Spatially-based urban energy modelling approach for enabling energy retrofits in Oxfordshire

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Abstract

The UK government has committed to achieving net zero carbon emissions by 2050. This will require a transformation of the housing sector as it has lagged previous emissions targets. Although millions of existing homes across the UK need energy improvements, the process of identifying suitable and eligible homes is presently a time-consuming task and energy suppliers are struggling to meet their targets. To address this challenge, this paper describes the application of a data-driven geographical information system-based approach to spatially identify suitable dwellings quickly and accurately by mapping and modelling baseline energy use and potential for energy retrofit measures, singularly and in combination.

Drawing on publicly available datasets on housing and energy, combined with local datasets, a neighbourhood with high fuel poverty in Bicester (Oxfordshire, UK) was selected. The DECoRuM model was then used to estimate current energy use and potential for energy reduction on a house-by-house level. The improvement measures were aggregated to encourage bulk installations and drive down installation costs. House-level energy assessment in the selected area using DECoRuM shows that a package-based approach comprising building fabric and heating system upgrade and solar PVs is effective at significantly reducing energy consumption and energy bills, as well as fuel poverty.

This spatially based urban energy modelling approach brings together energy calculations and spatial mapping to address the barriers to mass retrofit programmes. The data collected can also be used to build brokering services amongst those who need energy improvements (households) with those can provide retrofit measures (installers) and those can sponsor energy measures (energy suppliers).

Introduction

The UK has committed to achieve net zero carbon emissions by 2050 (BEIS, 2019). This will require a significant step forward for the domestic building sector as it has lagged behind previous emissions targets (BEIS, 2018a). This is particularly true for the old and inefficient existing housing stock (CCC, 2019; Friedler and Kumar, 2019) which is only currently supported by the Energy Company Obligation (ECO) programme. The ECO is, however, insufficient to meet the current target (IET, 2018).

Under the ECO programme, energy suppliers (utilities) are obligated to reduce CO_2 emissions and fuel poverty from households in a cost-effective manner. Although millions of homes across the UK need energy improvements, the process of identifying suitable homes with eligible residents is presently a time-consuming task (using community events, door-knock or social media campaigns). This is one reason suppliers are struggling to meet their targets. Whether through the ECO or an improved deep retrofit programme, rapid and accurate identifying dwellings that need retrofit and the extent of work required is needed.

Geographical information system (GIS) based spatial mapping combined with energy modelling has the potential to provide this rapid assessment of existing conditions which can be used to project retrofit potential for large areas. Spatially mapping energy consumption and variations of retrofit potential have been explored internationally for years. Whether through district scale modelling and mapping of energy use intensity (EUI) in Dublin, Ireland (Ali, Shamsi, Hoare, & O'Donnell, 2018). Block level EUI for New York City and Los Angeles in the USA (Howard, 2013). House-by-house level mapping of energy consumption and energy bills estimates in Cambridge and Gainesville in the USA (Howard, 2013). Solar potential mapping of roof capacity in Cambridge USA (Howard, 2013) and Bristol, UK (Open Data Bristol, 2020). In addition, Google also has a site called Project Sunroof (Google, 2020) to map solar potential for rooftops over much of the USA. Retrofit potential has been explored using a fabric package in Rotterdam City, NL (Mastrucci, Baume, Stazi, & Leopold, 2016) and a user oriented design support tool for fabric retrofit in Switzerland (Buffat et al., 2017).

Within this context, this paper describes the application of a localised GIS-based decision support tool to spatially identify (model and map) suitable households for ECO-obligated suppliers more quickly, accurately and cost-effectively, using a case study in Oxfordshire (UK). Drawing on publicly available datasets on housing and energy, and combining it with local datasets an optimal neighbourhood is selected and dwellings are then targeted for specific energy interventions and packages of measures.

Methodology

There are two primary levels to the assessment. First, a neighbourhood is selected for house-by-house investigation of retrofit potential, prioritised based on need (high energy use, high fuel poverty). Second, the selected neighbourhood is modelled and mapped to assess current energy consumption, what retrofit measures will be deployed, and the impact of deep energy retrofits on projected energy consumption.

Identification of a focal neighbourhood using rapid assessment

To identify a focal area for mapping, publicly available datasets were examined for the case study city - Bicester, UK. These included, the Ordnance Survey Mastermap, Energy Performance Certificates (EPC) (MHCLG, 2017), the UK Government's sub-national energy (BEIS, 2017b) and fuel poverty (BEIS, 2017a) data at lower layer super output area (LSOA) (areas of approximately 400-800 dwellings). By super-imposing these datasets, neighbourhoods with high energy consumption and high rates of fuel poverty were identified.

Energy modelling

A GIS-based Domestic Energy, Carbon counting and carbon Reduction Model (DECoRuM) was used to estimate energy use and potential for energy reduction on a house-by-house level. In the DECoRuM model, energy consumption and CO_2 emissions are the result of heat loss calculations from fabric and ventilation characteristics, estimated energy use from heating, domestic hot water and electricity use as calculated using the Building Research Establishment's (BRE) Domestic Energy Model (BREDEM-12). Data for calculations include actual house characteristics gathered from historic (Digimap) and current maps (OS Mastermap and Google street view), EPCs (MHCLG, 2017), literature describing home characteristics based on age and typology (e.g. Tabula/Episcope (BRE, 2014)), and completed questionnaires on home characteristics. Carbon factors are taken from the UK Government's Standard Assessment Procedure (SAP) (BRE, 2019) and energy bill costs are taken from uSwitch (2020) wherein current energy costs and standing charges are taken from the most used energy provider in the mapped area. The results for each household are displayed on a map using GIS; in this instance, MapInfo.

The background calculator of DECoRuM, BREDEM-12, in its original form required input data for almost 95 parameters to predict dwelling energy consumption (Anderson et al., 2002). Though all these data are measurable, it is difficult to obtain in practice, owing to the high cost of detailed on-site surveys. This poses considerable problems for energy modelling on an urban scale. In response to this problem, DECoRuM's data reduction technique classifies the 95 input data parameters required by BREDEM-12 into four categories:

1. *Data common for all dwellings* (50 input parameters, e.g. degree day region, height above sea level, site wind speed) sourced from BREDEM-12 reference tables (Anderson, et al., 2002; BRE, 2015), English House Condition Survey.
2. *Data derived from built form of the dwellings* (five input parameters, e.g. zone areas, occupancy, window area) from standard dwelling configurations reports.
3. *Data derived from age of the dwelling* (18 input parameters, e.g. heating system, controls, U-values) sourced from BREDEM-12 reference tables, English House Condition Survey.
4. *Data collected for individual dwellings* (22 input parameters, e.g. ground floor area) Characteristics that are collected and entered into the model include: built form, floor area, dwellings age, exposed wall area, orientation, wall, roof and window type and insulation where available, renewables, etc.

Assumptions / limitations:

- Desktop data collection and entry (e.g. façade observations) can be time intensive.
- Occupancy where unknown, is calculated from floor area using the BREDEM-12 method.
- Behaviour assessment is limited: occupancy times, heating schedules, window opening schedules, etc. are not modelled.
- Assumptions are made about occupant behaviour, e.g. temperature set-point.
- Baseline wall construction and U-values (unless known, e.g. reported in EPCs) are based on the age of the home where construction methods are well documented (e.g. BREDEM reference tables).
- Different scenarios must be calculated separately and cannot vary within a given timeframe; calculations are static.

Retrofit mapping approach

The retrofit mapping approach first identifies distribution of the need for wall insulation, roof insulation and photovoltaics (PV) among the dwellings. Existing wall and roof insulation conditions are taken from dwelling age and EPC data. Existing PV data are taken from EPC and Google street view / satellite map.

Second, where all three measures listed above are needed, a 'deep retrofit' package is tested on a selected cluster of dwellings. Particular attention is given to common dwellings types in the area as this would allow planning for a large scale mass-retrofit of a single package. The improvement measures are aggregated to encourage bulk installations and drive down installation costs. Finally costs and savings for retrofits in these areas are considered.

Though there is no official definition for 'deep retrofit' or 'deep energy retrofit' as it is sometimes referred, deep retrofit work aims to reduce consumption by 50% or more (Less, Fisher, & Walker, no date). The deep retrofit as applied in this paper, approaches the problem from the point of view that current policy, i.e. ECO3, is insufficient to meet net zero carbon targets. Instead of retrofitting one measure at a time, deep retrofit aims to improve the dwelling in a number of aspects, e.g. fabric efficiency, systems efficiency and energy production.

The following measures make up the deep energy retrofit package:

Fabric measures:

- Improved airtightness - 1.0 $m^3/h.m^2$@50pa
- Walls: (U-value: 0.13); Loft (U-value: 0.11); Floor: U-value: 0.13; Windows: (U-value: 0.8); Doors: (U-value: 1.0)

Systems:

- Space heating - Air source heat pump (ASHP): coefficient of performance (COP) = 2.6 (Greater London Authority, 2018); Renewable Heat Incentive (RHI) payment £0.107/kWh through June 2020 (Ofgem, 2020).
- Water heating - 80mm jacket insulation on hot water tank, insulated pipework, cylinder thermostat
- Electricity - 100% low energy light bulbs / PV kWp dependent on roof capacity; 50% self-consumption

Costs for most measures are gathered from (Currie & Brown and AECOM, 2019; Palmer, Livingstone, & Adams, 2017). In addition, floor insulation, door and PV costs were found online (www.greenmatch.co.uk and www.homeadviceguide.com).

Results

Rapid energy assessment

In consideration of the ECO focus, fuel poverty was prioritised. For this reason, a neighbourhood (LSOA) with the highest level of fuel poverty (11%) in Bicester was selected (figure 1). This area also has over 10% of dwellings with vulnerable residents, i.e. residents with a disability or long term health problems (UCL, 2015). Aggregating all EPCs for Bicester, the selected neighbourhood was also found to have the most dwellings with ‘very poor’ & ‘poor’ roof insulation levels. The area however, had a mid-range (among Bicester LSOAs) mean energy consumption of 15,243 kWh. This aligns with the UK’s medium range of typical domestic consumption values (Ofgem, 2019b).

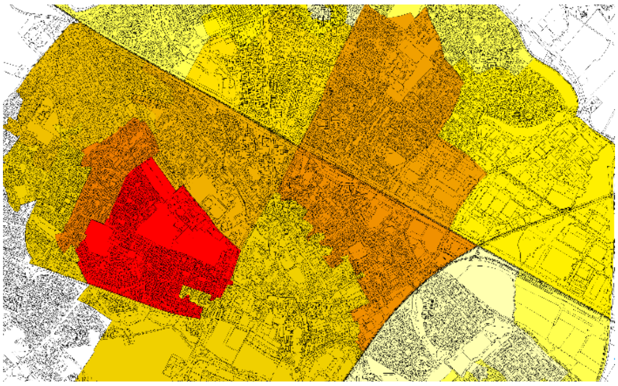

Figure 1: Town of Bicester with most fuel poor (red) to least fuel poor LSOAs (white). Map© Crown Copyright and Database Right 2019. Ordnance Survey (Digimap Licence).

Neighbourhood characteristics

Preliminary analysis of the selected area (comprising 440 dwellings) indicated that the two most common dwelling classifications were 1950 - 1965 terraced and 1950 - 1965 semi-detached. Figure 2 shows the distribution of dwelling types in the selected area.

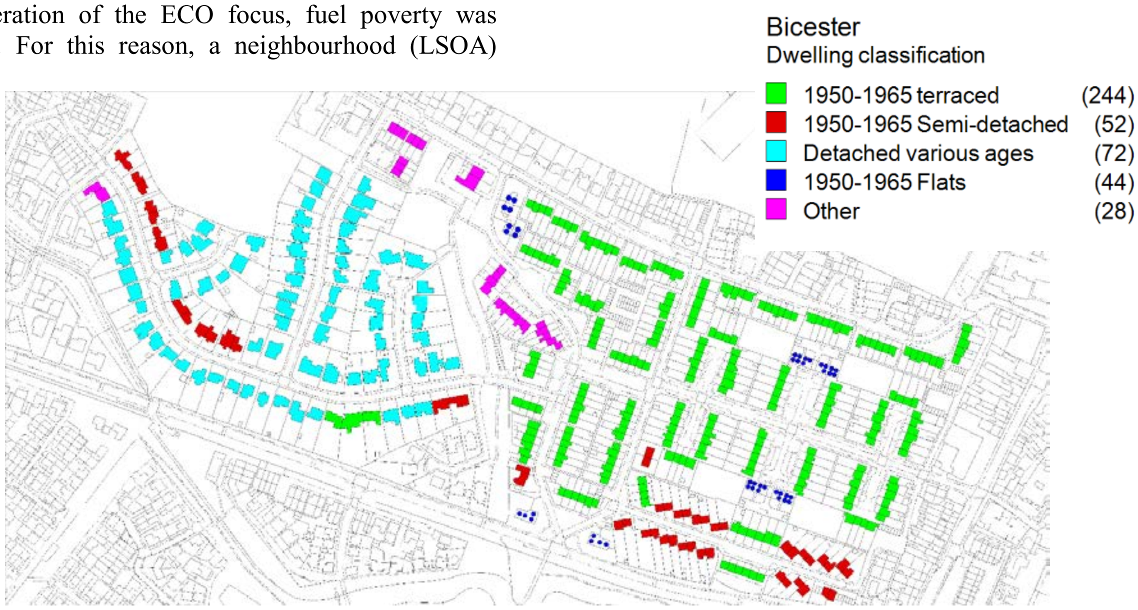

Figure 2: Dwelling type distribution. Map© Crown Copyright and Database Right 2019. Ordnance Survey (Digimap Licence).

There is an estimated total of 299 (68%) dwellings in need of cavity wall insulation, 319 (73%) with less than 100mm of roof insulation, and only 14 dwellings with existing PV. Figure 3 shows the dwellings that are estimated to need wall insulation and significant levels of roof insulation (those with <100 mm of existing insulation).

Baseline results

The largest consumers in the selected neighbourhood area are the large detached houses, as shown in the left-hand side of the map in Figure 2. This type of dwelling will prove most difficult to retrofit, especially in an aggregated sense, as the dwellings are all very different in form and size. The majority type on the right-hand side of the map will be easier to plan in a mass-retrofit scenario. These would be ideal for testing a mass deep retrofit programme to explore what works and what does not. Table 1 shows the descriptive statistics of the modelled baseline data and figure 4 shows the energy use intensity (EUI) for the mapped area. Though the energy consumption is normalised to area, the large detached houses on the left of the map are the largest users. However, though there is some distribution of high consumers on right side of the map also.

Table 1: Descriptive statistics for the baseline model

	Energy kWh/year ($kWh/m^2/year$)	**Energy bills £/year**
Mean	17,491 (205)	£898
Median	14,982 (206)	£706
Min	4,272 (64)	£371
Max	93,247 (453)	£12,492

Retrofit results

Following the modelling and mapping (figure 5) of a deep retrofit package in the 440 dwellings, the mean total annual energy reduction potential is 90% and mean total annual energy bill reduction potential is 70%. Table 2 shows the descriptive statistics of the modelled retrofit data for the dwellings. As is seen for the minimum statistic in energy bills, the negative value indicates payments through the RHI for heat pump use. Though feed-in-tariffs are no longer available for PV generation, the PV is also useful in reducing costs.

Table 2: Retrofit model descriptive statistics

	Energy kWh/year ($kWh/m^2/year$)	**Energy bills £/year**
Mean	1,466 (21)	£225
Median	1,421 (21)	£224
Min	266 (4)	-£88
Max	4,241 (47)	£573

Table 3 shows the details for the common dwelling types, i.e. those with more predictable fabric needs.

Table 3: Common dwelling results

	1950-65 terraced	**1950-65 semi-detached**
Dwellings count (% of total)	244 (55%)	52 (12%)
Mean baseline EUI ($kWh/m^2/yr$)	194	228
Mean retrofit EUI ($kWh/m^2/yr$)	23	21
EUI reduction (%)	89%	92%
Mean baseline energy bills	£792	£990
Mean retrofitted energy bills	£225	£224
Energy bills reduction (%)	68%	73%

Figure 3: Dwellings in need of wall and roof insulation. Map© Crown Copyright and Database Right 2019. Ordnance Survey (Digimap Licence).

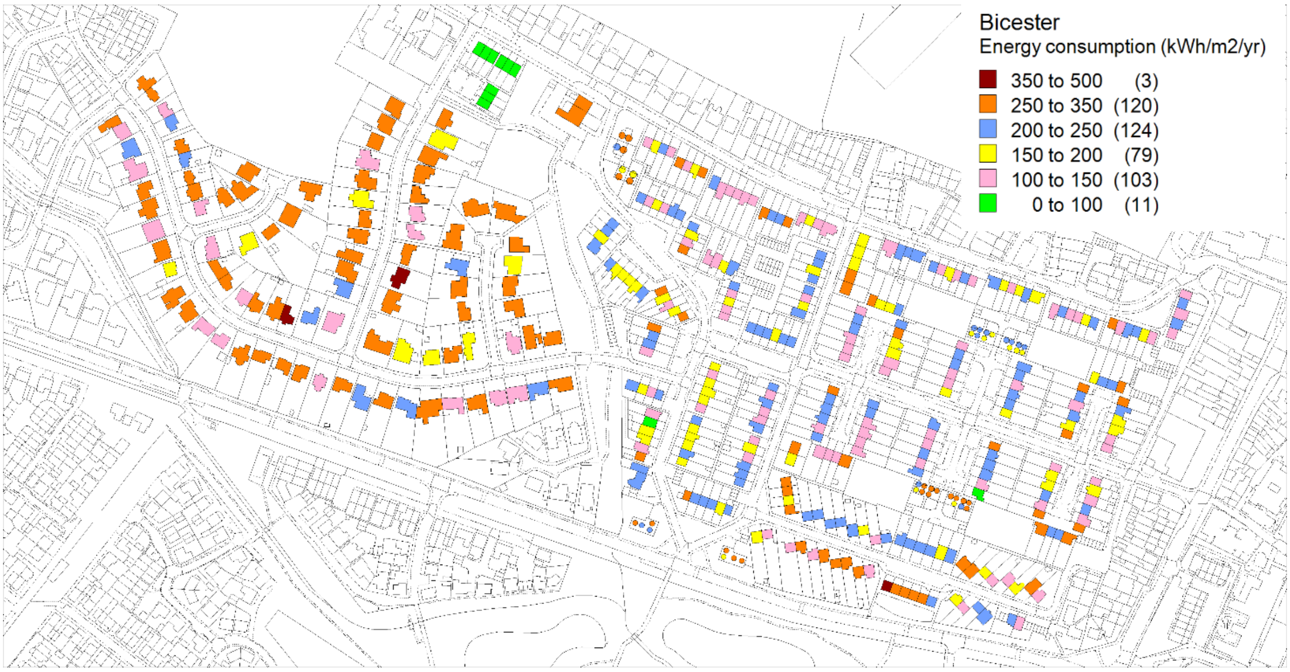

Figure 4: Baseline energy use. Map© Crown Copyright and Database Right 2019. Ordnance Survey (Digimap Licence).

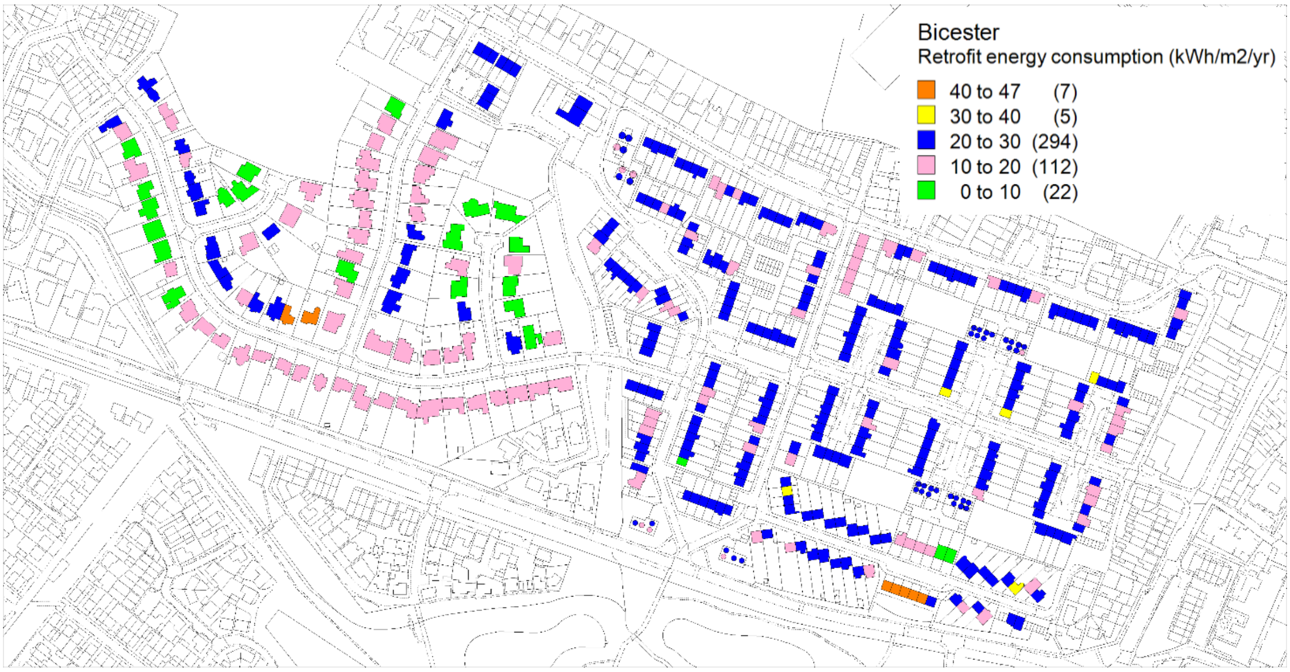

Figure 5: Retrofit energy use. Map© Crown Copyright and Database Right 2019. Ordnance Survey (Digimap Licence).

Costing retrofit

Overall, the mean cost to retrofit is £16,200 while a full retrofit package can cost up to £24,000. The average cost to upgrade the building fabric alone is £4,050, while for installing ASHP, about £9,000 is estimated. The average cost to install PV is £3,000 (average size 2 kWp) and a maximum of £9,200 (maximum size 6.2 kWp).

Figure 6 shows the distribution of energy savings by dwelling type in the selected area. The median energy savings is highest in detached dwellings. This, however, is also true of the median for total cost to retrofit (figure 7). Table 4 however, shows that though it can be more costly to retrofit the large detached dwellings, it is less costly per unit of energy saved. Overall, however, as the utility cost for electricity is £0.13 per kWh, the mean simple return on investment for the three dwellings types ranges from 24 – 34 years.

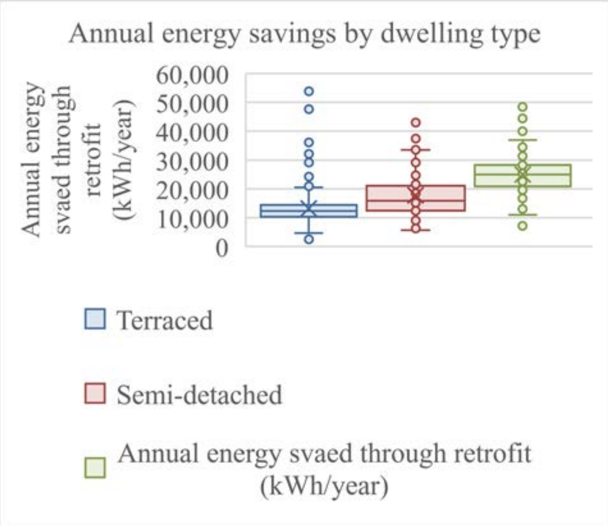

Figure 6: Energy savings by dwelling type.

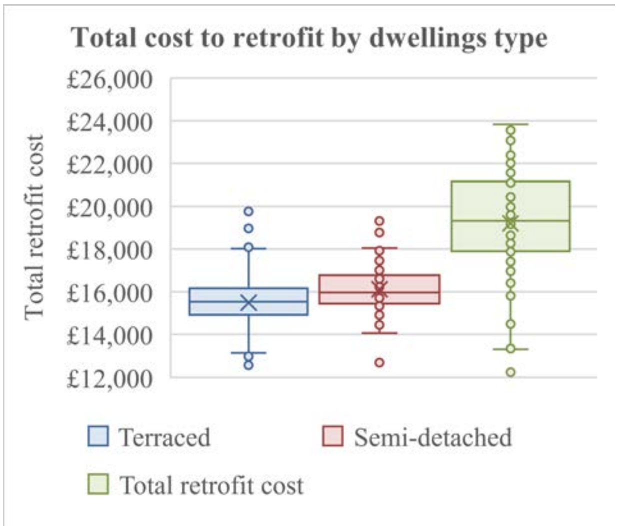

Figure 7: Total cost to retrofit by dwelling type.

Table 4: Cost per unit of energy (kWh) saved through retrofit

	Terraced	Semi-detached	Detached
Mean	£1.36	£1.05	£0.83
Median	£1.28	£0.99	£0.83
Min	£0.30	£0.39	£0.41
Max	£6.48	£2.80	£2.26

Discussion

House-by-house energy assessment of the selected area using DECoRuM has shown that a package-based approach comprising building fabric, heating system upgrade and solar PVs is effective at significantly reducing energy consumption and energy bills, thereby relieving fuel poverty. The old and inefficient UK housing stock will require deep energy retrofits to meet the government's net zero emissions target. GIS modelling and mapping of retrofit opportunity can also help accelerate the reduction of fuel poverty that is widespread in the existing housing stock by assisting in scaling up energy retrofits. The process would involve identifying what dwellings are suitable and where they are located and aggregating the retrofits. The current analysis has shown that 80-90% reductions in total energy consumption are achievable in theory; however, the performance gap should be expected (Energiesprong, 2019; Gupta, Gregg, Passmore, & Stevens, 2015).

This spatial mapping approach to enabling mass energy retrofits can be further utilised by District Network Operators (DNOs) to ascertain the effect of area-based low energy retrofits on peak energy demand. Local authorities can overlay the retrofit energy maps with socio-economic and lifestyle data (Experian, Mosaic) to target appropriate households for installing retrofit measures. The colour-coded energy maps provide community energy groups with visual feedback on tracking dwelling energy use. As smart meters are installed every home in the UK this decade (BEIS, 2018b; Ofgem, 2019a), these can provide greater validation of energy modelling results before and after retrofit.

According to Currie & Brown and AECOM (2019), it is more costly to retrofit than to build to the same performance specification in new build. As retrofit is essential to meet reduction targets, reduced costs are needed. Retrofit kits such as mass-producible pre-manufactured façade solutions (e.g. Energiesprong (2019)) coupled with mass retrofit effort should in theory reduce upfront costs. As has been explored by Energiesprong (2019), Catapult (2019) proposes that similarly, in the UK, a 'Retrofit Kit' of parts from a menu of components that would work together reliably and flexibly to cover a wide range of building forms, thereby enabling mass customisation. Increasing volumes through larger-scale demonstrators will improve the evidence base and help to increase volumes.

In neighbourhoods like this one in Bicester (Oxfordshire), the first step to mass energy retrofit is to begin with identifying and analysing the baseline energy use of the most common dwellings type like the 1950-65 terraced housing. Formulating a retrofit approach to this dwelling type would allow retrofitting 60% of the selected area. Identifying the dwellings that need cavity wall and roof insulation (e.g. the full retrofit) would isolate the dwellings that need full building fabric retrofits. Figure 8 on the following page shows full blocks of these terraced dwellings where a theoretical complete building fabric based energy retrofit, similar to Energiesprong (2019), could be applied to clusters of 5 – 7 dwellings (or more) at a time. (Figure 8 is a close-up view of figure 3.)

Figure 8: Clustered dwellings for deep retrofit. Map© Crown Copyright and Database Right 2019. Ordnance Survey (Digimap Licence).

At this stage implementation of the methods described here would require different levels of expertise depending on the step. Home energy survey to improve the local dataset could be carried out by local authority or community groups. Collection of dwelling characteristics outside of home energy survey would require a higher level of expertise such as a local authority energy manager, energy assessor, or retrofit provider. Spatially mapping of the data would require a basic level of GIS understanding; however, though mapping is highly beneficial to communicating needs, it is not essential to analysing the data. After clusters have been identified as priority areas, further assessment would be highly recommended to cross-check insulation levels and heating system needs.

Conclusion

The study has demonstrated the application of a spatial mapping approach that brings together energy calculations and GIS mapping with community engagement to model, map and manage baseline energy use and potential for energy reduction on a house-by-house level, and aggregated to a neighbourhood scale. This mapping approach can also address the barriers to mass energy retrofit programmes, and the business needs of both ECO obligated energy companies and technology providers seeking suitable dwelling of deploying energy retrofit measures.

The GIS approach is designed to support energy suppliers, local authorities and community organisations to aggregate installation of measures so as to encourage bulk installations and drive down costs of installation and develop outreach programmes to invite eligible households to adopt the measures. The data collected for such energy mapping models can also be used to build brokering services amongst those who are in need of energy improvements (households), who can provide retrofits (installers) and who can sponsor energy measures (e.g. ECO-obligated suppliers or technology providers).

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References

Ali, U., Shamsi, M. H., Hoare, C., & O'Donnell, J. (2018). *Gis-based residential building energy modeling at district scale.* BSO 2018: 4th IBPSA-England Conference on Building Simulation and Optimization, Cambridge, United Kingdom, 11-12 September 2018.

Anderson, B. R., Chapman, P. F., Cutland, N. G., Dickson, C. M., Henderson, G., Henderson, J. H., . . . Shorrock, L. D. (2002). *Bredem-12 model description: 2001 update* BR 438). Watford: B. R. Institute. http://www.iea.org/media/statistics/eemanual/UK_BREDEM_model_description.pdf

BEIS. (2017a). *Fuel poverty data measured as low income high costs (2015 data)* [Data set]. Retrieved from https://www.gov.uk/government/statistics/sub-regional-fuel-poverty-data-2017

BEIS. (2017b). Sub-national consumption statistics. Retrieved Date Accessed, 2018 from https://www.gov.uk/government/publications/regional-energy-data-guidance-note.

BEIS. (2018a). *Clean growth strategy: Leading the way to a low carbon future*. London: HM Government Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/700496/clean-growth-strategy-correction-april-2018.pdf.

BEIS. (2018b). *Smart meters: A guide*. London: GOV.UK Retrieved from https://www.gov.uk/guidance/smart-meters-how-they-work.

BEIS. (2019). Uk becomes first major economy to pass net zero emissions law. Retrieved Date Accessed, 2020 from https://www.gov.uk/government/news/uk-becomes-first-major-economy-to-pass-net-zero-emissions-law.

BRE. (2014). *Building typology brochure england: September 2014* 296-024). Watford: B. R. Establishment.

http://episcope.eu/fileadmin/tabula/public/docs/brochure/GB_TABULA_TypologyBrochure_BRE.pdf
BRE. (2015). *Bredem 2012: A technical description of the bre domestic energy model: Version 1.1*. https://www.bre.co.uk/filelibrary/bredem/BREDEM-2012-specification.pdf
BRE. (2019). Sap 10.1 (pp. 178). Watford: Building Research Establishment.
Buffat, R., Schmid, L., Heeren, N., Froemelt, A., Raubal, M., & Hellweg, S. (2017). Gis-based decision support system for building retrofit. *Energy Procedia, 122*, pp. 403-408.
Catapult. (2019). *Homes fit for the future; retrofit towards a sector-wide roadmap 2020*. London: https://s3-eu-west-1.amazonaws.com/media.cp.catapult/wp-content/uploads/2020/01/30170148/HIP-Retrofit-Towards-a-Sector-Wide-Roadmap-%E2%80%93-2020-WEB.pdf
CCC. (2019). *Uk housing: Fit for the future?* London: C. o. C. Change. https://www.theccc.org.uk/wp-content/uploads/2019/02/UK-housing-Fit-for-the-future-CCC-2019.pdf
Currie & Brown, & AECOM. (2019). *The costs and benefits of tighter standards for new buildings*. London: C. B. a. AECOM.
Energiesprong. (2019). Energiesprong works! In Energiesprong (Ed.). energiesprong.org: Energiesprong.
Friedler, C., & Kumar, C. (2019). *Reinventing retrofit: How to scale up home energy efficiency in the uk*. London: G. Alliance. https://www.green-alliance.org.uk/resources/reinventing_retrofit.pdf
Google. (2020). Project sunroof. Retrieved Date Accessed, 2020 from https://www.google.com/get/sunroof.
Greater London Authority. (2018). *Low carbon heat: Heat pumps in london*. London: https://www.london.gov.uk/sites/default/files/low_carbon_heat_-_heat_pumps_in_london_.pdf
Gupta, R., Gregg, M., Passmore, S., & Stevens, G. (2015). Intent and outcomes from the retrofit for the future programme: Key lessons. *Building Research & Information, 43*(4), pp. 435-451.
Howard, A. (2013). *The residential energy map: Catalyzing energy efficiency through remote energy assessments and improved data access* Cambridge: MIT. http://web.mit.edu/energy-efficiency/docs/EESP_Howland_ResidentialEnergyMap.pdf
IET. (2018). *Scaling up retrofit 2050, in why a nationwide programme to upgrade the existing housing stock is the only way for the uk to achieve its carbon saving goals*. https://www.theiet.org/media/5276/retrofit.pdf
Less, B., Fisher, J., & Walker, I. (no date). Deep energy retrofits x10. *Home Energy — Home Performance Contractor's Guide to Energy Efficient Remodeling*.
Mastrucci, A., Baume, O., Stazi, F., & Leopold, U. (2016). A gis-based statistical approach to prioritize the retrofit of housing stocks at the urban scale. *Journal of Energy Challenges and Mechanics, 3*(4), pp. 186-190.
MHCLG. (2017). Energy performance of buildings data: England and wales. Retrieved Date Accessed, 2019 from https://epc.opendatacommunities.org/.
Ofgem. (2019a). Smart meters: Your rights. Retrieved Date Accessed, 2019 from https://www.ofgem.gov.uk/consumers/household-gas-and-electricity-guide/understand-smart-prepayment-and-other-energy-meters/smart-meters-your-rights.
Ofgem. (2019b). Typical domestic consumption values. Retrieved Date Accessed, 2019 from https://www.ofgem.gov.uk/gas/retail-market/monitoring-data-and-statistics/typical-domestic-consumption-values.
Ofgem. (2020). Tariffs and payments: Domestic rhi. Retrieved Date Accessed, 2020 from https://www.ofgem.gov.uk/environmental-programmes/domestic-rhi/contacts-guidance-and-resources/tariffs-and-payments-domestic-rhi/current-future-tariffs.
Open Data Bristol. (2020). Solar potential. Retrieved Date Accessed, 2020 from https://opendata.bristol.gov.uk/explore/dataset/solar-potential/map/?location=17,51.45737,-2.59491&basemap=jawg.streets.
Palmer, J., Livingstone, M., & Adams, A. (2017). *What does it cost to retrofit homes? Updating the cost assumptions for beis's energy efficiency modelling*. London: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/656866/BEIS_Update_of_Domestic_Cost_Assumptions_031017.pdf
UCL. (2015). *Datashine census* [Data set]. Retrieved from http://datashine.org.uk/
uSwitch. (2020). Uswitch. Retrieved Date Accessed, 2020 from https://www.uswitch.com/.