https://www.heatpumpready.xyz/`. It uses the micro-web framework Flask (version 2.1.1), which depends on the Jinja Template engine for rendering static pages and the Werkzeug WSGi (Web Server Gateway Interface) toolkit, which acts as the interface between the web server and python application. The Project Code is located at `https://github.com/benbrowne7/EPCProject` Python was chosen due to its rich data handling and visualisation libraries as well as my relative experience in the language. The Flask web framework was chosen over the popular Django, due to its lightweight, flexible nature. The .py files found at the root of the are application: 'app.py', 'config.py', 'helper.py' and 'maps.py'. 'app.py' handles all the HTTP GET requests to render various html pages and the required functionality for them. 'helper.py' provides the helper functions for 'app.py', such as data organization, date checking to determine certificate validity and calculations using certificate data. 'maps.py' includes functionality to produce various graphs and maps, using various .csv files found in app/data/. The Jinga2 templating engine[3] allowed for consistency across content pages, with every .html file extending 'base.html', which handled elements such as the header and footer and contained the required javascript code for dynamically swapping out maps and charts in embedded iframes. Jinga2 has 'block' functionality, allowing for blocks of content to be defined in 'base.html', with the child templates able to fill in as required.

The 'PostgreSQL Database' component of the project architecture diagram 3.1 is coloured grey, representing its lack of a concrete implementation. The PythonAnywhere hosting platform[4] allows for the easy integration of a Postgres database with the application and would be used to store additional user inputted data, such as energy usage and home improvements, not detailed on the dwellings EPC. Functionality to distribute this information to interested parties would also be implemented. The purpose of such a database is detailed in section 4.2.

Table 3.1 summarises each part of the application before linking its associated functionality to the overall intended aims and contributions of the project, set out in the introductory chapter 1.2. The aims will be referred back to in subsequent sections as appropriate.

[1] https://acmsigsoft.github.io/EmpiricalStandards/docs/?standard=EngineeringResearch
[2] https://www.edrawmax.com/
[3] https://jinja.palletsprojects.com/en/3.0.x/templates/
[4] https://www.pythonanywhere.com

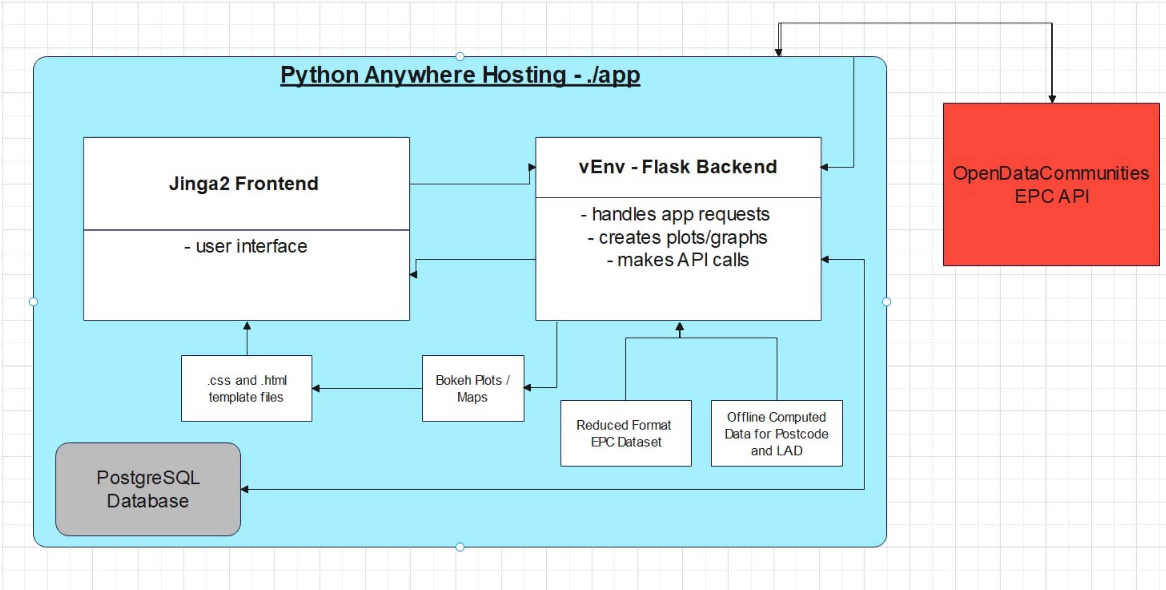


Figure 3.1: Project Architecture Diagram

Feature of App	Aims/Contributions	Open Issue Addressed
Av. EPC/HPR Choropleth Map 3.2.3	A4 A4 A5	Identification 'Heat Pump Ready' Areas Comparing Energy Performance Between LAD
LAD Page 3.2.4	A4 A4	Identification 'Heat Pump Ready' Areas Comparing Energy Performance Between LAD
Individual Page 3.2.5	A2 A3 A5	Determining Eligibility for Boiler Upgrade Scheme Rating for Dwellings Heat Pump Readiness Comparing Energy Performance Between Dwellings

Table 3.1: Summary of each part of the application, the aims/contributions it attempts to fulfil and which open issues it is targeting

3.2 Design

3.2.1 Data

Domestic EPC certificate data was downloaded for use offline in .csv format and individual certificates were acquired through API requests with the appropriate headers at the certificate endpoint[5] and recommendations endpoint[6] during realtime use of the application.

Data Pre-processing was minimal as the certificate data quality was high and consistent, with instances of missing data in interested columns being rare. The approximately 24 million offline certificates (including certificates issued up to and including 02/02/23) were downloaded as a .zip, which when extracted, contained 30GB of 342 folders named by Local Authority District (LAD) 2.1, with each folder containing 2 .csv files; 'certificates.csv' and 'recommendations.csv', each row representing a unique dwelling. The numerous .csv files throughout the project were read in as pandas dataframes for easy manipulation and analysis. All certificate.csv files were transformed to a reduced format version, named 'domestic-[ONS_CODE]-[LAD_NAME]-small.csv', to under 20 features/columns from over 90. This reduced the total size of the dataset to under 5GB and so could be directly uploaded to the hosting platforms file system for direct utilisation by the application. Notable columns of this reduced dataset included: 'LMK_KEY', 'POSTCODE', 'CURRENT_ENERGY_EFFICIENCY', 'PROPERTY_TYPE', 'TENURE', 'LODGEMENT_DATE' and various ratings for individual features of the dwelling to be used in 'heat pump readiness' calculations, detailed in 3.2.2.

The data requested using the opendatacommunities API[5] is updated regularly, containing all new certificates up to the previous month; the downloaded certificates used to produce the plots for each local authority district, would need to be manually re-downloaded offline, with dimension reduction, before being re-uploaded to the hosting platform, in order for the application to use the latest certificate data available.

Supplementary data for the EPCs included 'ONS2LAD.csv' which allowed for the conversion between ONS codes and Local Authority District names, 'Local_Authority_Districts_(December_2020)_UK_BUC.SHP' and its corresponding shapefile components were used to plot a map of England and Wales by LAD boundaries 3.3 and individual LAD's, overlaying points of average energy performance for postal outcodes 3.4. Data for mapping was found at[7] and postcode data at[8]. As detailed in the background 2.1, the evolving nature of LADs sometimes meant some certificates could not be included in the mapping as their LAD code at the time was no longer present in the 2020 mapping data used. This however was an insignificant amount of data points (¡0.5%) and so dropping these points had little effect on any subsequent calculations. Small alterations to filenames also had to be made throughout the project to ensure compatibility with LAD names including the removal of full-stops and hyphens.

3.2.2 Methodology for Calculating the Heat Pump Readiness (HPR) Rating

One of the main aims of the project was to use EPC data to calculate a 'heat pump readiness' (HPR) rating for an individual dwelling A3, which could then be used to compare against similar properties or averaged across postcode/LAD to provide insight into which areas had particularly high or low levels of dwellings that could be classed as heat pump ready A4.

The specific features of the EPC considered were: 'window-energy-efficiency', 'wall-energy-efficiency', 'roof-energy-efficiency', 'floor-energy-efficiency' and overall 'current-energy-efficiency' (the headline epc rating). Features such as 'Mainheat-energy-efficiency' and 'hot-water-energy-efficiency' were not included, as these properties, although useful in assessing a homes heating efficiency levels, are dependant on the type of heating system used in the dwelling, unlike the other features included (excluding 'current-energy-efficiency'). These specific features of a dwelling give an idea to its levels of insulation, which can be a large factor in determining how effective and efficient an installed heat pump can be, with installs in poorly insulated buildings **increasing heat pump size and electrical demand**, which can lead to excess install costs, labour and electrical infrastructure upgrades; all barriers to heat pump uptake [28]. The importance of optimum installation and operating conditions has been highlighted during field trials of heat pumps back in 2008, conducted by The Energy Saving Trust (EST), who found average SPF

[5] https://epc.opendatacommunities.org/api/v1/domestic/certificate/:lmk-key
[6] https://epc.opendatacommunities.org/api/v1/domestic/recommendations/:lmk-key
[7] https://geoportal.statistics.gov.uk/
[8] https://www.freemaptools.com/download-uk-postcode-lat-lng.htm

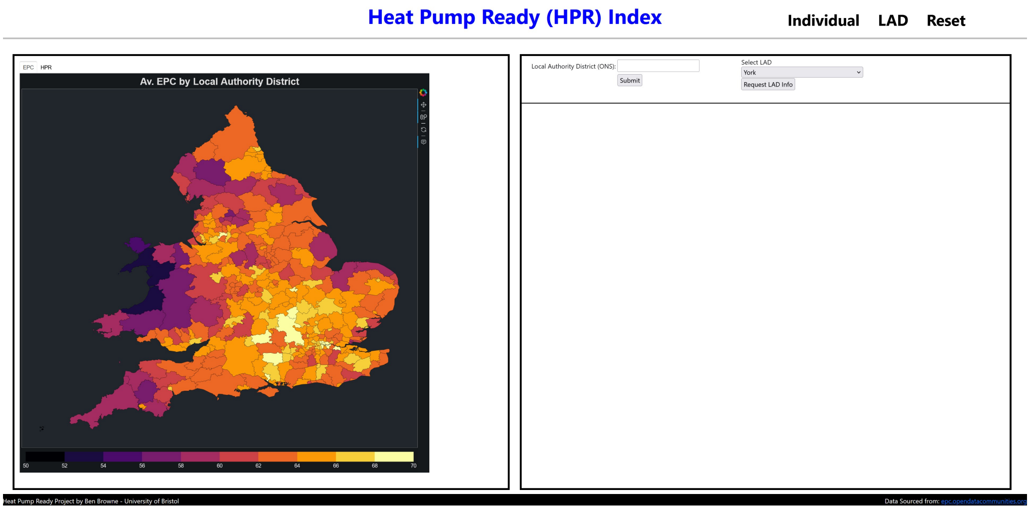


Figure 3.2: Home Page of Application

values to be just 1.5-2.1 for ASHP [31], with the majority of systems performing so badly that '*they would not qualify as renewable energy under proposed European standards*'[9].

This is also made clear through the eligibility requirements for the Government funded Boiler Upgrade Scheme (BUS)[10], which include no outstanding EPC loft or wall insulation recommendations, unless an explicit exemption has been acquired.

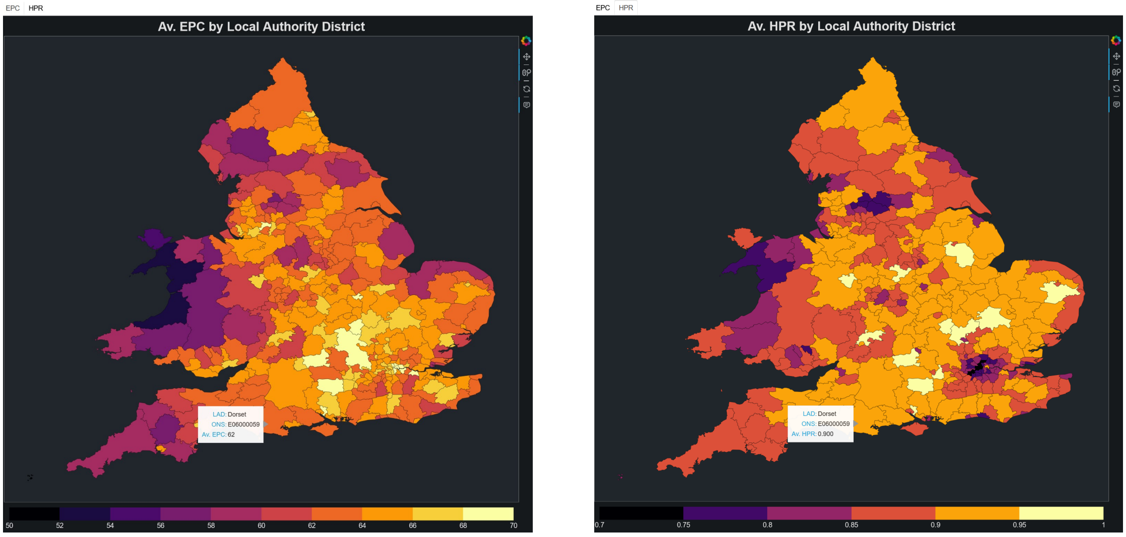
The HPR was calibrated around an value of 1, above indicating an '*ideal candidate*' for a heat pump. Drawing from the Boiler Upgrade Schemes requirements and the high insulation standards for efficient heat pump operation, it was concluded that a dwelling with at least ratings of 'Good' for wall and roof/loft efficiency ratings are likely to be good heat pump candidate and should have a HPR rating >1. This was considered in the HPR calculation by having these 2 features weighted double. Each feature rating has 5 possible values: [very-good, good, average, poor, very-poor], corresponding to [0, 1, 3, 6, 10] points in the model, with poorer ratings contributing more heavily to the score. The headline 'current-energy-efficiency' value, is inverted and scaled. A score of 100 translating to 0 points, with every -10 in score corresponding to $+0.5$ points in the model. All scores were summed to give a final score which could range [0, 70], the *lower* the value the *more heat pump ready*. This score was then translated linearly to a rating [1.2, 0.2] using numpys 'interp' function, meaning a final score of < 14 corresponded to a hpr value of ≥ 1. Ratings ≥ 1.1 were deemed 'Strong Candidates', ≥ 1 'Good Candidates', ≥ 0.7 'Some Improvements Needed' and <0.7 'Major Improvements Needed'.

3.2.3 Home Page

The Home Page of the tool Figure 3.2, has a navbar located in the top right allows for page switching and a reset which returns the user to the homepage 3.2, clears the active session and redefines the users screen dimensions. The right side contentbox is where user requests are made and where the response body lies.

The tool has 2 main branches of functionality: one focused on individual dwellings and the other looking at Local Authority Districts. The left-hand side contentbox contains a large choropleth map of England and Wales, made up of bounded LAD regions and coloured based on average EPC rating or HPR rating, Figure 3.3. These averages were calculated offline using all available data for each LAD. The data[11] used to plot was in .shp format, which contained the digital vector boundaries for Local Authority Districts in the UK as of December 2020. The boundaries chosen were 'BUC' or ultra generalised boundaries (500m), clipped to the coastline. Higher resolutions resulted in slower plot times and the chosen boundaries were deemed sufficient for the maps purpose. The Geopandas library was used to read in the data as a GeoDataFrame object, named 'map', before indexes corresponding to Scottish or Northern Ireland districts were dropped (those with ONS codes beginning 'N' or 'S'). The geoframe

[9] https://www.theguardian.com/environment/2010/sep/08/heat-pumps-green-heating
[10] https://www.gov.uk/apply-boiler-upgrade-scheme/check-if-youre-eligible
[11] https://geoportal.statistics.gov.uk/datasets/ons::local-authority-districts-december-2020-uk-buc/



(a) EPC (b) HPR

Figure 3.3: Map of Average EPC and HPR Rating Across Local Authority Districts in England and Wales

object was then iterated through, with each LAD 'shape' matched to its corresponding precomputed mean EPC and HPR value, in order to build corresponding 'EPC_MEAN' and 'HPR_MEAN' columns, before being added to 'map'. 'map' was then transformed to a GeoJSONDataSource object, imported through the 'bokeh.models' package.

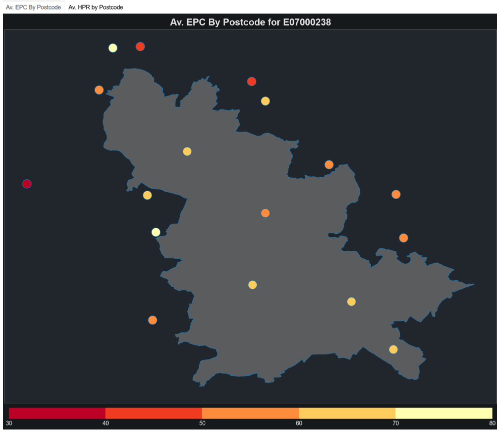
The bokeh library[12] was chosen for its support with geodata and interactivity features, such as zooming and 'HoverTools', enabling a user to view additional details, such as district name, ons code and average value when hovering over specific areas of the plot. The 'Inferno' color palette was chosen with 10 color distinctions in increments of 2 ranging from [50,70] for average EPC score and with 6 distinctions in increments of 0.05 ranging from [0.7,1] for average HPR score (darker indicating a lower average score). A small toolbar is located at the right axis with 'pan', 'wheel-zoom', 'reset' and 'label' options, for moving around, zooming, resetting and for enabling/disabling labelling on the map. Plots were then labelled as appropriate and output as .html files, made viewable in the application by embedding as *iframes*.

The 2 maps, displayed in Figure 3.3, were initially switched between using css styled buttons situated to the right of the map and could be viewed on any page on the application. Upon discovery of bokehs 'TabPanel' class, which allowed for multiple plots to be switched between in a single .html file, the buttons were dropped for better usability and a cleaner format (A5). This Tab functionality (top-left of plots) was subsequently implemented across the application. The 2 choropleth maps were originally computed offline due to relatively slow plot times and necessity to be viewable near instantaneously on the applications landing page. All other plots are rendered in realtime, discussed in 3.3. The maps provide a broad overview of the current energy performance levels of individual LADs in England and Wales (A4), regarding EPC rating and the derived HPR rating, to quickly identify areas that show particularly low or high scores. This may be useful for policy makers or local authority district officials as part of larger data visualisation and analysis report, used to target funding and schemes aiming to boost the uptake of heat pumps (i.e., Clean Heat Streets project discussed in 2.3.3 to areas showing a high average HPR rating or to target areas of low average HPR rating in an attempt to get more homes 'heat pump ready' (A4), by for example running local loft/wall insulation upgrade schemes.

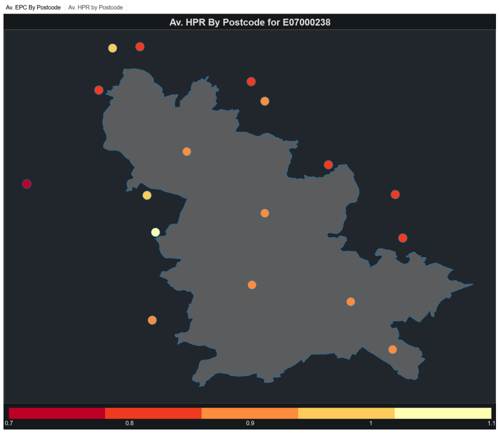
3.2.4 Local Authority District Functionality

In the 'LAD' part of the application, a individual LAD must be selected, either through a user inputted ONS code or via the drop down select menu, the request is then handled by either 'ladsingle()' or 'ladrequest()' in app.py. Both function similarly, first running session checks, then determining the chosen LAD, returning to the previous page if unable to resolve the LAD. Functions in 'map.py' produce the maps and graphs for the visualisation part of the response. Other helper functions are called to construct

[12] https://docs.bokeh.org/en/latest/



(a) Av EPC by Postal Outcode



(b) Av HPR by Postal Outcode

Figure 3.4: Av EPC/HPR by Postal Outcode for Local Authority District

the body of the request response as shown in Figure 3.7, this body is then returned in a rendertemplate() call, with the variables passed as parameters for subsequent rendering by the Jinga2 templating engine. Flask provides functionality for *sessions*, allowing data to be stored for later access by the application. I use these sessions to save responses, allowing them to be rendered on different pages and for storing data such as LAD names.

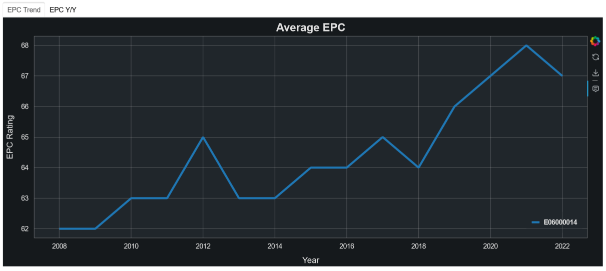
Figure 3.7 shows a typical rendered response: Statistics such as average EPC and HPR rating regarding the chosen LAD are displayed here, alongside colour coded percentile strings indicating how the LAD compares to its peers and the proportion of dwellings classified as 'good candidates' (HPR ratings over 1). Below is the chart area where, initially, 4 different plots could be swapped between. 2 are plots of the LADs region with overlayed points for any inclusive postal outcodes, plotted according to their lat/long coordinates and colour graded by the average EPC or HPR rating of all its constituent dwellings 3.4 (These were later cut from this graph section and moved over the the left hand side of the application following evaluation feedback 4.1). This gives the user a more granular view of the current energy performance of the district (A4) and which postal outcodes score particularly low or high. This additional insight can again be used in conjunction with other data and studies, to target more localised schemes or awareness campaigns to maximise the adoption of heat pumps (A4). Such schemes would also have the advantage over those more national in scope, by being more flexible and better tailored to the target area, with their effectiveness easier to evaluate and track. The 'Clean Heat Streets' Project in Oxford, detailed in 2.3.3, is a model example of this in practice.

After the dropping of the LAD/postcode maps, the other 2 graphs 3.5 were combined into 1 using bokehs 'TabPanel' functionality. These graphs track the average EPC rating of certificates issued by year and the yoy % change in this value. The yoy % values can be averaged to give an average annual increase in EPC rating. This value can then be used for other dwellings in the region, particularly those with expired certificates, to give 'adjusted' EPC ratings, reflecting potential upgrades to a dwelling over time not documented in the EPC report and rating. Following feedback 4.1, an additional graph 3.6 was added, showing the distribution of EPCs by age.

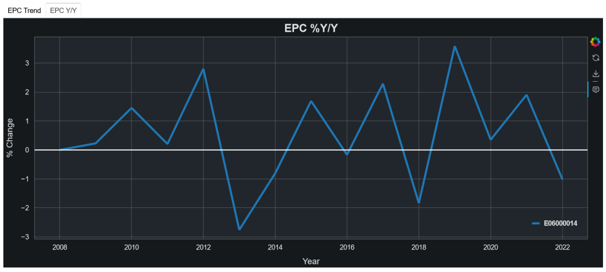
3.2.5 Individual Dwelling Functionality

In the 'Individual' part of the application, a postcode must be entered by the user and is then submitted. Length checks are carried out and the input is transformed to the required format, before being constructed into string ready for an API request to the endpoint[13]. If the returned response is 'None', i.e. an invalid postcode was submitted, the user is made aware by an alert and is returned to the previous page. Otherwise, each house address in the response is added to the list 'house_list' and the dictionary 'key_dict', with (address, lmk-key) as (key,value) pairs. Both are stored as sessions variables, so that individual certificates and recommendations for a specific home can be acquired after the function returns. The 'addressselector.html' page is then rendered, with the 'house_list' variable passed in so an additional form can be populated with all the postcode associated addresses. Once an addresses is submitted 'sin-

[13]https://epc.opendatacommunities.org/api/v1/domestic/search



(a) Av. EPC by Year



(b) % Change EPC Y/Y

Figure 3.5: Graph Pane of LAD Response

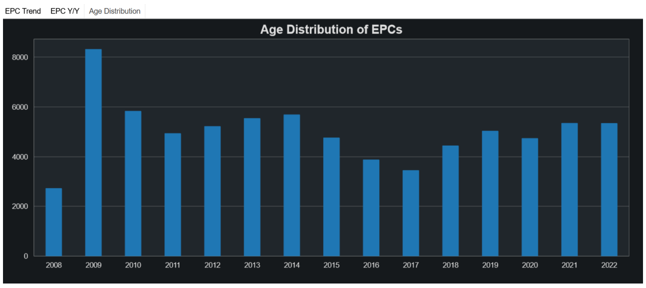


Figure 3.6: Age Distribution of EPCs

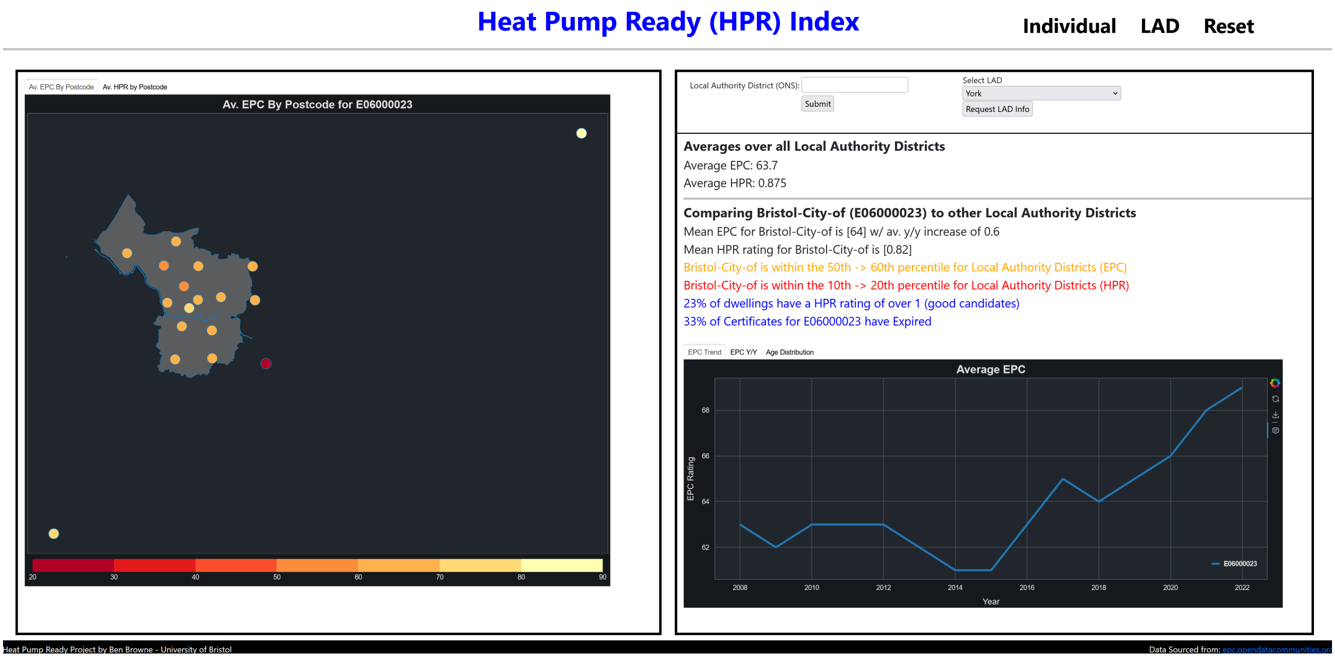
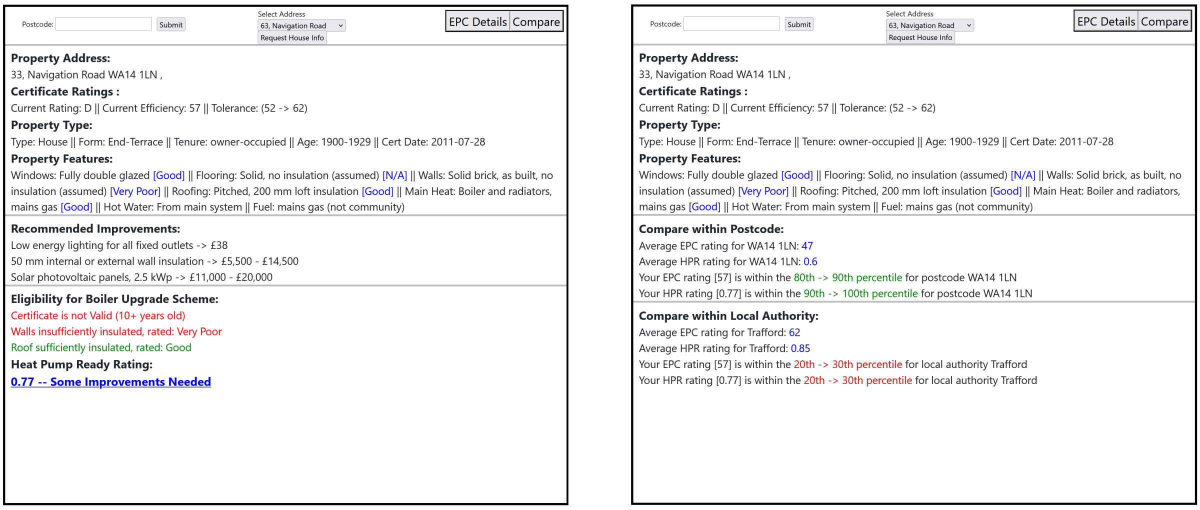


Figure 3.7: LAD Page Response



(a) Details for Dwelling

(b) Comparing Dwelling in Postcode and LAD

Figure 3.8: Individual Page Response

glerequest()' is called and the contentbox is filled as shown in Figure 3.8, using the response data gathered via an API request to the certificate and recommendations endpoints, alongside the 'lmk-key' associated with the chosen address.

The first section of the body acts as a summary of the property, with details on the properties age, type, current EPC rating and certain features on the EPC report: Windows, Flooring, Walls, Roofing, Main Heat Supply, Hot Water Supply and main fuel type used.

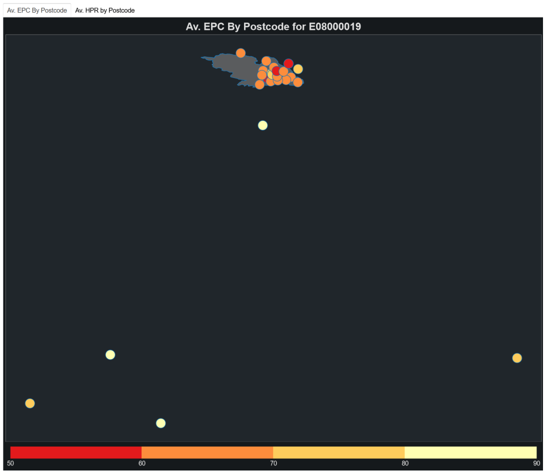
The next section uses the data returned from the 'recommendations' request, and details the recommended improvements for the property. Unlike the 'certificate' responses, the recommendations responses are largely inconsistent, with an individual improvement being potentially located in 3 different fields of the response: 'improvement-summary-text', 'improvement-id-text' or 'improvement-descr-text'. The 'determineimprovement()' helper function is designed to extract the specific improvement using key words but cannot always do so, returning 'Unable to Resolve Improvement' if so. In addition, for unknown reasons, sometimes improvements associated with the certificate viewable at[14] are not included in the return response. The estimated cost for the improvement is found in the 'indicative-cost' field, but again is inconsistent in its availability.

The 'Eligibility for the Boiler Upgrade Scheme' tries to determine the dwellings eligibility for the BUS (A2) by checking against its 3 main requirements: Valid EPC (<10 years old) and no outstanding loft or cavity wall improvements. The 'checkdates()' function determines the age of the certificate based on its issuance date and the current date, returning True if less than 10 years old. Ideally the remaining two requirements would be checked directly against the return recommendation response fields, but due to the unreliable nature of these responses detailed above, the final 2 requirements are inferred through the 'WALLS_ENERGY_EFF' and 'ROOF_ENERGY_EFF' ratings, with ratings of 'Average' and above meeting the requirement. This cutoff was decided through a limited sampling of certificates and checking whether an 'Average' rating corresponded to a recommended improvement in that feature, which in the majority of cases, did not. The 3 requirements are then colour coded, green for met and red for not met.

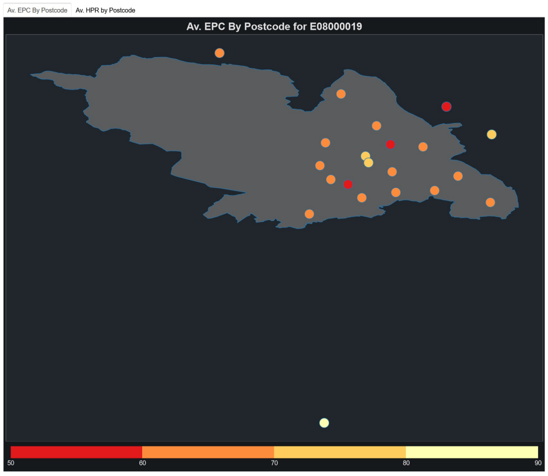
The 'Heat Pump Ready Rating' returns the HPR rating for the chosen property (A3), as calculated in 3.2.2.

The user can then compare the property with its postcode neighbours and within its Local Authority, by switching to the 'compare' tab, to show how the chosen individual dwelling ranks in relation to the rest of the postcode and district (A4), shown in Figure 3.8 A fresh API call to retrieve EPC postcode data is executed and sorted into lists. 'heatpumpready()' calculates the HPR rating for each dwelling and mean values for EPC and HPR ratings over the postcode, as well as where the individual dwelling lies in percentile terms for its postcode and LAD, averages and percentiles for each LAD have been precomputed and accessible to the application at '/data/constit_data.csv'. Tags are then computed corresponding to

[14]epc.opendatacommunities.org



(a) Error Postcode Points in LAD Map



(b) Corrected Postcode Points in LAD Map

Figure 3.9: 'Rogue' Postcode Points for LAD Maps

the percentile position: 0-29th percentile as red, 30-69th percentile as orange and 70-99th percentile as green. 'comparesingle.html' is then rendered with the data passed in as strings. The rational behind including percentiles statistics for a dwelling is give users a better understanding of where their home ranks in terms of energy efficiency (EPC) and heat pump readiness (HPR) when compared to their peers (A4). Such an understanding could prompt owners to seek home improvements or confirm any suspicions that their home is 'below average' in terms of these 2 metrics.

3.3 Testing

Throughout the project correctly scaling plots to make best use of the users screen size was a challenge. At first all plots were produced offline and embedded as iframes, requiring the iframe content to be sized up or down to fit the container they were situated in. This solution could not be made to work properly, so the process of producing the plots in realtime, with dimensions set dynamically according to the users screen size was opted for instead. The only exception to this being the full England and Wales choropleth maps 3.3, which needed to be available instantaneously. The dimensions of the users screen are calculated on entry to the application and saved as a session variable for use by other functions. The 2 EPC graphs 3.5 were produced using using precomputed data found in '/data/EPCByYear/'. The 2 LAD plots 3.4 posed more of a challenge as the data for plotting the LAD boundaries, 'local-authority-district.GEOJSON' (equivalent to the shapefile used to produce 3.3), took too long to process. The 'multiprocessing' python package to load the boundary data in the background was considered, but ran the risk of the user submitting an LAD request before the data was fully loaded, resulting in an error. Therefore the decision to split the 'local-authority-district.GEOJSON' file into its constituent parts, so that the chosen LAD boundary data could be loaded in dynamically, was taken. This allowed for the plots to make best use of the users screen space (A5).

It was later discovered that the full England and Wales choropleth maps 3.3 could be rendered in real time, if the data was used in shapefile format rather than GEOJSON. Then posed the issue of getting the users screen dimensions and saving them as a session variable **before** the 'bigmap()' function was called. This was addressed by changing the landing page ('/') of the application to 'base.html', saving the dimensions, then redirecting to the old landing page using a <meta> tag, after a sufficient delay. This means the input fields and map have a slight delay in rendering for the user but allows the map to better fill the left contentbox. The map does not have to be recomputed, unless the application is 'Reset' and the updated screen dimensions must be obtained.

As show in Figure 3.9 some of the Local Authority District postcode plots contain outer postcodes not situated in the associated LAD,which can cause some 'real' postcode points to become bunched ontop of each other, impacting the user ability to form a good impression of the energy performance across the LAD. This is due to *'rogue'* certificates (postcodes) in the downloaded EPC data for a specific local authority. The exact cause of this is unknown as some dwelling certificates are located in certificate data for vastly different parts of the UK. For example, certificate data for Sheffield (E08000019) 3.9, contains EPCs for dwellings located in Bristol. This is not an uncommon occurrence so had to be dealt with by filtering out postcodes whose coordinates were excessively far away from the mean of all postcode coordinates, determined to be 1.8 standard deviations away, for either the latitude or longitude coordinates. As Figure 3.9 shows, the updated map has correctly filtered out the 'rogue' points, making the relevant points more distinguished and visible (A5).

Chapter 4

Critical Evaluation and Further Work

In line with the Design Science Evaluation Methodology[1], the tool was demoed to members of the Centre for Sustainable Energy (CSE)[2] during a 1 hour recorded video call. Feedback regarding potential limitations and oversights of the tool were gathered, as well as ideas for additional features and possible directions the tool could be taken in to provide real value to users. Some of this feedback had direct consequences for the development of the tool 4.1 and some formed the basis of critical analysis and evaluation of the tools functionality 4.3 and the data-sets it used 4.2.

4.1 Evolution of the Projects Design

Across the duration of the project, additional research, unexpected challenges and feedback on the tool, both from my supervisor and members of CSE, resulted in an evolution of the proposed idea into its current form. From the beginning my intention was to work on a data based project involving energy in the UK. Discussions with my supervisor highlighted the importance of working with a sufficiently large, quality data-set, leading to the scope of the project narrowing, until we decided on using the Energy Performance Certificate data-set (∼24 million entries) in the context of heat pumps, a highly topical and important area of current research. Initially, the intention was to conduct analysis of the current trends in heat pump adoption and use machine learning to predict/simulate future trends, but discovery of the shortcomings of the EPC 2.1.2 4.2 and the desire to instead build something that could **aid the adoption of heat pumps** to produce a more *useful* tool, meant this direction was taken instead.

The tool was first built with individual homeowners in mind and particularly those interested in heat pumps, this led to the development of the 'heat pump ready' (HPR) rating using the homes EPC information. I also felt that being able to compare your homes energy performance with neighbours was important, with ability to compare at various levels present throughout the tool. Next the projects scope was expanded to include local authority districts and postcodes, with the rational being that if the HPR ratings for all the belonging individual dwellings was aggregated, then an areas 'heat pump readiness' could estimated, which could be useful to policy makers in *identifying candidate areas* for heat pump adoption schemes.

The feedback session with CSE represented an important stage of the projects development and led to decisions regarding additional functionality and tweaks to the tools visualisation aspects. Some of these changes are detailed in the following section, with references back to the project aims they attempt to contribute towards.

To increase user engagement levels with the tool and provide multiple perspectives of energy performance for an area or dwelling (A5), it was felt that the left hand side of the application could be utilised more, which originally displayed the large England and Wales Choropleth map 3.3 in all parts of the app. For example, when a LAD had been selected, the left sided view switched to a plot of the LAD with the energy performance breakdowns for each postal out-code 3.4. For an individual dwelling this left side was instead utilised as an 'info' page (Figure 4.1), giving context to the provided information

[1] https://acmsigsoft.github.io/EmpiricalStandards/docs/?standard=EngineeringResearch

[2] https://www.cse.org.uk/

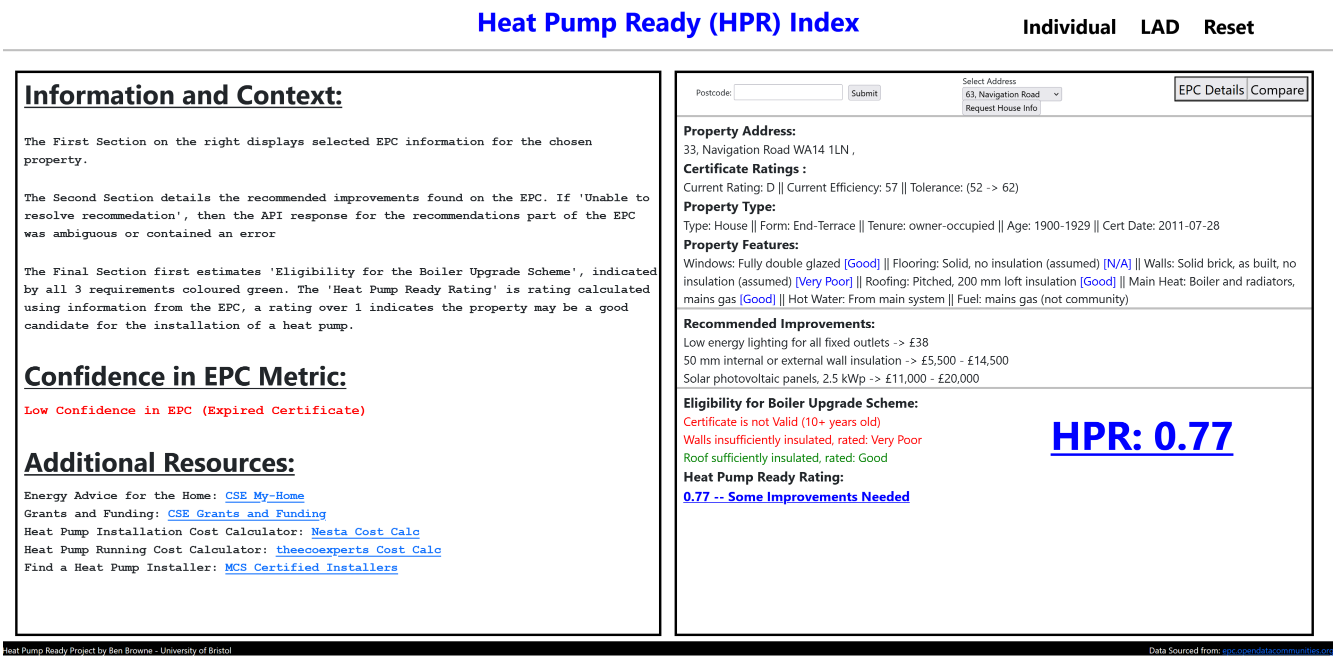


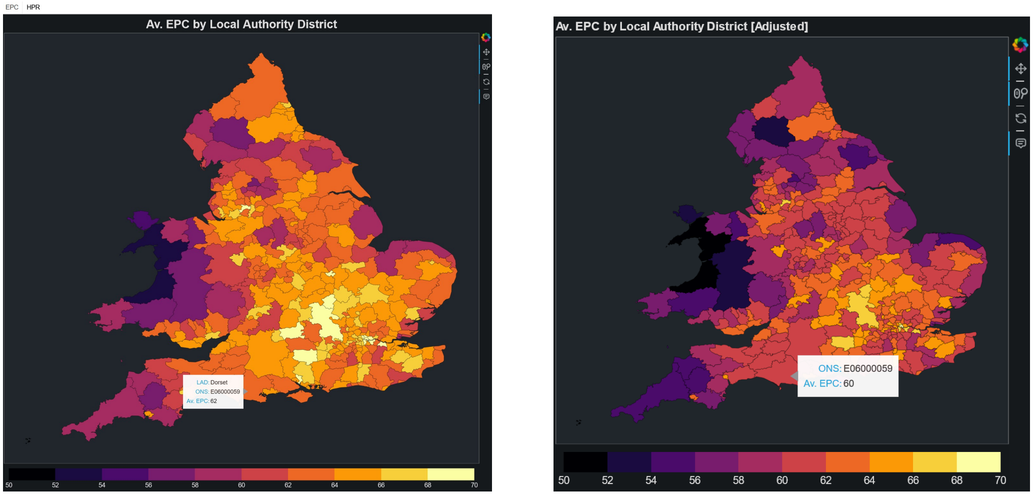
Figure 4.1: Information and Context Page

and ratings on the right hand side (A2) and links to sites where a user (home owner) could get advice regarding energy in the home, grants/funding available for home improvements and cost calculators for heat pumps (those discussed in 2.3. Alternatively, a street view of neighbouring houses (i.e google map view) and their energy performance could have been displayed, being 'inherently interesting' to users, despite 'not necessarily being particularly useful'. Although a better option, time restrictions meant the simpler option was taken.

The feedback sessions also prompted the implementation of a simple 'confidence' metric, to assess the level of confidence for a single EPC certificate. This was displayed on the left hand side and is determined by the age of the certificate, the thinking being that older certificates are more likely to contain outdated information than newly issued ones. Expired certificates returned 'Low Confidence', those between 5-10 years old returned 'Moderate Confidence' and those less than 5 years old returned 'High Confidence', coloured coded red, orange and green respectively. Clearly this is rather arbitrary, so was not generalised to local authority districts, instead the proportion of expired certificates for the chosen LAD was displayed, as well as, the inclusion of an additional graph describing the distribution of certificate ages for each LAD 3.6. This confidence metric could have been taken further, if combined with other data, detailed in 4.4.

4.2 Inaccuracies of the EPC

With the project relying heavily on EPC data, it inherently shares some of the criticisms and drawbacks of EPCs, some of which are detailed previously, 2.1.2. Such criticisms with EPCs lie in their *inconsistencies* and *inaccuracies*, a result of various factors, such as inconsistent evaluations between different assessors, generalised improvement recommendations and the overall assumptive nature of the methodologies carried out to produce an EPC, in particular RdSAP for existing dwellings. The UK government recognises that variability in EPC results exists and is likely to be as a result of "unintentional discrepancies", but also recognise that *"deliberate manipulation of the results may also occur"*, as a result of the financial value attached to higher EPC ratings leading to building owners or third parties (e.g. letting agents) trying to 'game' the system [12]. This is in reference to *'bunching'*, where the manipulation of input data results in the **performance of properties otherwise below a band stagnating just above the threshold** [1]. These misclassifications may give users of the tool a false sense of reality regarding their dwellings energy performance, whether or not it meets the current and future minimum energy standards (MEES) and more accurately assessed dwellings ranking lower when compared to their 'bunched' peers. More broadly, this has the potential for unacceptable levels of uncertainty, skewing overall national results,



(a) Av. EPC

(b) Av. EPC Error Adjusted

Figure 4.2: Map of Average EPC Rating and Adjusted for Errors Map

providing a **distorted impression of the national housing stock's energy efficiency**; a distortion that would be reflected particularly in the projects average EPC map by local authority district (LAD) 3.3.

Although the effect of bunching and errors during the generation of an EPC are difficult to quantify with variability likely existing across LADs, using research by A. Hardy and D. Glew [22], described in section 2.1.2, who estimated the proportion of EPCs containing errors to be **36% - 42%** with ratings typically changing by '4 points due to errors' and D. Jenkins [26], who found similar properties to have an average difference of **11.1 points**, stemming from inconsistent evaluations, we can estimate the distortion from 'true' EPC ratings ('true' being the rating at the time of assessment, if carried out without error) in our average EPC map by LAD. This was carried out by recalculating the mean EPC ratings for each LAD: randomly selecting 40% of certificates as those containing errors and decreasing their headline EPC rating by 7 points (midpoint of the two estimates described above), before re-plotting the map as shown in Figure 4.2. Adjusting for errors in this way lead to a decrease of 2.4 points in the mean epc rating of each LAD; although a relatively small decline it resulted in 7 districts classified at an **E** rating (score 39-54) compared to 3 otherwise and 341 districts classified at an **D** rating (score 55-68) compared to 335 without adjusting for errors. This discrepancy would be a tolerable level of uncertainty, but is based on the assumption that the error rate and the significance of said errors on the EPC rating is consistent across the nation. It is likely that some regions of England and Wales would have 'adjusted' mean values greater than 2.4 points, adding greater levels of distortion to the nations housing stock's energy efficiency. More focused research would be required to *identify the existence of these regions*.

A potential mitigation for these uncertainties, proposed by Geissler and Altmann [18], is that energy software should have more clearly defined data input and quality control measures to identify professionals uploading consistently inaccurate EPCs. Such measures are mentioned in the Department for Business, Energy and Industrial Strategys' (BEIS), Call for Evidence: energy performance certificates publication, with some assessors and accreditation bodies using apps to identify errors and populate some input fields at the time of the assessor visit using 'smart defaults'. The potential use of machine learning in new methods of quality assurance to reduce the number of errors when producing an EPC is also suggested by A. Hardy and D. Glew [22].

Upon implementation of the 'confidence metric' based on a certificate's age 3.2.5, it was found that, on average, **30% of certificates for an LAD have expired**. This adds further uncertainty to the reliability of these EPC's, as home upgrades to improve energy performance, may have taken place since and changes to the EPC assessment procedure (RdSAP) 2.1.1 may result in a different EPC if assessed using current standards, all else equal. It could be argued that these certificates should have been dropped from the data-set, but that decision wasn't taken due to them consisting of a non insignificant proportion of the data.

The effect of the EPC energy efficiency headline rating, in isolation, should have minimal impact on our calculated 'heat pump readiness' (HPR) ratings 3.2.2, due to its relatively low weighting in the score. However, inaccuracies with the certificate as a whole, do question the *reliability and robustness* of the HPR rating, which is based upon specific energy efficiency ratings included in the EPC, ratings which can often be derived through assumptions made about the underlying feature (i.e., wall type). For example, the assumed U-Values for solid walls, a measure of thermal transmittance expressed as the *transfer of heat in watts per square metre of area per degree difference in temperature (W/m2K)* [35], have been found to represent a **significant source of uncertainty** when estimating the energy performance of dwellings. The industry standard default U-Value of 2.1 W/m2K for a solid brick wall used in energy assessments was found to underestimate the thermal performance of a wall by approximately one third, a finding consistent across multiple studies [35] [27]. With solid-walled houses compromising of approximately 25% of England's Housing stock [9], as of 2012, it is likely a not insignificant proportion of the EPC data-set, have had their energy performance underestimated, specifically resulting in the 'walls-energy-efficiency' rating, a doubly weighted component of the HPR rating, being unreliable for these dwellings and **consequently resulting in a lower HPR rating than otherwise**.

In addition the inaccurate default thermal performance assumptions, findings by [35] indicated a clear relationship between *moisture content and poor thermal insulation* for solid walls, with wet values being 1.5 to 3 times higher, applicable to situations where water could travel through the wall as a liquid; for example, due to faulty rainwater drains or prolonged ingress from wind-driven rain. It was also noted that effects of moisture on the U-value of traditionally constructed walls needed to be further investigated and quantified. Such conditions may not have been accounted for during the EPC assessment or arose at a later date, both adding further uncertainty to the accuracy of the HPR rating for solid-walled dwellings.

4.3 Other Uncertainties in the Heat Pump Readiness Calculation

The Methodology for calculating the HPR rating 3.2.2 takes into account features of the dwelling such as the level of wall, floor, roof and windows insulation. Although these features can give us a good indication if a correctly installed heat pump would operate at the required efficiency levels, there are other factors that would impact a dwellings 'heat pump readiness' that are not considered in the calculation or included in the EPC. Such factors include the property type, built form, tenure, property age and internal heating apparatus.

Nestas' work in identifying dwelling characteristics indicative of a heat pump 2.3.3 showed that property types such as 'House' and 'Bungalow' were more indicative of a heat pump installation than, for example, 'Flats'. This is often due to the higher costs and extra permissions required from both residents and the local council.[3] However, the Electrification of Heat demonstration project (June 2020 - October 2021)[4], funded by the UK Government's Department for Business, Energy and Industrial Strategy, showed that heat pumps could be successfully installed in all property types, across all age bands, concluding that 'the suggestion that there are **particular home archetypes in Britain that are "unsuitable" for heat pumps is not supported by the project experience and data'**. These installations broken down by property type and era, are displayed in Figure 4.3.

The trials initial findings would suggest that our HPR rating is **applicable to all property types and ages** and is therefore useful in providing insight about the dwellings 'heat pump readiness'. The degree to which this insight is applicable to real life scenarios, however, is more uncertain, as it was noted there being a 'greater challenge in successfully designing heat pump systems for older homes' (pre-1945 properties). Challenges such as, required upgrades to pipes, ducts and radiators as part of an internal heat system[5], would make a dwelling less 'heat pump ready' and would likely not be apparent in their associated EPC and so *not* reflected in the HPR rating.

Feedback during the evaluation session with CSE also highlighted the absence of considering the increased electricity demand associated with a rise in heat pump uptake. It is likely that some areas despite appearing 'heat pump ready' (average HPR rating over 1) would not have the grid infrastructure in place to support the increased electricity demand from a rapid uptake in heat pump installations, particularly during peak demand. These concerns are explored in depth using evidence from a heat pump field trial [29], who identify 4 potential grid problems arising from mass deployment of heat pumps

[3] https://bhesco.co.uk/heat-pumps-block-flats-brighton-hove-sussex
[4] https://es.catapult.org.uk/news/electrification-of-heat-trial-finds-heat-pumps-suitable-for-all-housing-types/
[5] https://sourceheatpump.com/air-source-heat-pumps-old-houses/

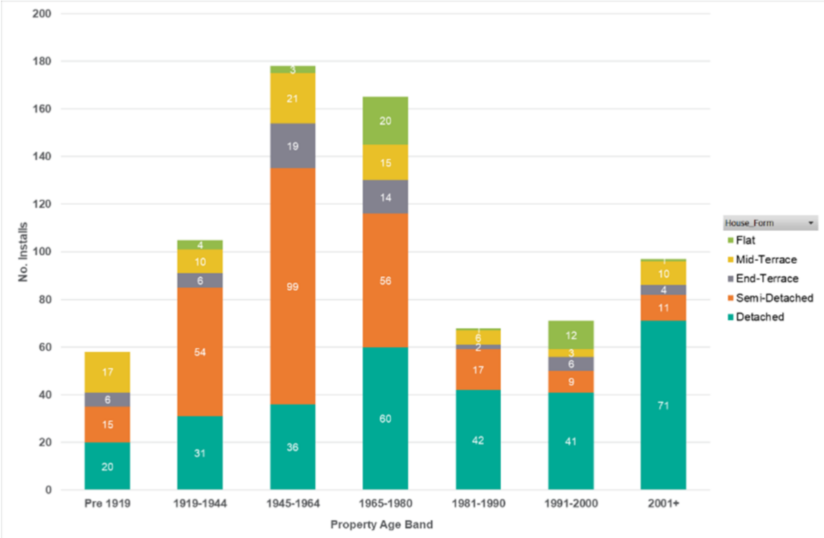


Figure 4.3: Breakdown of property type and era of heat pump installations 4

in the UK, at either a national level or substation level. It was found that **at 20% heat pump uptake, peak grid demand increases by 7.5GW (14%)** and that the shape of the national grid profile would be slightly altered with the formation of a **morning peak in demand**, which would be enhanced under higher heat pump deployment scenarios. Similar modelling, found that 100% heat pump uptake in all homes '**more than doubles** peak GB electricity demand'. [43]

Although analysis regarding the national grids ability to cope with this increased demand is out of scope for this report, it is an **important consideration to make** when assessing an areas 'heat pump readiness', alongside its average HPR rating, which only considers dwellings at an individual level.

On the other hand, at an individual level, the increased electricity demand from an single heat pump installation should be less of a consideration when assessing a dwellings 'heat pump readiness'. Therefore users of the tool wanting insight into how suitable a heat pump would be in their home using its HPR rating, are not disadvantaged by the exclusion of this increased electrical demand in the HPR rating calculation.

4.4 Further Work

The feedback session with CSE gave me a better perspective of the ways the tool could be improved and the various directions it could be taken in to ultimately aid heat pump adoption in the UK; some of which are detailed in the following section.

Following on from the notion of increased demand on the national grid following heat pump uptake 4.2, it was suggested the tool could incorporate grid capacity and substation data, available on the Nation Grids Capacity Map[6], an example of which shown in Figure 4.4. Combined with research modelling heat pump demand on the grid [29] [43] and local rates of heat pump adoption, estimates as to the number of heat pumps an area or substation could support before requiring infrastructure improvements could be made. These estimates could then be used to **aid the planning of grid infrastructure improvements**, helping to avoid the scenario of grid stability becoming a bottleneck in the UK's heat pump adoption plans.

The assumptive nature of the EPC regarding occupants behaviour, energy preferences and the potential for EPCs to contain outdated information and errors 4.2, means that EPC's are not always representative of the real life energy performance of a dwelling. It was suggested that a possible solution to this would be using supplementary household data with the EPC, such as, smart meter data, directly inputted energy data from the home owner or data collected using data loggers (i.e., air quality), to give a more realistic picture of the dwellings energy performance. Doing so at local community, street or house level could result in an **'incredibly useful tool'**, but introduces data privacy issues that must

[6]https://www.nationalgrid.co.uk/our-network/network-capacity-map-application

Figure 4.4: Example Substation Capacity Data 6

be handled appropriately. The unimplemented postgres database, shown in the projects architecture diagram 3.1, would allow for collection of this data, which could be stored in the form of an 'updated' EPC, including fields for actual annual energy consumption and replacing outdated fields (i.e., updated loft insulation figures). Not only would this data result in a more accurate HPR rating calculation by the tool, but could also be made accessible to other interested parties, such as those involved in heat pump retrofit projects, to get a better initial understanding of any interested dwellings energy performance and their suitability for the project.

A different direction for the tool was also suggested; where the tool be used to form a collection of potential '*houses of interest*', for localised heat pump installation schemes such as the 'Clean Heat Streets' project in Oxford 2.3.3. Candidate dwellings and home owners would then be assessed in person to determine their suitability for the trial. The formation of such a collection could be based on numerous criteria set by the project, such as wall-type, floor size, roof orientation, HPR rating and location. The tool would therefore require the ability to filter for various set conditions to narrow the search to selected dwellings. Such functionality, if incorporated into real projects, could **directly aid heat pump adoption**, going beyond the projects initial set aims 1.2.

For a production level tool, the feedback session highlighted the importance of knowing the end user and *tailoring* the application specifically to their needs, in order to better the user experience and make the tool more useful, rather than targeting multiple users like the tool in its current form (individuals and policy makers). Therefore, if the tool was to be taken forward, it is likely that is would only focus on a single end user group. Examples of which include: heat pump interested home owners, local authority district policy makers or project managers supervising a heat pump retrofit programme. As the scale of heat pump adoption required to reach net zero by 2050 is so substantial, CSE sees tools and projects targeting all levels of users and scope as having **equal importance**. A production level tool would also likely require a re-haul of the user interface and made more *aesthetically pleasing* to the human eye. A way of doing so would be to use a bespoke, data visualisation dashboard interface, rather than the Flask framework as chosen. Such frameworks include Streamlit[7] and Ploty[8], frameworks that specialise in interactive data visualisation, which may have allowed the tool to achieve more in the limited timeframe and mitigated scaling issues present throughout development. Ultimately, the advantages of switching were deemed not worth the extra time at the relatively late stages of the project.

[7]https://streamlit.io/
[8]https://plotly.com/dash/

I believe the lack of availability of certain data-sets limited the usefulness and effectiveness of certain features of the tool. The confidence metric for example, implemented in the latter stages of the project 3.2.5, could have been improved with the integration of data regarding the 'average frequency and investments of home energy improvement upgrades' for dwellings. Such data could not be found at any level (i.e., area, income) but could have been used to better determine the probability of when an EPC certificate would be classed as 'outdated', where home improvements has been conducted without reflecting on the EPC. This improved 'confidence' metric could then have been generalised over local authority districts, to **reduce the uncertainty** in energy performance metrics 4.2.

Similarly, the 'heat pump readiness' rating could have been calibrated better and adjusted using the **MCS Heat Pump Installations Database**, containing details of all MCS certified heat pump installations across the UK. This data could have been used to identify dwellings with installed heat pumps with absolute certainty; then the EPC information for these dwellings, specifically the ratings used in the heat pump readiness calculation 3.2.2, could then be used to calibrate and tune the HPR rating so that ratings over 1 would better reflect a 'good candidate' for a heat pump. The EPCs of dwellings that differed significantly from those of these identified dwellings would therefore not achieve ratings above 1. This would have resulted in a HPR rating that could better identify dwellings that are or are not suitable for a heat pump. Unfortunately this data is not available to the public, only accessible with MCS certified credentials.

Chapter 5

Conclusion

The Project set out to use the Energy Performance Certificates dataset for domestic dwellings in England and Wales to assess a dwellings 'heat pump readiness', which was aggregated over local authority districts and outer postcodes, to provide insight into the level of heat pump readiness for certain areas. The tool has two main branches of functionality, targeting two types of user: the individual homeowner who has a prior interest in heat pumps and policy makers (i.e., council officials) involved in increasing levels of heat pump adoption in their area of influence. The individual user is given a summary of their dwellings important EPC information, whether they qualify for the Boiler Upgrade Scheme, a 'heat pump readiness' rating which assesses the suitability of a heat pump in their home and provides various links to other existing tools, such as heat pump cost calculators, which would aid them in deciding whether a heat pump is the correct choice for them. The policy maker user is provided with a large scale map where areas of relatively low/high energy performance (EPC) or 'heat pump readiness' (HPR) can be identified, a more granular view is also provided, to identify postcode areas which may be suitable for targeted heat pump programmes or schemes to improve energy performance through insulation upgrades, in the preparation for heat pumps or equivalent low carbon heating solutions.

The importance of increasing heat pump adoption levels nationwide cannot be understated and without addressing the concerns and barriers to heat pump adoption 2.3.3, the UK will almost certainly fall short of its ambitious target of net zero by 2050. My tool aims to play a small role in aiding this adoption both at an individual homeowner and policy level.

I believe that all of the project aims were contributed towards, to various extents. Section 2.3.3 clearly outlines the current state of heat pump adoption in the UK (A1), why its acceleration is crucial and the various barriers and challenges faced on the road ahead. The 'individual' user layer of functionality addresses (A2); giving those interested in the installation of a heat pump a rough measure of their homes suitability for one, derived from the corresponding EPC (A3). Various plots of maps and graphs, at local authority, postcode and national level, regarding energy performance are available in the 'LAD' layer of functionality, allowing insights to be drawn about the energy performance of areas and their suitability for heat pump campaigns (A4). All these insights are available on an easy to access web app `https://www.heatpumpready.xyz//`, in the form of coloured coded data or interactive plots, all requiring minimal user input and prerequisites (A5).

The tool in its current form represents a foundation to be built upon and with further work and a narrower focus, has the potential to directly aid heat pump adoption in the UK. Discoveries through additional research and insights gathered from the feedback session with CSE, provided me with many directions the tool could be taken in to provide real value to users, making a meaningful contribution to increasing levels of heat pump uptake across the UK. This could involve focusing on homeowners, allowing for the combination of user inputted data and EPC information to form a more accurate 'heat pump readiness' rating and the formation of an 'updated' EPC, stored in a postgres database available to third parties interested in up to data information regarding the energy performance of particular dwellings. Alternatively, the tool could be built to be utilised in heat pump retrofit programmes (i.e., Clean Heat Streets Oxford 2.3.3) where it could be used to create a portfolio of 'homes of interest', filtered by a criteria set by the retrofit programme specifications. Such a portfolio would then have to be manually inspected by retrofit professionals but would help streamline the initial processes of finding potential suitable candidates. At a wider level, the tool could be used by policy makers to not only assess an areas 'heat pump readiness' in terms of the suitability of the housing stock but in regards to grid capacity, providing estimates to an areas electricity demand headroom for heat pump uptake and where infrastructure improvements should be prioritised.

I believe each direction for the tool to be achievable, with the potential to provide real utility in the UK's adoption of heat pumps and consequently the fight against climate change. The Centre for Sustainable Energy (CSE) regards tools directed at all levels and stages of heat pump adoption as *'equally important'*, as the challenges faced ahead are so great, with the implications of failure even greater.

Bibliography

[1] Bunching of residential building energy performance certificates at threshold values. *Applied Energy*, 211:662–676, 2018. doi:10.1016/j.apenergy.2017.11.077.

[2] Sara Abd Alla, Vincenzo Bianco, Annalisa Marchitto, Federico Scarpa, and Luca A. Tagliafico. Impact of the utilization of heat pumps for buildings heating in the italian power market. pages 1–5, 2018. doi:10.1109/EEM.2018.8469904.

[3] Anna M. Brockway and Pierre Delforge. Emissions reduction potential from electric heat pumps in california homes. *The Electricity Journal*, 31(9):44–53, 2018. URL: https://www.sciencedirect.com/science/article/pii/S1040619018302331, doi:https://doi.org/10.1016/j.tej.2018.10.012.

[4] P. Carroll, M. Chesser, and P. Lyons. Air source heat pumps field studies: A systematic literature review. *Renewable and Sustainable Energy Reviews*, 134:110275, 2020. URL: https://www.sciencedirect.com/science/article/pii/S1364032120305621, doi:https://doi.org/10.1016/j.rser.2020.110275.

[5] CCC. Uk housing: Fit for the future? 2019. URL: https://www.theccc.org.uk/wp-content/uploads/2019/02/UK-housing-Fit-for-the-future-CCC-2019.pdf.

[6] CCC. The sixth carbon budget the uk's path to net zero. 2020.

[7] Modassar Chaudry, Muditha Abeysekera, Seyed Hamid Reza Hosseini, Nick Jenkins, and Jianzhong Wu. Uncertainties in decarbonising heat in the uk. *Energy Policy*, 87:623–640, 2015. URL: https://www.sciencedirect.com/science/article/pii/S0301421515300306, doi:https://doi.org/10.1016/j.enpol.2015.07.019.

[8] Alexandra Christenson. Greenhouse gas emissions, uk: provisional estimates: 2021. 2022.

[9] Communities and Local Government. English housing survey, 2010. 2012.

[10] Heating Hot Water Industry Council. Skills, training and the future of heat - a critical component in the transition to low carbon heating. 2022.

[11] Martin de Waardt. April 2020. URL: http://essay.utwente.nl/81055/.

[12] Department for Business, Energy and Industrial Strategy, BEIS. Call for evidence: energy performance certificates for buildings. 2018.

[13] Houses Department for Levelling up and Communities. Energy performance of buildings certificates statistical release january to march 2022 england and wales. 2022.

[14] Housing Department for Levelling Up and Communities. English housing survey energy report, 2020-21. 2021.

[15] Office for National Statistics. Energy efficiency of housing in england and wales: 2022. 2022.

[16] Franz Fuerst, Patrick McAllister, Anupam Nanda, and Peter Wyatt. Does energy efficiency matter to home-buyers? an investigation of epc ratings and transaction prices in england. *Energy Economics*, 48:145–156, 2015. URL: https://www.sciencedirect.com/science/article/pii/S0140988314003296, doi:https://doi.org/10.1016/j.eneco.2014.12.012.

[17] Ankita Singh Gaur, Desta Z. Fitiwi, and John Curtis. Heat pumps and our low-carbon future: A comprehensive review. *Energy Research Social Science*, 71:101764, 2021. URL: https://www.sciencedirect.com/science/article/pii/S221462962030339X, doi:https://doi.org/10.1016/j.erss.2020.101764.

[18] Susanne Geissler and Naghmeh Altmann. How to make the best use of epcs. *Austrian Energy Agency: Vienna, Austria*, 2015.

[19] HM Goverment. Heat and buidings strategy. 2021.

[20] HM Goverment. Net zero strategy: Build back greener. 2021.

[21] Benjamin Greening and Adisa Azapagic. Domestic heat pumps: Life cycle environmental impacts and potential implications for the uk. *Energy*, 39(1):205–217, 2012. Sustainable Energy and Environmental Protection 2010. URL: https://www.sciencedirect.com/science/article/pii/S0360544212000333, doi:https://doi.org/10.1016/j.energy.2012.01.028.

[22] A. Hardy and D. Glew. An analysis of errors in the energy performance certificate database. *Energy Policy*, 129:1168–1178, 2019. URL: https://www.sciencedirect.com/science/article/pii/S0301421519301867, doi:https://doi.org/10.1016/j.enpol.2019.03.022.

[23] House of Commons Business, Energy and Industrial Strategy Committee. Energy efficiency: building towards net zero. 2019.

[24] Patrick Hughes. Geothermal(ground-source)heat pumps: Market status, barriers to adoption, and actions to overcome barriers. 12 2008. URL: https://www.osti.gov/biblio/948543, doi:10.2172/948543.

[25] IPCC. Synthesis report of the ipcc sixth assessment report (ar6). 2023.

[26] David Jenkins, Sophie Simpson, and Andrew Peacock. Investigating the consistency and quality of epc ratings and assessments. *Energy*, 138:480–489, 2017. URL: https://www.sciencedirect.com/science/article/pii/S0360544217312823, doi:https://doi.org/10.1016/j.energy.2017.07.105.

[27] Francis G. N. Li, A.Z.P. Smith, Phillip Biddulph, Ian G. Hamilton, Robert Lowe, Anna Mavrogianni, Eleni Oikonomou, Rokia Raslan, Samuel Stamp, Andrew Stone, A.J. Summerfield, David Veitch, Virginia Gori, and Tadj Oreszczyn. Solid-wall u-values: heat flux measurements compared with standard assumptions. *Building Research & Information*, 43(2):238–252, 2015. arXiv:https://doi.org/10.1080/09613218.2014.967977, doi:10.1080/09613218.2014.967977.

[28] Joseph Lingard. Residential retrofit in the uk: The optimum retrofit measures necessary for effective heat pump use. *Building Services Engineering Research and Technology*, 42(3):279–292, 2021. arXiv:https://doi.org/10.1177/0143624420975707, doi:10.1177/0143624420975707.

[29] Jenny Love, Andrew Z.P. Smith, Stephen Watson, Eleni Oikonomou, Alex Summerfield, Colin Gleeson, Phillip Biddulph, Lai Fong Chiu, Jez Wingfield, Chris Martin, Andy Stone, and Robert Lowe. The addition of heat pump electricity load profiles to gb electricity demand: Evidence from a heat pump field trial. *Applied Energy*, 204:332–342, 2017. URL: https://www.sciencedirect.com/science/article/pii/S0306261917308954, doi:https://doi.org/10.1016/j.apenergy.2017.07.026.

[30] Lorraine Murphy. The influence of the energy performance certificate: The dutch case. *Energy Policy*, 67:664–672, 2014. URL: https://www.sciencedirect.com/science/article/pii/S0301421513011841, doi:https://doi.org/10.1016/j.enpol.2013.11.054.

[31] Department of Energy and Climate Change. Detailed analysis from the first phase of the energy saving trust's heat pump field trial. 2012. URL: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/48327/5045-heat-pump-field-trials.pdf.

[32] officenationalstatistics. Household projections in england: 2016-based, 2018.

[33] Samantha Organ. Minimum energy efficiency – is the energy performance certificate a suitable foundation? *International Journal of Building Pathology and Adaptation*, 39:581–601, 2020. doi:https://doi.org/10.1108/IJBPA-03-2020-0016.

[34] Simon Pezzutto, Gianluca Grilli, and Stefano Zambotti. European heat pump market analysis: Assessment of barriers and drivers. *International Journal of Contemporary Energy*, 3:62–70, 10 2017. doi:10.14621/ce.20170207.

[35] Soki Rhee-Duverne and Paul Baker. Research into the thermal performance of traditional brick walls. 2013.

[36] Jan Rosenow, Pedro Guertler, Steven Sorrell, and Nick Eyre. The remaining potential for energy savings in uk households. *Energy Policy*, 121:542–552, 2018. URL: https://www.sciencedirect.com/science/article/pii/S030142151830421X, doi:https://doi.org/10.1016/j.enpol.2018.06.033.

[37] Amir A. Safa, Alan S. Fung, and Rakesh Kumar. Comparative thermal performances of a ground source heat pump and a variable capacity air source heat pump systems for sustainable houses. *Applied Thermal Engineering*, 81:279–287, 2015. URL: https://www.sciencedirect.com/science/article/pii/S1359431115001477, doi:https://doi.org/10.1016/j.applthermaleng.2015.02.039.

[38] H. Singh, A. Muetze, and P.C. Eames. Factors influencing the uptake of heat pump technology by the uk domestic sector. *Renewable Energy*, 35(4):873–878, 2010. URL: https://www.sciencedirect.com/science/article/pii/S0960148109004273, doi:https://doi.org/10.1016/j.renene.2009.10.001.

[39] Iain Staffell, Dan Brett, Nigel Brandon, and Adam Hawkes. A review of domestic heat pumps. *Energy Environ. Sci.*, 5:9291–9306, 2012. URL: http://dx.doi.org/10.1039/C2EE22653G, doi:10.1039/C2EE22653G.

[40] statista. Annual amount of heat pumps in operation in the united kingdom (uk) from 2013 to 2019, 2020.

[41] Energy UK Department for Business and Strategy. Energy consumption in the uk (ecuk) 1970 to 2020. 2020.

[42] Paul Watson. An introduction to uk energy performance certificates (epcs). *Journal of Building Appraisal*, 5:240–250, 2010. doi:https://doi.org/10.1057/jba.2009.22.

[43] S.D. Watson, J. Crawley, K.J. Lomas, and R.A. Buswell. Predicting future gb heat pump electricity demand. *Energy and Buildings*, 286:112917, 2023. URL: https://www.sciencedirect.com/science/article/pii/S0378778823001470, doi:https://doi.org/10.1016/j.enbuild.2023.112917.

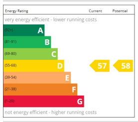
[44] Wu Yunna and Xu Ruhang. Green building development in china-based on heat pump demonstration projects. *Renewable Energy*, 53:211–219, 2013. URL: https://www.sciencedirect.com/science/article/pii/S0960148112007380, doi:https://doi.org/10.1016/j.renene.2012.11.021.

Appendix A

An Example Appendix

33, Navigation Road WA14 1LN

Domestic EPC



Certificate Details	
LODGEMENT DATE	28 Jul 2011
CURRENT ENERGY RATING	D
POTENTIAL ENERGY RATING	D
CURRENT ENERGY EFFICIENCY	57
POTENTIAL ENERGY EFFICIENCY	58
PROPERTY TYPE	House
BUILT FORM	End-Terrace
CONSTRUCTION AGE BAND	England and Wales: 1900-1929
TENURE	owner-occupied
Location	
ADDRESS	33, Navigation Road
POST TOWN	ALTRINCHAM
POSTCODE	WA14 1LN
COUNTY	(no value available)
LOCAL AUTHORITY	Trafford (E08000009)
CONSTITUENCY	Altrincham and Sale West (E14000532)
Other	
LMK KEY	659751769262011072818213328988619
BUILDING REFERENCE NUMBER	1202688868
INSPECTION DATE	28 Jul 2011
TRANSACTION TYPE	marketed sale
ENVIRONMENT IMPACT CURRENT	50
ENVIRONMENT IMPACT POTENTIAL	51
ENERGY CONSUMPTION CURRENT	247
ENERGY CONSUMPTION POTENTIAL	242
CO_2 EMISSIONS CURRENT	8.0
CO_2 EMISS CURR PER FLOOR AREA	48
CO_2 EMISSIONS POTENTIAL	7.9
LIGHTING COST CURRENT	112
LIGHTING COST POTENTIAL	69

(a)

HEATING COST CURRENT	1318
HEATING COST POTENTIAL	1324
HOT WATER COST CURRENT	99
HOT WATER COST POTENTIAL	99
TOTAL FLOOR AREA	154.15
ENERGY TARIFF	Single
MAINS GAS FLAG	Y
FLOOR LEVEL	NODATA!
FLAT TOP STOREY	(no value available)
FLAT STOREY COUNT	(no value available)
MAIN HEATING CONTROLS	2106
MULTI GLAZE PROPORTION	100
GLAZED TYPE	double glazing installed during or after 2002
GLAZED AREA	Normal
EXTENSION COUNT	0
NUMBER HABITABLE ROOMS	7
NUMBER HEATED ROOMS	7
LOW ENERGY LIGHTING	38
NUMBER OPEN FIREPLACES	0
HOTWATER DESCRIPTION	From main system
HOT WATER ENERGY EFF	Good
HOT WATER ENV EFF	Good
FLOOR DESCRIPTION	Solid, no insulation (assumed)
FLOOR ENERGY EFF	N/A
FLOOR ENV EFF	N/A
WINDOWS DESCRIPTION	Fully double glazed
WINDOWS ENERGY EFF	Good
WINDOWS ENV EFF	Good
WALLS DESCRIPTION	Solid brick, as built, no insulation (assumed)
WALLS ENERGY EFF	Very Poor
WALLS ENV EFF	Very Poor
SECONDHEAT DESCRIPTION	None
SHEATING ENERGY EFF	N/A
SHEATING ENV EFF	N/A
ROOF DESCRIPTION	Pitched, 200 mm loft insulation
ROOF ENERGY EFF	Good
ROOF ENV EFF	Good
MAINHEAT DESCRIPTION	Boiler and radiators, mains gas
MAINHEAT ENERGY EFF	Good
MAINHEAT ENV EFF	Good
MAINHEATCONT DESCRIPTION	Programmer, room thermostat and TRVs
MAINHEATC ENERGY EFF	Good
MAINHEATC ENV EFF	Good
LIGHTING DESCRIPTION	Low energy lighting in 38% of fixed outlets
LIGHTING ENERGY EFF	Average
LIGHTING ENV EFF	Average
MAIN FUEL	mains gas (not community)

(b)

WIND TURBINE COUNT	0
HEAT LOSS CORRIDOR	NO DATA!
UNHEATED CORRIDOR LENGTH	(no value available)
FLOOR HEIGHT	2.15
PHOTO SUPPLY	0.0
SOLAR WATER HEATING FLAG	(no value available)
MECHANICAL VENTILATION	natural
LODGEMENT DATETIME	2011-07-28 18:21:33
FIXED LIGHTING OUTLETS COUNT	24
LOW ENERGY FIXED LIGHTING OUTLETS COUNT	9
UPRN	100012797666
UPRN SOURCE	Address Matched

Recommendations

improvement	indicative cost
Low energy lighting for all fixed outlets	£38
50 mm internal or external wall insulation	£5,500 - £14,500
Solar photovoltaic panels, 2.5 kWp	£11,000 - £20,000

(c)

Figure A.1: Example Full EPC