Getting to net zero: Islington's social housing stock

RESEARCH

STEPHEN EVANS
DANIEL GODOY-SHIMIZU
PHILIP STEADMAN
SHYAM AMRITH
DOMINIC HUMPHREY
PAUL RUYSSEVELT

*Author affiliations can be found in the back matter of this article

ABSTRACT

This paper describes the development of a detailed plan to get the social housing stock of the Borough of Islington in London, UK, to net zero carbon emissions. This stock is very diverse in form, age and construction, and includes houses, flats and maisonettes. A total of 4500 buildings containing some 33,300 dwellings were modelled using the 3DStock method. Six packages of measures combining fabric improvements, heat pumps and photovoltaic installations were evaluated for each dwelling individually, in terms of costs, the impacts on gas and electricity use, and predicted cuts in carbon emissions. The rollout of measures between 2020 and 2030 was modelled with a specially developed scenario tool, allowing the user to set different criteria and priorities. Fabric measures on their own were shown to achieve only a 13% cut in gas use on average. Heat pumps are the key to displacing gas use. With all measures combined and taking account of the predicted decarbonisation of the electricity supply, it is only possible to achieve an overall 70% cut in emissions by 2030.

POLICY RELEVANCE

The development of a detailed practical plan of action is described: an applied case study with the close engagement of the local authority—not a theoretical desk exercise. Each dwelling in Islington's housing stock was examined and measured separately. The modelling did not rely on 'archetypes' as in many such studies. Realistic retrofit options were analysed in each case, using current cost data from practitioners. The same approach could be applied directly to other London boroughs, and for local authorities outside the capital, although different costs and other local factors would apply. For readers outside the UK, the methodology and tools could serve as exemplars. The findings about the respective contributions of heat pumps, solar photovoltaics and fabric measures, and the effects of different priorities in the rollout of retrofits, have relevance for policymaking more generally at local and national levels.

CORRESPONDING AUTHOR:
Philip Steadman
UCL Energy Institute, University College London, Central House, Upper Woburn Place, London WC1H 0NN, UK
j.p.steadman@ucl.ac.uk

KEYWORDS:
buildings; carbon emissions; decarbonisation; housing stock; local authority; net zero; social housing; UK

TO CITE THIS ARTICLE:
Evans, S., Godoy-Shimizu, D., Steadman, P., Amrith, S., Humphrey, D., & Ruyssevelt, P. (2023). Getting to net zero: Islington's social housing stock. *Buildings and Cities*, 4(1), pp. 524–544. DOI: https://doi.org/10.5334/bc.349

1. INTRODUCTION: PREVIOUS STUDIES AND RESEARCH AIMS

In early 2021, the London Borough of Islington commissioned the authors to advise the Council on how to get their social housing stock to net zero carbon emissions by 2030. Many papers and reports have been published on the general subject of retrofitting stocks of dwellings. A recent special issue of *Buildings & Cities* provides an international review and a comprehensive coverage of the literature (Wade & Visscher 2021). Dowson *et al.* (2012) discuss the challenges and barriers in the UK. There is a large literature reporting case studies of the retrofitting of one or a few buildings in practice. A recent review by the Energy in Buildings and Communities Technology Collaboration Programme of the International Energy Agency (IEA) (2023) describes a series of 'success stories' across Europe involving energy efficiency measures and renewables. Studies have been published that have used energy simulation models on one or more representative residential buildings, as, for example, Chen *et al.* (2020) who analyse a series of combinations of passive, active and renewable efficiency measures.

At the opposite extreme are national retrofit strategies aimed at meeting political targets for improving energy performance and reaching net zero. The policy of the Italian Ministry for Ecological Transition (2021), for example, is based on a cost–benefit assessment methodology applied to a small range of supposedly representative building archetypes, including houses and apartment blocks, large and small. Reductions in energy use and emissions calculated for these archetypes using simulation are extrapolated to the national stock on the basis of floor area. The present work lies, in its scale, between these extremes.

The aim of this paper is to describe the development of a detailed practical plan of action for a local government client. The work has special interest and wider lessons for two reasons. First, because of Islington's complex history, the Borough's stock is extremely diverse. There are 18th- and 19th-century houses, most in conservation areas. Sites bombed in the Second World War were rebuilt with infill blocks of flats and maisonettes of various lengths. Many estates built from the 1960s onwards contain mixtures of low-, medium- and high-rise blocks. From the 1970s, the Borough commissioned some high-density low-rise developments with complex forms. A more extensive historical account with photographs of selected buildings is given in Appendix A in the supplemental data online.

The second point of special interest is that the advice offered to the Borough has covered every one of a large number of houses and blocks of flats or maisonettes individually, taking account of its geometry, materials, equipment, fuels used and existing energy improvements. The study has not depended, as many have, on generic descriptions and dwelling archetypes. A range of scenarios has been developed for programmes of retrofits up to 2030 and beyond, allowing for different social and financial priorities, requiring different patterns of expenditure, and resulting in different long-term pathways to reduce emissions.

The research questions addressed by the paper are therefore:

- Is it possible for a local authority in London to get its social housing stock to net zero by 2030?
- What technologies and measures can achieve the greatest progress towards net zero, at what cost?
- How can programmes of retrofits be planned, and their costs and effects evaluated?

The paper is structured as follows. Grouping of the Islington stock; Retrofit measures and technologies; Methodology part 1: Modelling the Islington stock in detail using 3DStock; Methodology part 2: The Pathways to NetZero tool; Results for packages of retrofits; Results for scenarios for the roll out of retrofit programmes; and Conclusions.

2. GROUPING OF THE ISLINGTON STOCK

Each building has been analysed separately, as mentioned. However, for the purposes of presenting the results, the Borough's complex heterogeneous stock has been classified into four groups, defined as follows:

- *High-rise*: buildings with heights of 18 m and over, or seven storeys and higher. This limit is set because fire regulations change at this height.
- *Medium-rise*: buildings (mostly blocks of flats or maisonettes) on four to six storeys, counting from the ground floor (including buildings with three domestic storeys over parking or shops on the ground level).
- *Low-rise*: buildings in estates on one to three storeys.
- *Street properties*: all buildings (predominantly houses) not in estates but on public streets, identified as such in the Council's data sets. Some of these are houses on four, five or six storeys, excluded nevertheless from the medium-rise group.

In total, the Islington Council stock in 2022 consisted of just over 4500 buildings/blocks, containing some 33,300 dwellings (houses, maisonettes or flats). These are broken down between the four groups as shown in Table 1. Note that for many of the buildings, particularly the larger ones, not all the flats are social housing owned by Islington. The counts here include all flats irrespective of ownership.

Table 1: Numbers of buildings and dwellings by building type groups

GROUP	BUILDINGS/BLOCKS	DWELLINGS
High-rise	83	5,303
Medium-rise	828	16,211
Low-rise	889	6,629
Street properties	2,768	5,166

The high-rise blocks are mostly in the range seven to 10 floors, with only four over 20 storeys. The medium-rise are mostly on four or five floors; the low-rise mostly on two or three floors; and almost all the street properties are in the range two to five storeys.

Low-, medium- and high-rise are found in different combinations on the Borough's 326 housing estates (Table 2).

Table 2: Distribution of combinations of building type groups within estates

NUMBER OF ESTATES	COMBINATIONS OF BUILDING GROUPS
8	Single high-rise with lower rise
15	Multiple high-rise with lower rise
1	Single high-rise alone
5	Multiple high-rise with no lower rise
7	Single medium-rise with lower rise
38	Multiple medium-rise with lower rise
7	Single medium-rise alone
69	Multiple medium-rise alone
42	Low-rise but not medium, high-rise or street properties
9	Low-rise and street properties but no medium or high-rise
116	Street properties alone
9	Not possible to classify

3. RETROFIT MEASURES AND TECHNOLOGIES

One of the first tasks in the project was to discuss with the Council what existing and emerging technologies and measures for cutting emissions from dwellings should be considered. What are their respective merits and drawbacks? This was to provide a basis for the detailed design of programmes of retrofits. Discussion focused first on the challenge of decarbonising space heating and water heating, the largest end users of energy in UK housing. Gas is used almost universally for heating in Islington, although two houses and four blocks of flats are heated by electric storage radiators or room heaters. A series of options was then considered: hydrogen as a domestic fuel; reducing fabric heat losses, including the Passivhaus Trust (2023) and Energiesprong (2023) methods; energy storage; local renewable energy sources, including biomass, solar thermal and solar photovoltaic (PV); and heat pumps.

The University College London (UCL) research team advised against hydrogen, despite the Council's initial interest in this option, for two reasons. Hydrogen can be generated from natural gas which—unless carbon capture systems are in place—releases CO_2. Or it can be generated by electrolysis, using electricity generated from renewables or nuclear, resulting in zero emissions. However, this is much less efficient overall than using the electricity directly to drive heat pumps. Arguably, hydrogen has greater future promise as a means of electricity storage, or in heavy transport, than in dwellings. Advice to the Council on fabric measures emphasised simple existing insulation materials and techniques and was sceptical about the cost-effectiveness of more advanced technologies. There was discussion about the fire risks of insulating high-rise buildings, as well as issues with the internal and external insulation of solid walls, and potential problems of ventilation and damp associated with insulation.

Among local renewable technologies, biomass was not recommended because of problems of air pollution, space for fuel storage in urban areas and doubts over whether burning organic materials is truly sustainable. Solar thermal has the problem of the supply of hot water being lowest at times of year when demand is highest. Solar PV, now one of the cheapest methods of generating electricity, was recommended on suitable roofs, although it might not be appropriate for high-rise or in conservation areas.

Discussion of heat pumps covered air-, ground- and water-source types. The Regent's Canal cuts across Islington, and the Council has previously commissioned studies of the possible use of water-source heat pumps for the large estates that border the Canal. These projects did not go ahead for financial and legal reasons. A range of considerations was debated for and against ground- and air-source heat pumps: their costs, the possible need to replace radiators, issues of noise with air-source and the availability of land for ground-source units. One merit of heat pumps, in times of increasing risks of heatwaves and overheating, is their potential to cool as well as heat.

The Borough has two heat networks serving their estates: the Bunhill scheme, which draws heat from the London Underground; and the Citigen scheme. Several others are in the development or planning stages. Islington has great potential for district heating because of its extremely high population density, the highest in the country. It is easier to change the heat source or fuel supplying a central plant, or to replace the plant itself, than to replace individual heating systems in many dwellings. Eleven high-rise, six medium-rise and five low-rise blocks, comprising 1206 dwellings, are presently on heat networks.

Some recent reports on heat pumps have stated that improved energy efficiency in dwellings, through fabric retrofits, is a prerequisite for effective heat pump installations (Carbon Trust 2020, HM Government 2023). This, if true, clearly increases the total cost and complication of getting the housing stock to net zero by this route. Others, however, have questioned this assumption, as, for example. Cambridge Architectural Research (BEIS 2021) and Lowe & Oreszczyn (2021). If the overriding goal is net zero emissions at lowest capital cost—not energy efficiency as such—then this could be reached with electric heat pumps and low-carbon district heating alone. Universal fabric retrofits would not be needed.

> High levels of insulation are not essential to the deployment of heat pumps and are only likely to be cost-effective in easy-to-treat properties.
>
> (Lowe & Oreszczyn 2021: summary)

However, the widespread deployment of heat pumps without some level of fabric retrofit would have significant implications for the capacity of the electricity distribution system and—depending on the relative fuel prices of electricity and gas—on household bills and related factors including fuel poverty. All this discussion of technologies was included in a report to the Council which has since been published (Steadman 2021).

On this basis, it was decided to explore six retrofit deployment scenarios with different packages of technologies and measures applied to all dwellings for which they are appropriate. These scenarios were designed to be additive, as follows:

1. *Do nothing*: This scenario nevertheless results in cuts in carbon emissions, because of the predicted future decarbonisation of the national electricity supply system. No allowances are made for incremental changes of existing plant or building envelope.
2. *Envelope measures only*: Wall insulation, roof and floor insulation, and replacement of single glazing with double glazing.
3. *Envelope measures plus air-source heat pumps*: All the envelope measures in scenario 2, plus air-source heat pumps throughout.
4. *Envelope measures plus air- or ground-source heat pumps*: All the envelope measures in scenario 2, plus ground-source heat pumps for blocks of flats where the site has sufficient free area for boreholes. Otherwise, air-source heat pumps throughout.
5. *Envelope measures plus heat pumps plus PV*: All measures as in scenario 4, plus rooftop PV installations on all buildings where the predicted electrical power generated is sufficient.
6. *All-in*: All measures in scenario 5 plus roof and floor insulation.

4. METHODOLOGY PART 1: MODELLING THE ISLINGTON STOCK IN DETAIL USING 3DSTOCK

The complete housing stock of the Borough was modelled for the project in three dimensions using the 3DStock method developed by the authors. 3DStock is not an energy simulation model: it is an iconic model of the stock as it exists, with data on many building characteristics, including data on actual energy consumption. The model represents both buildings and premises within buildings, floor by floor. For the domestic stock it models flats and maisonettes within blocks on each floor level, as well as any non-domestic uses in the blocks such as shops or social centres. The buildings are all located on a digital map base, and areas of open land within estates and the gardens of houses are all represented. 3DStock models are snapshots in time: the model for Islington used data for 2019/20.

The modelling method is complex, and only a summary is provided here. For full details of the methodology, and previous applications of 3DStock, see Evans *et al.* (2017) and Steadman *et al.* (2020). Work is in hand to make a national 3DStock model, and statistical analyses more widely available to both professional and non-specialist users. Ordnance Survey AddressBase maps provide addresses and Unique Property Reference Numbers (UPRNs) by which the addresses can be located on the maps. UPRNs also provide reference points to which information on dwellings from several sources can be linked. Otherwise, data have been linked by matching addresses, or have been matched spatially, for property-level data (*e.g.* Energy Performance Certificates—EPCs) and geographically aggregated data (such as census data or aggregated energy consumption figures), respectively.

The footprints of buildings come from the digital maps. The three-dimensional (3D) forms of their external envelopes, including the forms of pitched roofs, are calculated from LiDAR (light detection and ranging) data collected from overflying aircraft by the Environment Agency. From the contiguities of footprints, it is known whether houses or blocks are detached, semi-detached or terraced. Areas of exposed wall and party wall can be estimated. Data on land parcels from HM Land Registry are used to determine the boundaries of sites and estates. Buildings that are listed and protected for their architectural importance, and the boundaries of conservation areas, are identified using data from Historic England. Census data on fuel poverty and indices of deprivation—not by household but by larger population units—come from the Office of National Statistics (ONS).

EPCs, where these exist, are attached to dwellings, and provide information on building materials, building ages, heating systems, floor areas and energy performance. Islington holds data on the actual energy consumption for 61 of the buildings, served by bulk gas. For the 4517 dwellings within these buildings, mean energy uses per dwelling were calculated from the empirical data. The former UK Department of Business, Energy, and Industrial Strategy (BEIS) has provided annual electricity and gas meter data from the supply companies to the authors. These data are confidential. For use in the Islington and other projects, they have—with BEIS's approval—been grouped within ranges of consumption value which are non-disclosive.

Islington Council holds data on its housing stock in Northgate software (Northgate Public Services 2022) and other databases, with dwellings identified by UPRNs. These too have been incorporated in the model; they include RdSAP (Reduced data Standard Assessment Procedure) data and the recommendations made by EPC surveyors for possible retrofit measures. RdSAP is the used by government for modelling and labelling the energy performance of dwellings. The Northgate database shows which dwellings are connected to district heating systems, allowing requirements for heat pumps and other retrofit measures to be targeted appropriately. The database also identifies which dwellings in blocks are tenanted, and which have been sold off under the Right to Buy scheme and are now leasehold. These mixtures of tenants and leaseholders can raise significant issues for the funding and management of programmes of retrofits. Figure 1 summarises the main data sources used in the 3DStock model of Islington.

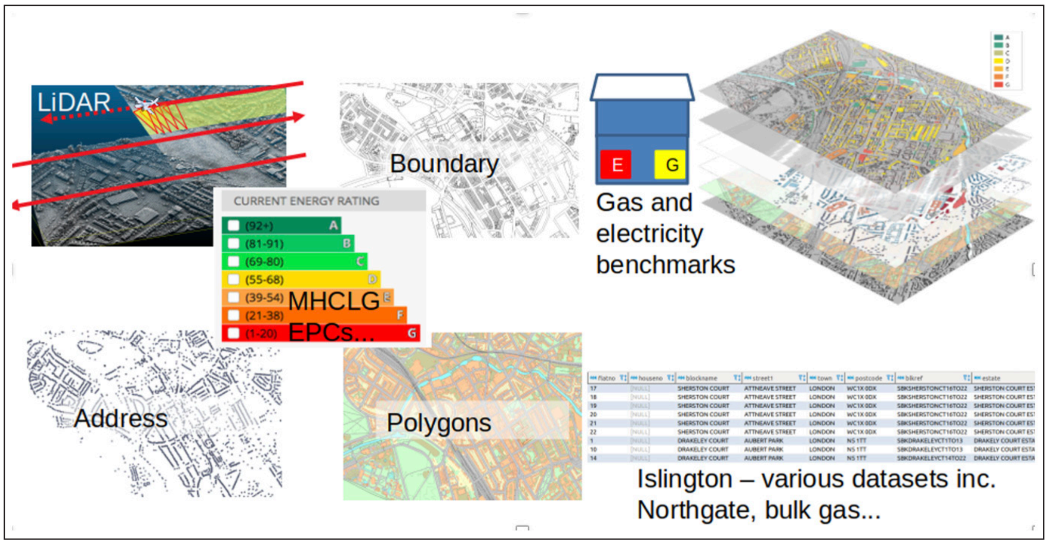

Figure 1: Data sources used in the construction of the 3DStock model of Islington, including data supplied by Islington Council.

3DStock models are not easy to validate systematically since there are no other direct equivalents. However, comparisons have been made between different sources of input data, and models of many individual buildings have been checked against independent sources such as Google Maps and Google StreetView. Estimates of domestic floor area from building geometry have been compared with EPC measurements, and a good correspondence found. The total energy consumption of the Islington social housing sample, estimated by the methods described above, was also found to match well with aggregate domestic energy data for the Borough from BEIS, as a proportion of the total stock (BEIS 2022).

4.1 ESTIMATING THE POTENTIAL OF ROOF-MOUNTED PHOTOVOLTAIC INSTALLATIONS

In previous work for the Greater London Authority (GLA), the authors developed the London Solar Opportunity Map (GLA 2022). This was used to estimate the potential of roof-mounted PV installations in Islington. The Solar Map again uses LiDAR to model not only buildings with their roof forms but also trees (which can cast shadows) and the geometry of the terrain. The total annual solar radiation (direct and diffuse) hitting each face of the model was calculated, taking account of aspect, slope and overshadowing.

These calculations were then culled to reject roof areas where solar potential is low (usually north-facing slopes), and the values were adjusted to reflect the likely efficiency of the solar panels that might be used (monocrystalline, polycrystalline, thin film, *etc.*). An overall efficiency of 15% was assumed (Gul *et al.* 2016). It was then possible to identify all social housing in Islington in the Map and calculate the amount of electrical power obtainable from PV on the roofs of the buildings. Even for blocks where the roof only covers the top-floor flats, it was assumed that solar panels might be installed, and a share of the power redistributed amongst the flats (although this might be difficult to organise in practice). Figure 2 shows a map of the solar potential for the Half Moon Crescent Estate.

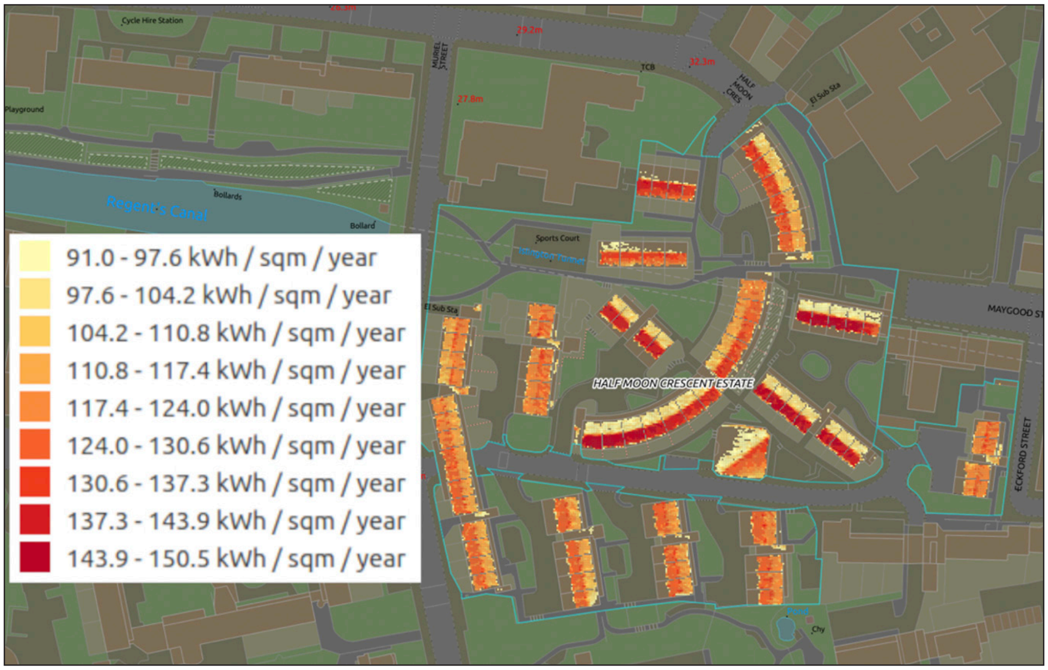

Figure 2: Solar potential (kWh/m²/year assuming 15% efficiency of PV panels) for Half Moon Crescent Estate. Notice the south- and south-west-facing roof slopes showing the greatest potential.

Figure 2 illustrates the level of detail available in the solar potential analysis, since this small estate has buildings facing in many different directions. Those with south-facing roof slopes show the greatest potential, while some of the terraces that have ridge alignments running north–south show significant potential on *both* their west- and east-facing roof slopes. This tool is designed to identify locations where solar might provide a viable retrofit solution, after which solar specialists would need to carry out on-site surveys to make more detailed calculations of the roof structure and the precise roof area available.

4.2 ESTIMATING THE SPACE REQUIRED FOR GROUND-SOURCE HEAT PUMPS

It was assumed that all dwellings might require a heat pump or access to heating and hot water from a heat pump in the future. The duty of the heat pump was assumed to be directly proportional to floor area, although a more refined method might also consider building age and levels of insulation. For houses this is relatively straightforward and air-source heat pumps might be the preferred solution. But for estates there is the question of where to locate the units (*e.g.* on balconies); and there may also be issues with the noise of the pumps.

Automated analyses were carried out to assess the potential for locating boreholes for ground-source heat pumps. This meant working out the total heat demand for the estate or block; matching this to groups of heat pumps of appropriate sizes; and assessing the area of land available within the site for boreholes, using the digital maps. The total demand of all the dwellings on an estate could then be compared with the number of boreholes that could be drilled within the estate boundary. This number was calculated automatically (and visualised on the map) based on the following assumptions:

- The underlying geology (London clay) could provide 5 kW of useful heat for every 100 m borehole if a closed loop system was used.
- Boreholes would have to be drilled no closer than 6 m apart and would only be drilled into natural surfaces and hardstanding.
- Boreholes should be at least 6 m away from any building.
- Boreholes should not be drilled in enclosed courtyards (due to lack of accessibility for the drilling rigs).

This work made it possible to calculate the capital costs, electricity costs, coefficients of performance and total energy savings of ground-source heat pump installations. Figure 3 shows boreholes, marked by beige dots, located on the Half Moon Crescent Estate. Dwellings are marked by red dots. To meet this demand, 122 boreholes would be needed in this case, but the analysis showed that only 117 boreholes could in theory be drilled.

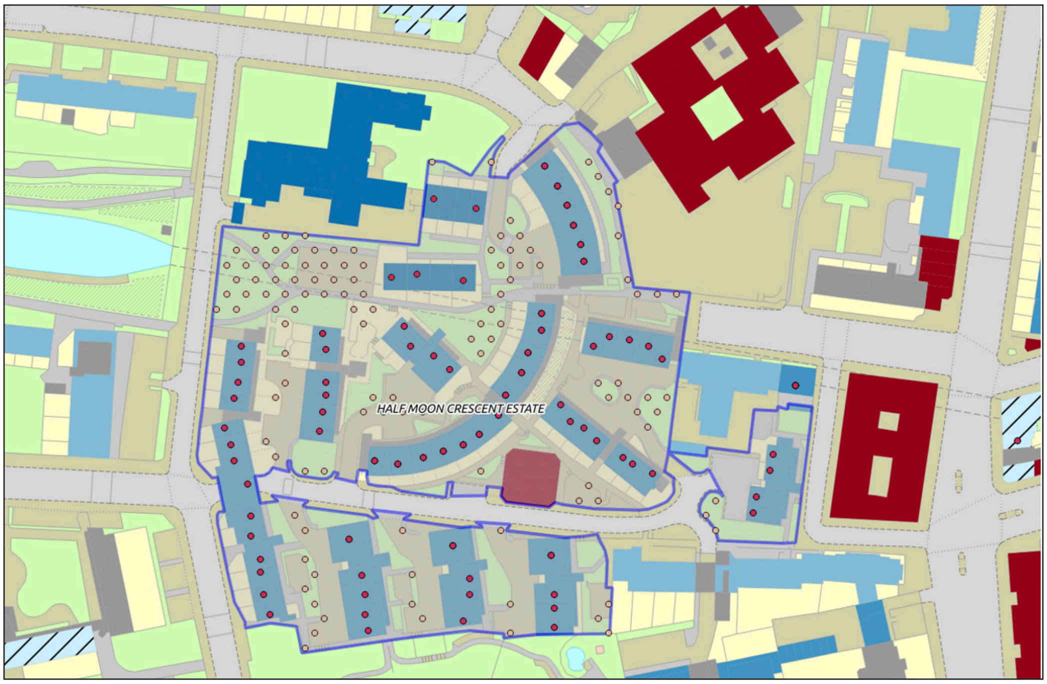

Figure 3: Half Moon Crescent Estate with the modelled borehole locations (beige circles) shown on the ground area within the estate boundary. Red circles show the addresses for social housing flats. Boreholes are 6 m apart and at least 6 m from the nearest building. Each 100 m borehole is assumed to deliver around 5 kW of useful ambient heat for the heat pumps.

5. METHODOLOGY PART 2: THE PATHWAYS TO NET ZERO TOOL

3DStock is the first of two software tools used for the study to model the existing state of Islington's social housing stock in detail. The second is the Pathways to NetZero tool, which is used for defining and exploring retrofit scenarios for improving the domestic stock to meet long-term targets for emissions reduction. As with the 3DStock method, there is only space here to give a broad overview of the Pathways tool. However, a detailed description will be available elsewhere, including its application to London and validation of its underlying processes (Godoy-Shimizu *et al.* 2023). The Pathways tool has been developed over several years to quantify the impacts on costs, energy use and emissions of different options for deploying retrofits across large stocks of buildings. As with 3DStock, it works at an individual dwelling level, and has been applied to the entire London domestic stock. For the Islington project it has been used to assess the retrofit scenarios and identify optimal plans for deployment.

The tool takes data from the 3DStock model and simulates the impacts of different packages of energy improvement measures. Each dwelling is assessed in terms of the impact on energy use and emissions. The associated capital costs of the measures are estimated, as well as related costs such as scaffolding and preliminaries. The tool allows for different policies to be evaluated, controlling for a series of factors. These include the way that the packages of retrofits are rolled out (*e.g.* on a cost-effectiveness basis, or prioritising homes in the most deprived areas); allowing for restrictions on their rollout (*e.g.* PV excluded from listed buildings or from conservation areas); or applying practical limits to the deployment of measures (*e.g.* specifying a maximum total spend per dwelling).

The Pathways tool uses a variety of data for each dwelling, including its estimated annual energy consumption, existing servicing systems, and the construction and form of the envelope, as well as external factors such as the demographics of the local area. As is the case for the entire London stock, data are not available consistently and uniformly across all of Islington's social housing stock. While certain fields come from a single source, *e.g.* built-form data from 3DStock, data on building services and materials come from several sources, depending on availability. These data

DOI: 10.5334/bc.349

were applied using a hierarchy, in which data sources that were more recent and/or more likely to be reliable were prioritised as follows:

1. *RdSAP data* on existing heating systems and materials were available for around 75% of the stock from the Northgate database.
2. Otherwise, data from EPCs were used.
3. A few dwellings are not in Northgate, nor do they have EPCs. In these cases, the model found the *nearest similar match*, by assuming that the dwelling had the characteristics of similar nearby properties, *e.g.* other flats in the same block, or similar houses on the same street.

Figure 4 shows the distribution of data sources on the Islington stock used in the analysis. For comparison, coverage of EPCs in public housing in the whole of London is around 50%. Because of missing data, it was possible to cover only 90% of the complete social housing stock in Islington.

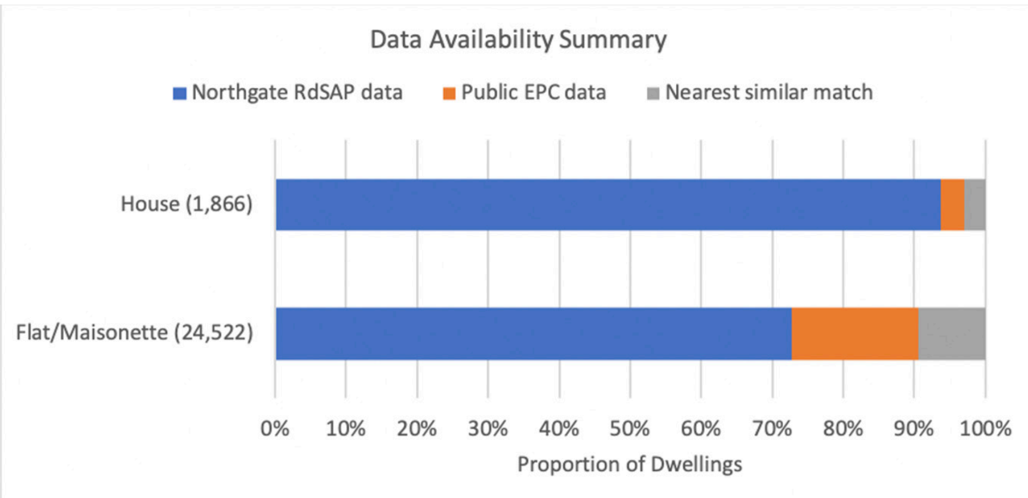

Figure 4: Proportions of the Islington housing stock for which information came from the different data sources.

When evaluating potential retrofits for a given dwelling, the Pathways tool is guided by the available data on the dwelling, alongside the scope of the scenario being assessed, and any restrictions on that scope. For example, in a scenario for rolling out wall insulation, houses with solid brick walls are deemed suitable for internal or external wall insulation (if they do not currently have insulation installed). Similarly, loft insulation to a maximum thickness of 270 mm is deemed to be financially viable, but only where the thickness of the existing insulation is less than 100 mm, reflecting existing guidance. Where appropriate, these dwelling-level assessments also consider external factors. For example, a house would be deemed suitable for rooftop PV only if the solar map showed significant potential, and other considerations—such as it being in a conservation area—would not prevent the installation.

The impacts of packages of retrofit measures on energy use are evaluated, sequentially; first envelope improvements, then system changes and finally local generation. The impacts of envelope improvements are estimated by calculating the current and post-retrofit heat loss parameters (HLP) for each dwelling. HLPs provide an overall measure of a thermal performance and can be calculated using the form and material properties of a building. The impacts of system changes are calculated using the estimated efficiencies (or coefficient of performance for heat pumps) and heating fuel, split between space and water heating. Finally, the impact of renewables (here rooftop PV) has been taken from the Solar Map. The results of these calculations have been compared with results from large-scale empirical data (BEIS 2013/2023), as well as simplified energy models (Hughes *et al.* 2013).

It is important to re-emphasise that these measures are all selected, evaluated and costed for each house or block individually, taking account of its present state and the existing heating system and insulation levels. Thus, the required areas of wall insulation are determined from the actual areas of exposed wall, and similarly for roof and loft insulation. These, in turn, are used to evaluate capital costs and changes in thermal performance. Within blocks, the exact floor areas and ceiling or roof areas of every flat and maisonette are known, but the plan layout of dwellings on each floor is not modelled explicitly, so that areas of exposed wall area cannot be measured for each dwelling. Average figures for exposed wall area per flat or maisonette are therefore derived from the known areas of exposed wall of the whole block.

5.1 RESTRICTIONS ON MEASURES

When defining the scenarios to be tested with the tool, restrictions can be placed on the application of measures, depending on the characteristics of dwellings and the context. For this project, it was assumed that PV panels and external wall insulation cannot be installed on buildings that are listed or in conservation areas; that only thin (and more expensive) double glazing can be used in conservation areas; and that internal wall insulation cannot be installed in listed buildings (but is acceptable for conservation areas). In addition, and following discussion with the Islington team, it was decided that dwellings connected to existing and proposed energy networks should not have improvements that would reduce their heating demand, since this would affect the performance of the networks. Some extra analyses were nevertheless carried out, without this restriction on networked dwellings, allowing them to have envelope improvements, but not changes to their heating plant.

Buildings above three storeys require specific fireproof materials where solid internal/external wall insulation is proposed. It has been assumed that a maximum of 30 m^2 of PV panels will be installed per house, broadly in line with typical house sizes. The viability of ground-source heat pumps has been estimated by calculating the site ground space available for the potential installation of boreholes for each large estate, as explained.

Other building-specific factors that may influence the rollout of individual retrofit measures, such as 'hard-to-treat' dwellings, are beyond the level of detail available within the data, so are not considered. Also, non-technological interventions such as behavioural changes are not considered in the calculations, *e.g.* the 'rebound effect' where occupants adapt to increased insulation by raising temperatures. The impact for each individual dwelling of increased insulation on gas use has been estimated approximately, using the existing energy benchmark of the property, along with the estimated fabric heat loss coefficients before and after the retrofit.

5.2 COSTINGS

The capital costs of retrofit packages have been based on published sources; on advice from the Islington team about recent retrofits in the Borough; and on advice supplied by Savills, property consultants with wide experience of housing retrofits in London and elsewhere, who were subcontracted by the authors. Savills advised that in the current market, preliminaries, overheads and profit, and materials relating to zero carbon works have been experiencing unprecedented price increases in the wake of a series of factors including the COVID-19 pandemic, Britain leaving the European Union (Brexit), general inflation, shortages of appropriate skilled labour in the decarbonisation sector, remedial works on high-rise blocks to ensure fire safety, and compliance with the PAS 2030/2035 home energy efficiency standard (BSI 2022). The Borough's ambition to achieve net zero by 2030 is very challenging and costly in this context.

With these considerations in mind, Savills drew data from their own recent tenders, the experience of their clients and consultation with London contractors working on retrofits, and used these baselines to estimate likely future trends in costs. It may be that some costs, such as the prices of heat pumps, will fall in future because of technical progress and economies of scale, but such projections have not been allowed for, and in general conservative assumptions have been made.

The UCL team provided Savills with the RdSAP and 3DStock model data for the Islington stock, aggregated to the house or block or level as appropriate. From these data, Savills derived a series of measures for costing the works: the average exposed wall area per dwelling, the average glazing area per dwelling and the number of dwellings per block. Costs of fabric measures were then estimated by multiplying the areas of surface by the appropriate cost per m^2 for each dwelling and multiplying by the total number of dwellings. The costings were made for all dwellings in each block, whether tenanted or leasehold, and no adjustments were made for the recovery of costs from leaseholders.

Special rates were used for the costing of retrofits to listed buildings and to houses and blocks in conservation areas, including higher specifications for replacement windows. The costing of wall insulation assumed that only cavity or internal insulation would be acceptable in these historic properties.

6. RESULTS FOR PACKAGES OF RETROFITS

Some of the key results from the Pathways tool are provided below, including the predicted impacts and costs for different packages of retrofit measures under different deployment scenarios. Given the complexity of the analyses, as well as the numbers of permutations of the scenarios tested, it is not possible to cover all the results here. More detail was provided to Islington in reports on the different building groups. A series of viewer files giving results from the tool were also produced for Islington. These allow readers to view all the results in Excel, and visualise the impacts of different scenarios, without the computing resources and data requirements for running the full Pathways tool. Extra analyses that can be viewed in these files include the impacts of different levels of maximum spend per dwelling; the effects of allowing retrofits to be carried out on dwellings on heat networks; and variations in the rate of rollout of improvements.

The costs of fabric measures, heat pumps and PV installations were calculated for all eligible houses and blocks and assembled into the six packages of retrofits listed above. Results were presented to the Council separately for high-, medium-, low-rise and street properties. Here grand totals for all four groups together are provided. First, the total impacts of rolling out the measures for each scenario to all dwellings are shown. These results, therefore, represent a 'final' state where all measures have been applied, as appropriate, to the entire stock. The consequences are then shown of scheduling the programmes of retrofits over the period to 2030 and beyond, setting different priorities for their ordering over time.

Figure 5 shows the total numbers of retrofit measures of each type, for each of the packages. Figure 6 gives the resulting expected change in total gas and mains electricity use. Since the calculation of energy use has been based on benchmarks, as mentioned, the results should be taken as indicative of the effects of measures, not as absolute changes. Figure 7 presents the total costs of all measures. Figure 8 shows the impact on total carbon emissions by decade to 2050. These take account of projections of the carbon intensity of the electricity grid, which is expected to fall substantially in the coming decades (BEIS 2013/2023).

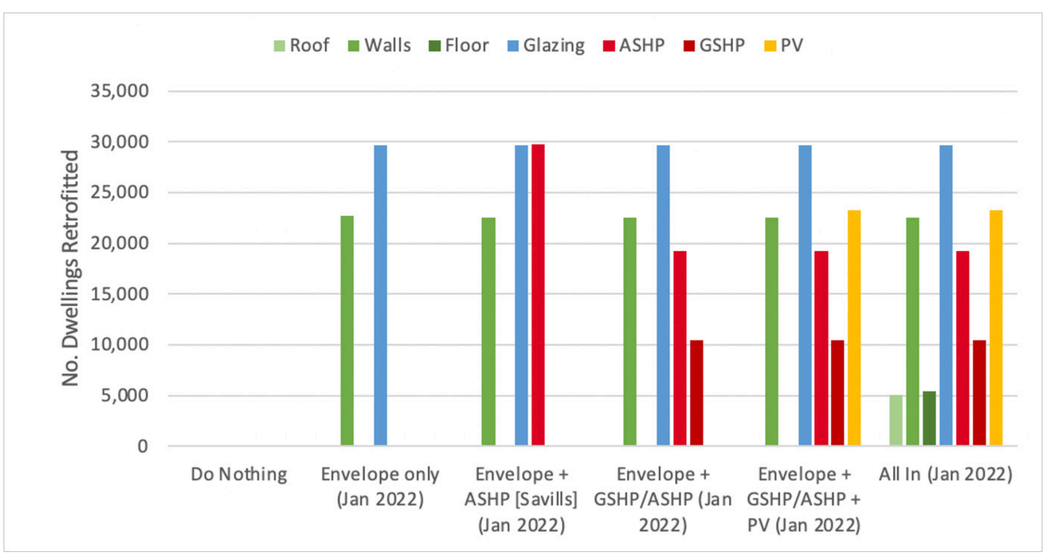

Figure 5: Total numbers of retrofit measures of each type for each package.

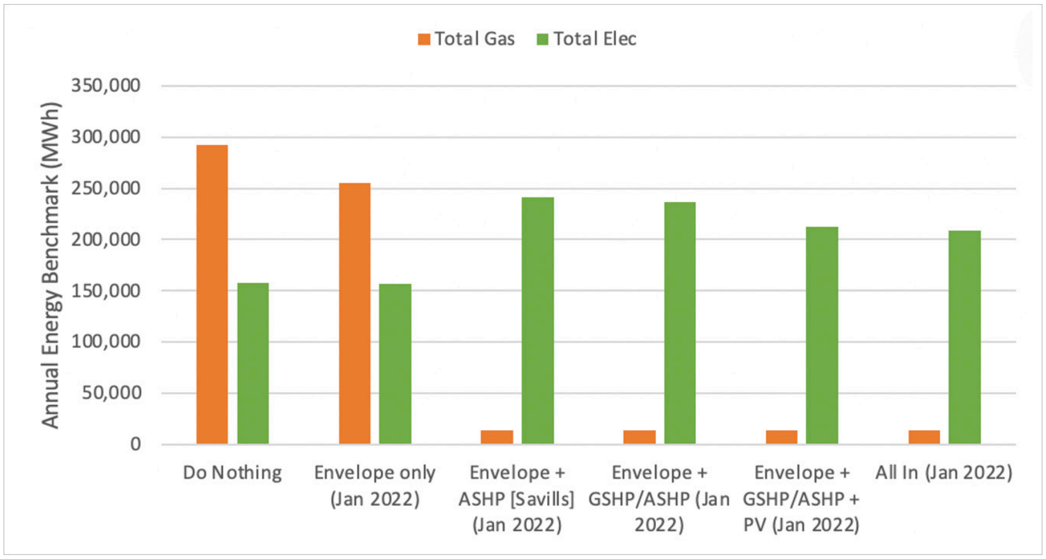

Figure 6: Resulting expected changes in the use of gas and mains electricity.

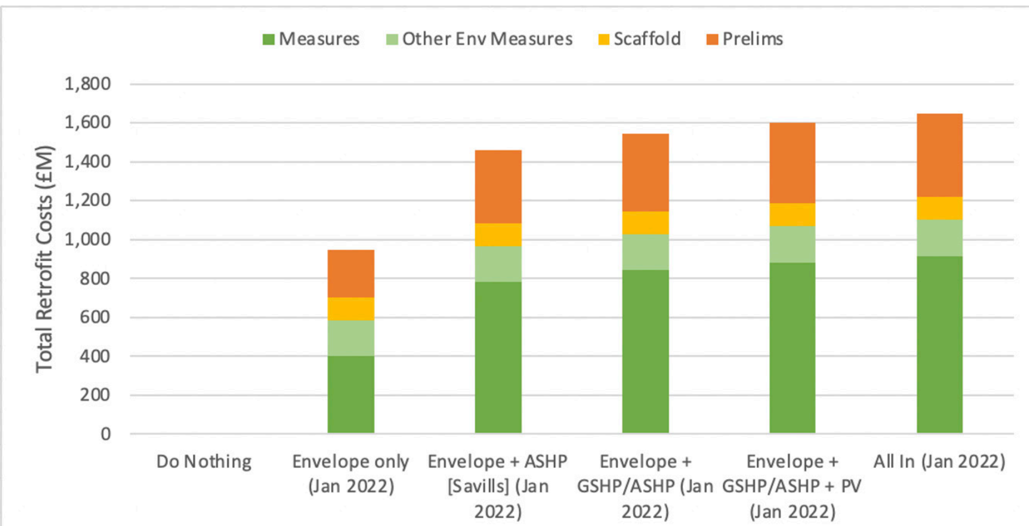

Figure 7: Total costs of all measures.

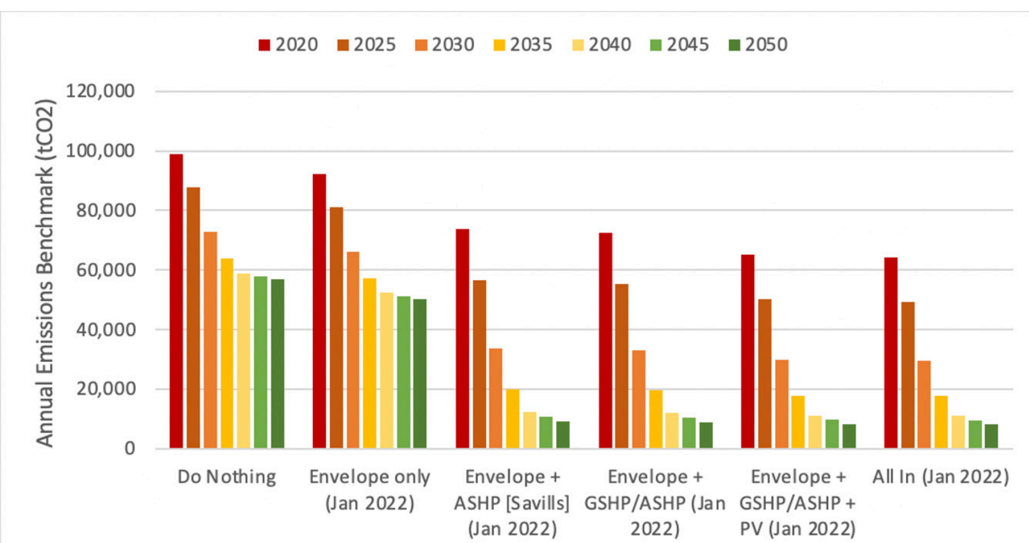

Figure 8: Total impact on carbon emissions by decade to 2050.

Carbon intensity is the amount of carbon emitted per unit of fuel consumed, measured in kg CO_2/kWh. When examining long-term changes to building performance, the carbon intensity of mains electricity is particularly important, as this value is projected to decrease considerably as the means of generation moves to renewables and nuclear. The carbon intensity of the grid is also critical in defining how close to net zero can be achieved in practice.

DOI: 10.5334/bc.349

Figure 9 presents the changes in total fuel costs based on assumed fuel prices of £0.02/kWh for bulk gas where this is applicable and £0.04/kWh elsewhere and £0.16/kWh for electricity, plus annual standing charges of £120 per household for gas and £54 per household for electricity. (These figures have proved to be optimistic compared with the very high energy costs being experienced in late 2022.) Finally Figure 10 gives the numbers of dwellings for which energy running costs either rise or fall.

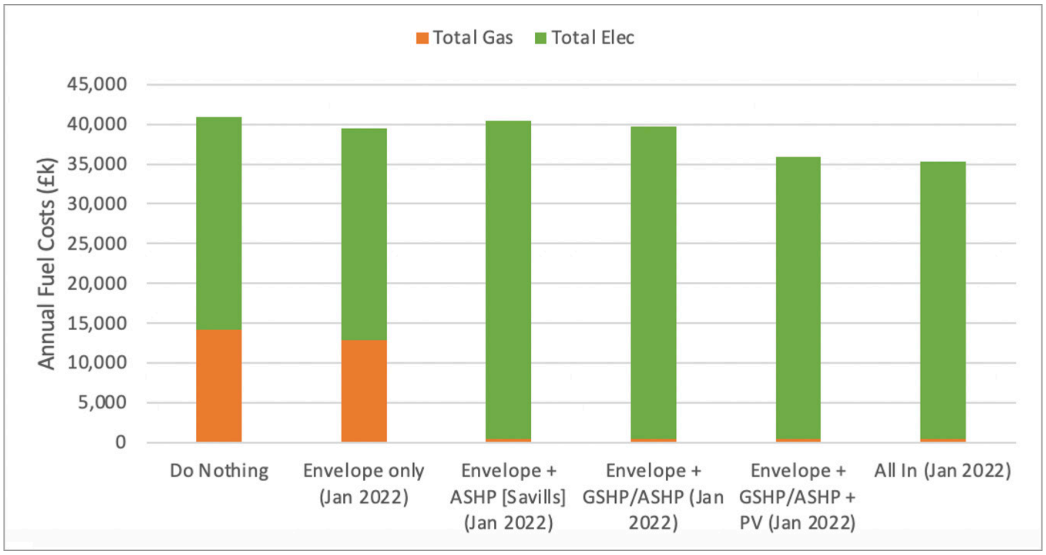

Figure 9: Changes in total fuel costs.

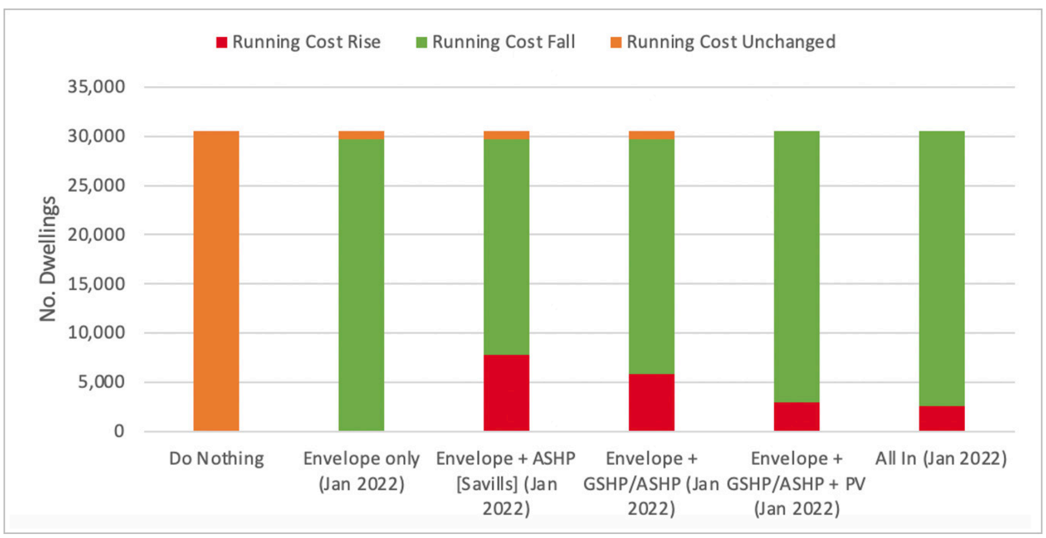

Figure 10: Number of dwellings for which energy running costs either rise or fall.

It should be noted that statistical analyses of domestic energy use have found that building envelope improvements can be associated with minor changes in electricity use, even in gas-heated properties (BEIS 2013/2023). The drivers for this are not clear, however, so this is not currently accounted for in the modelling. As a result, package 2 shows a very small change in electricity use (associated with the electrically heated flats). Also, for packages 3–6, it is assumed that any dwellings with existing gas cooking will switch to electric cooking, alongside the electrification of their heating plant. The existing property data do not include information on cooking facilities, so the numbers cannot be established.

6.1 DISCUSSION OF THE RESULTS FOR PACKAGES OF RETROFITS

All these results are brought together and summarised in Table 3. Note that the numbers of flats and houses shown are the numbers retrofitted, rather than the sample size. These counts differ slightly between scenarios, reflecting the suitability of the retrofit measures considered in each scenario. The 'Do nothing' scenario results in a 26% drop in emissions by 2030 because of the decarbonisation of the electricity supply system, as explained. None of the packages results in a total cut in emissions greater than 70% by 2030, even where all gas use is removed from the dwellings, since the process of decarbonisation of electricity supply is not predicted to be complete by this date. Naturally, under each scenario, emissions would continue to fall beyond 2030, given the expected continuing fall in carbon intensity of the grid to 2050. (For context, the projections suggest a carbon intensity for the grid of around 0.1 kg CO_2/kWh in 2030, and 0.03 kg CO_2/kWh in 2050, compared with the present figure of around 0.2 kg CO_2/kWh (similar to mains gas), and around 0.5 kg CO_2/kWh a decade ago.)

Table 3: Overall results

Note: ASHP = air-source heat pump; GSHP = ground-source heat pump; PV = solar photovoltaic.

		RETROFITS		CAPITAL COSTS		IMPACT		
SCENARIO	RETROFIT MEASURES PACKAGE	HOUSES	FLATS	TOTAL (£ MILLIONS)	AVERAGE (£ THOUSANDS/ DWELLING	GAS KWH (% COMPARED WITH 2020)	ELECTRICITY KWH (% COMPARED WITH 2020)	EMISSIONS 2030 (% COMPARED WITH 2020)
1	Do nothing	0	0	0				–26%
2	Envelope only	2,282	27,444	947	31.9	–13%	0%	–33%
3	Envelope + ASHP	2,282	27,449	1,460	49.1	–95%	54%	–66%
4	Envelope + GSHP/ASHP	2,282	27,449	1,545	52.0	–95%	50%	–67%
5	Envelope + GSHP/ASHP + PV	2,282	28,226	1,603	52.5	–95%	35%	–70%
6	All in	2,282	28,226	1,648	54.0	–95%	33%	–70%

One of the most striking and significant findings is that envelope measures on their own (package 2) produce on average only a 13% drop in gas use. There has been much emphasis in recent government debate, and in the British press, on insulation as a supposed route to cutting emissions from dwellings. The pressure group Insulate Britain has made this the focus of its campaign. It is important, of course, both socially and politically, to improve the poorest-performing dwellings in the stock, to reduce fuel poverty and raise levels of thermal comfort. But improving energy efficiency and cutting emissions are not the same goals. This result, especially compared with the results for packages with air- and ground-source heat pumps, confirms the arguments made by Lowe & Oreszczyn (2021).

(It should be noted that one factor in the lower-than-expected reduction may be the replacement of existing double glazing with new double glazing, which incurs a cost but produces relatively little energy saving.)

With heat pumps installed (packages 3–6), gas use is almost completely replaced. The remaining gas consumption is associated with the dwellings connected to the heat networks with a gas-fired central plant. (The scenarios, as mentioned, do not allow buildings currently on district heating schemes in Islington to switch to local heat pumps.) Presumably these networks will transition to low carbon plant in due course, but this is not accounted for in the modelling. Meanwhile, electricity use rises by around 50% in compensation. The introduction of PV in packages 5 and 6, providing local electricity generation, means that the rises in mains electricity use associated with heat pumps are to an extent offset, and are now around 35%. The potential roof space for PV varies considerably between building types across the Islington stock. In particular, the high-rise blocks are minimally overshadowed from surrounding buildings, but at the same time have the smallest roof area per dwelling.

The average total costs per dwelling vary from £32,000 for the 'Envelope only' package 2 to £54,000 for the 'All-in' package 6. This again emphasises what a substantial cost is involved in fabric measures for a relatively modest cut in emissions. Heat pumps add, on average, between £17,000 and £20,000 to the total cost per dwelling.

6.2 VARIATIONS BETWEEN BUILDING TYPE GROUPS

This broad pattern of results is replicated across the different built-form groups—high-, medium-, low-rise and street properties—although there are differences in detail. The high-rise group comprises just flats, of course. Package 2 (Envelope measures) produces only a 10% cut in gas use because of the compactness of the buildings and the low ratio of exposed wall area to volume. The opportunity for PV installations is limited, and packages 3–6 each reduce gas use by 76% by the switch to heat pumps. The maximum reduction in emissions by 2030 is 61%. Costs per dwelling, perhaps surprisingly and despite the complications of access and scaffolding, are lower than the overall average costs. This is partly because connection to heat networks is more common in high-rise than in the other groups, so there were fewer cases for which transition to local heat pumps was allowed.

The medium-rise group is the largest, with some 15,000 flats plus just 60 houses. The results for all packages are very comparable with the totals for all groups in Table 3. Package 2 cuts gas use by 13% as in the overall results. In the low-rise group, which comprises 4200 flats and 1500 houses, gas use is cut in package 2 by 8%. Otherwise, the results are again comparable with the totals for all groups. The street properties are made up of 700 houses and 4000 flats. The costs are generally higher than the overall averages, because of the larger sizes of the houses. On the other hand, the envelope package 2 cuts gas use by 21% because of the higher ratio of exposed wall and roof area to volume in both low-rise blocks and houses.

7. RESULTS FOR SCENARIOS FOR THE ROLL OUT OF RETROFIT PROGRAMMES

The Pathways to Net Zero tool, as mentioned, also allows the user to define and explore options for the scheduling of different packages of measures up to some final date. For Islington this end date was 2030 in all cases, but it is possible to set other dates. This final section describes the tool's facilities for scenario building and gives examples.

The way in which interventions are rolled out will affect both individual households and the Council. For the households, the rollout order will determine when their property will be improved. For example, prioritising improvement measures to buildings with poor EPCs will result in a different rollout compared with prioritising buildings in areas with high levels of deprivation. For Islington, scenarios were explored in which measures were scheduled based on their cost-effectiveness (to prioritise dwellings expected to give a greater reduction in emissions per £1 spent); to reduce emissions as quickly as possible (by prioritising buildings with the largest expected reduction potential); and for schedules based on current EPC grades and fuel poverty data. The following four policy criteria for scheduling were tested.

- *Scenario 1 (EPCs)*: Retrofits are ordered by the current EPC grades of dwellings, treating those with the poorest grades first, moving from grades G to A. This is in effect a simplified version of the government's Minimum Energy Efficiency Standard (MEES) approach (BEIS 2017/2023). Within each grade the order of dwellings is randomised.
- *Scenario 2 (Fuel poverty)*: Retrofits are ordered to relieve fuel poverty, using the aggregated Census data. Buildings in areas with the highest levels of fuel poverty are treated first.
- *Scenario 3 (Maximum impact)*: Retrofits are ordered to maximise reductions in emissions. Buildings with the largest emissions are treated first.
- *Scenario 4 (Cost-effectiveness)*: Retrofits are ordered to maximise cost-effectiveness. Buildings with the highest predicted emissions reduction per £1 of capital spend are retrofitted first.

The six packages of measures (from 'Envelope only' to 'All-in') were applied in each scenario; and the building improvements were assumed in the first place to be implemented uniformly between 2020 and 2030 (retrofitting 9% of the stock per year). Thus, the present and final states of the stock are identical across the scenarios; only the state of the stock in the intervening years changes between scenarios, according to the order in which measures are implemented. In each case the precise rollout of measures is calculated at the individual dwelling level, based on the analyses of the dwelling's current characteristics, energy performance and retrofit potential and costs.

For example, a house with a grade B EPC, with a high expected potential for emissions reduction, but with a very high associated capital cost, might be scheduled to be retrofitted in 2022 under the 'Maximum impact' scenario, in 2025 under the 'Cost-effectiveness' scenario and only in 2029 under the 'EPC' scenario. It is important to note that some of these variables—the predicted emissions reduction and predicted cost—depend on the specific retrofit measures being applied; while others—the current EPC grade and the of level fuel poverty in the area—do not. Therefore, the retrofit year for each dwelling will depend on both the rollout scenario and the measures being considered. The distribution of retrofitted dwellings by age (Figure 11) and the rollout of measures (Figure 12) for the four scenarios show how the different criteria influence the dwellings treated and the types of measures installed over time.

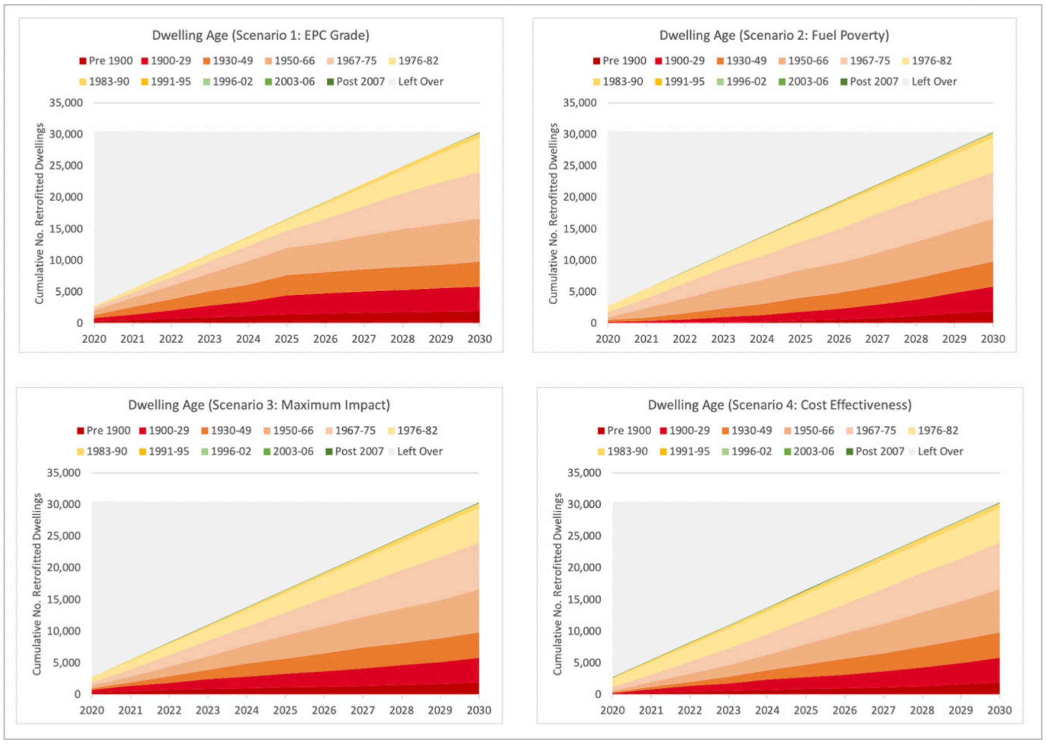

Figure 11: Distributions of retrofitted dwellings by age.

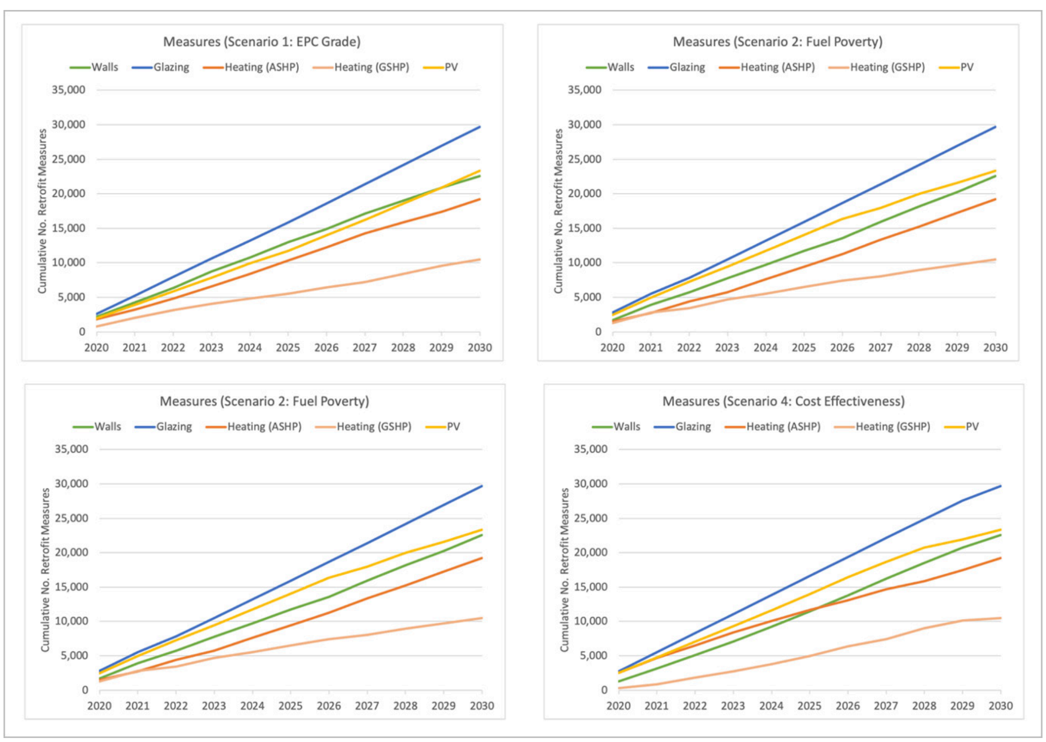

Figure 12: Rollout of measures for the four scenarios.

As might be expected, the choice of drivers strongly influences the patterns of rollout, both in terms of the buildings improved as well as the types of measures prioritised. For example, it has been shown that domestic EPC grades are correlated (albeit not as strongly as expected) with building age (Liddiard *et al.* 2021). Thus, when improvements are rolled out on the basis of current EPC grade (scenario 1), the older buildings are typically prioritised over the more recently constructed ones.

Meanwhile, comparison between the 'maximum impact' and 'cost-effective' scenarios (3 and 4) also reveals the impact on the rollout of measures across different building types. The former typically prioritises larger and older properties since—all else being equal—they tend to have greater potential for emissions reduction. In contrast in the 'cost-effective' scenario, newer dwellings are retrofitted sooner. This process is driven by features such as the presence of cavity walls. Cavity wall insulation has a typically lower impact than solid-wall insulation, but is considerably cheaper.

The next set of graphs show the resulting impact on the performance of the stock to 2030 (Figure 13); the impact on the performance of the stock to 2050 (Figure 14); and the capital costs (Figure 15). As may be expected, the graphs illustrate the difference that choice of rollout has on the outgoing costs, as well as how quickly the improvements are observed. Considering scenarios 3 and 4, which are explicitly driven by the expected costs and impacts, the 'maximum impact' scenario 3 shows a clear concave curve of costs, where more expensive but higher impact measures are implemented first. In contrast to this, the 'cost-effectiveness' scenario 4 shows a convex curve, where buildings requiring cheaper measures are retrofitted first and the more expensive measures are carried out later.

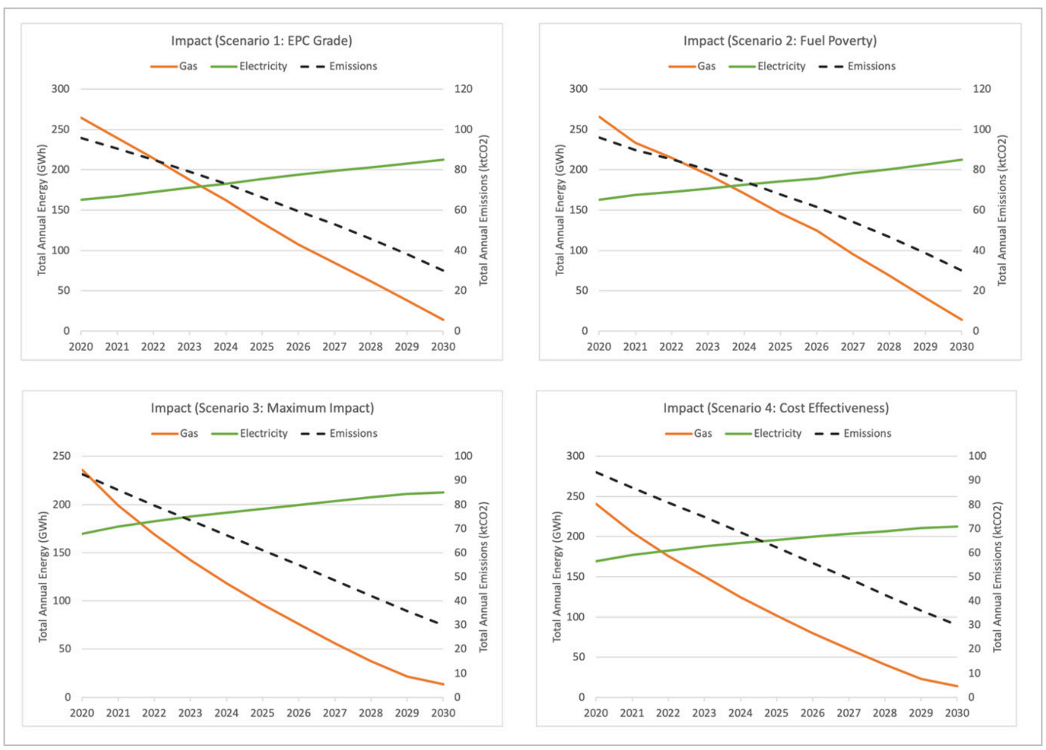

Figure 13: Impacts on the performance of the stock to 2030.

The impact on energy and emissions may not be so pronounced. However, the focus on high impact over cost-effectiveness under scenario 3 does affect the performance of the stock. Across the 2020–30 period, rolling out the same retrofits under the 'cost-effectiveness' approach amounts to a 11.5% higher 'total impact' scenario.

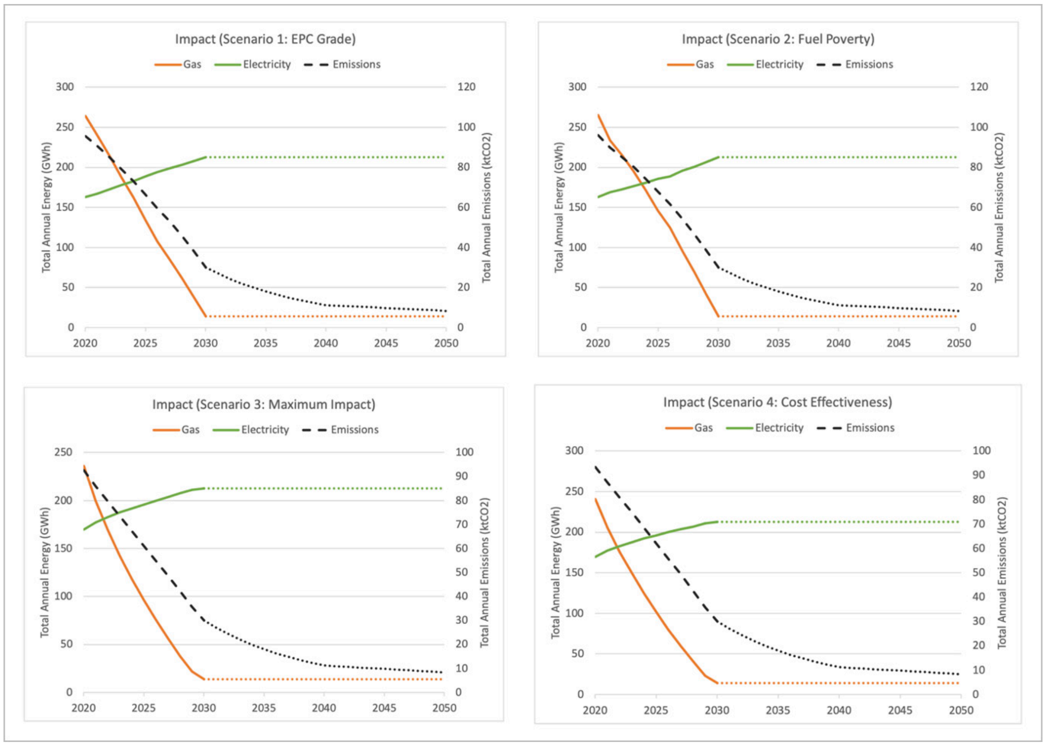

Figure 14: Impacts on the performance of the stock to 2050.

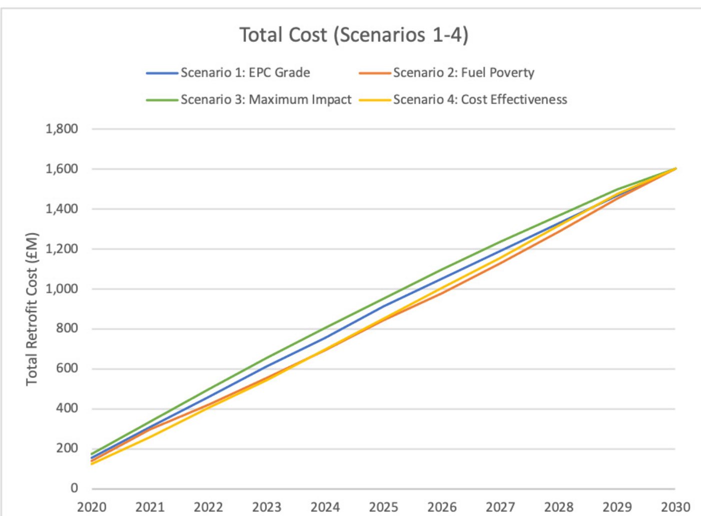

Figure 15: Capital costs.

8. CONCLUSIONS

By analysing each of the 33,300 dwellings in the Islington social housing stock individually, we have been able to show the potential contribution towards achieving net zero emissions of a series of measures: fabric improvements, heat pumps and photovoltaic (PV) installations.

The scope of the analyses as well as the size and complexity of the stock means that there are several areas of uncertainty in the study. These reflect both the availability and the accuracy of the data describing the current buildings within 3DStock, as well as the assumptions and methods used in the Pathways to NetZero tool. Naturally, the level of accuracy that could be achieved when examining a single building will always be higher than when examining tens of thousands. However, the uncertainties have been accounted for in a variety of ways: through procedures to process the raw input data to identify and exclude instances of unlikely or inconsistent data; through collaboration with Islington council employees (who, for example, provided information on recent measures that were not covered within the Energy Performance Certificate (EPC) data); and through comparison against empirical data where available. For around 10% of the dwellings, reliable data were not available and so they were excluded from the pathways analyses altogether. More difficult to resolve are the uncertainties that arise from the period of analysis. The expected changes in emissions calculated across the scenarios is strongly driven by the grid, for example. Thus, if the projected improvements to the carbon intensity of mains electricity are not achieved, then this would directly impact on the relative benefits of electrification of heating. Similarly, changes in system manufacturing or the construction industry may mean that the relative costs of the measures may change over time. The impacts of these long-term factors on the large-scale deployment of retrofits are subjects of ongoing study with 3DStock and the Pathways tool.

The outstanding finding is the relatively modest contribution of fabric measures. What is more, although such measures are simple technologically, they are expensive and complex since they must be tailored individually to dwellings and much craft work is involved. The Italian national plan finds that fabric measures are only 'optimal' for new buildings and mentions their high costs (Italian Ministry for Ecological Transition 2021: 28). Chen *et al.* (2020) state that extreme fabric retrofits are needed to achieve large cuts in energy use, but that these are 'not economically feasible'. The present authors' calculations have excluded the rebound effect, but recent work by Peñasco & Anadón (2023) has indicated that this might cancel out some of the gains from fabric measures. The key to net zero is the transition to all-electric homes and the decarbonisation of the national and local electricity supply. Heat pumps are the most efficient route, but electrical resistance heating also removes emissions.

With the most effective of the packages of measures it was only possible to get Islington 70% of the way to net zero (in theory) by 2030. This was not due, however, to any intrinsic limits to the technologies themselves; it was because the UK electricity network is not predicted to be fully decarbonised by that date. Net zero could be approached by 2050.

The cost figures given here are costs to Islington Council. This and similar programmes of decarbonisation throughout the UK domestic stock will create additional costs for other actors, specifically for the necessary extension and reinforcement of the electricity supply network as fossil fuels are phased out. The argument has been made here that heat pumps might be installed in many cases unaccompanied by fabric improvements. None of the retrofit packages considered in the present study excluded envelope measures. It is possible, however, that Islington or others might elect to save costs in this way. But should they do so, some costs would be transferred elsewhere since the electricity loads on the grid would be higher than if fabric improvements had been carried out.

There are other major issues to do with skills training, logistics, raising funds from local and national sources, and integrating retrofits into the Borough's capital programme, all of which are out of the scope of this paper. The Borough will want to reconcile its programme of retrofits with other priorities for the stock, including cutting fuel poverty and treating problems of damp, mould and overheating.

The methods used for this study of Islington are directly applicable to all London boroughs using UCL's 3DStock model of the capital. This is because dwellings and buildings are treated individually so there is no question of archetypes being unrepresentative. Here is where the present study differs from most previous research. We take the kind of detailed analysis of specific individual buildings made in many case studies and apply it automatically to very large populations of buildings.

In fact, the Pathways to NetZero tool has already been applied to the entire housing stock of London, both public and private (Godoy-Shimizu *et al.* 2023). A 3DStock model has been built of the domestic stock of Wales, and construction of a comprehensive model of the English stock is in progress. In due course, it should therefore be possible to apply the analyses described here nationally. The cost figures used in the present analysis are special to London. New updated costs would be needed outside the capital, and allowance made for variations in climate. The international relevance of the work is clearly more limited and is confined to the methodology and the principles of the analytical tool.

ACKNOWLEDGEMENTS

Augustin Gibaud and Michael Woodrow of the UCL Faculty of Engineering Science provided advice on fire risks. Valentina Marincioni of the UCL Institute for Environmental Design advised on moisture risks. Islington Council very kindly gave permission to publish this paper. The authors would like to acknowledge the substantial contributions to this study made by the Council, in particular by Glenn McCorkindale, Simon Kwong, Matthew West, Paul Rickwood, Kevin Byrne, Hannah Bowman, Rodrigo Matabuena and other members of the client group. John Kiely and John Barnes of Savills provided cost data on retrofits. Zachary Gill of SOAP retrofit shared his professional experience.

AUTHOR AFFILIATIONS

Stephen Evans orcid.org/0000-0002-6692-907X
UCL Energy Institute, Bartlett Faculty of the Built Environment, University College London, London, UK

Daniel Godoy-Shimizu orcid.org/0000-0002-6765-9606
UCL Energy Institute, Bartlett Faculty of the Built Environment, University College London, London, UK

Philip Steadman orcid.org/0000-0001-8204-5584
UCL Energy Institute, Bartlett Faculty of the Built Environment, University College London, London, UK

Shyam Amrith orcid.org/0000-0002-8726-891X
UCL Energy Institute, Bartlett Faculty of the Built Environment, University College London, London, UK

Dominic Humphrey orcid.org/0000-0002-6172-0509
UCL Energy Institute, Bartlett Faculty of the Built Environment, University College London, London, UK

Paul Ruyssevelt orcid.org/0000-0002-4406-4458
UCL Energy Institute, Bartlett Faculty of the Built Environment, University College London, London, UK

COMPETING INTERESTS

The authors have no competing interests to declare.

FUNDING

The research was funded by the London Borough of Islington.

SUPPLEMENTAL DATA

Supplemental data for this article can be accessed at: https://doi.org/10.5334/bc.349.s1.

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TO CITE THIS ARTICLE:
Evans, S., Godoy-Shimizu, D., Steadman, P., Amrith, S., Humphrey, D., & Ruyssevelt, P. (2023). Getting to net zero: Islington's social housing stock. *Buildings and Cities*, 4(1), pp. 524–544. DOI: https://doi.org/10.5334/bc.349

Submitted: 25 April 2023
Accepted: 11 July 2023
Published: 26 July 2023