A new local energy mapping approach for targeting urban energy renovations

Rajat Gupta
Oxford Institute for Sustainable Development
School of Architecture, Oxford Brookes University
Oxford UK OX3 0BP
UK
rgupta@brookes.ac.uk

Matt Gregg
Oxford Institute for Sustainable Development
School of Architecture, Oxford Brookes University
Oxford UK OX3 0BP
UK
mgregg@brookes.ac.uk

Keywords

local and regional energy planning, retrofit, residential sector, publicly available data

Abstract

Large-scale energy renovations need to be better targeted, more cost-effective and result in a higher uptake to alleviate fuel poverty and reduce energy use. This paper presents a localised Geographical Information System (GIS) based approach using publicly-available national and local datasets on housing and energy to plan mass renovation and provide targeted low carbon measures across UK cities. The study used these datasets to first, spatially identify an area for energy renovation (high energy use and/or fuel poor), and then applied a bottom-up carbon mapping model (called DECoRuM) to estimate energy use and potential for reduction on a house-by-house level, and aggregated to urban scale.

To identify an appropriate neighbourhood case study area (covering over 600 households), publicly available datasets were assessed for the town of Bicester, UK, which included Ordnance Survey Mastermap and Address-point data (to identify dwelling characteristics e.g. built form), Energy Performance Certificate data (EPC) and sub-national energy statistics. When the modelled EPC data were compared with the actual sub-national data, the EPC mean energy use was found to be over 3,000 kWh/yr more than the sub-national figure at lower layer super output area. Following this initial analysis, an area with both high fuel poverty and energy use was selected for deeper investigation.

Following this rapid energy assessment, a community engagement campaign was led by the local authority to gather detailed data from householders on their dwellings, to improve the energy model. House-level energy assessment in the selected area showed that a package based approach comprising fabric improvement, heating system upgrade and solar photovoltaics emerged as the most effective in reducing CO_2 emissions. Costs and payback periods however, hinder this success in specific dwellings. Energy improvements in older dwellings such as 1930–1949 semi-detached (dominant type in the area) demonstrated shorter payback periods due to large baseline energy. The online GIS visualisation of the results is considered particularly helpful for local authorities and community groups in planning local energy action.

Introduction

Energy efficient renovation[1] is a priority for the UK Government as it reduces carbon emissions, reduces costs to energy consumers, reduces fuel poverty, and improves local and national economies including provision of employment opportunities. Specifically, the UK approach to energy efficient renovation involves improving thermal efficiency through better insulation and improved airtightness, improving heating efficiency through installation of advanced systems and reduced electricity consumption through energy management (DECC, 2014).

---

[1] Renovation in this study is defined as improvement works, with a main focus on the building shell, capturing the full economic energy efficiency potential of existing buildings that leads to greater energy performance (Shnapp, Sitja and Laustsen, 2013). The term 'retrofit' is used synonymously in the UK; however, for the purposes of this study, the term renovation is used.

There is a clear need for domestic renovation in the UK (Dowson et al., 2012). This is apparent given that over three quarters of the 28 million dwellings in the UK were built before 1980; resulting in a majority of the domestic stock pre-dating energy efficiency standards. Based on construction and demolition rates, over two thirds of the homes that will exist in the UK in 2050 have already been built (Boardman, 2007).

The 2011 UK Carbon Plan states that "By 2050, all buildings will need to have an emissions footprint close to zero" (HM Government, 2011, p. 5). In context, dwellings in the UK are amongst the least energy efficient in Europe (ACE, 2015), and are responsible for over a quarter of the UK's annual GHG emissions (Palmer and Cooper, 2013). In response to this, the UK developed a number of renovation policies including Carbon Emissions Reduction Target (CERT), Community Energy Savings Programme (CESP), Warm Front, and the Green Deal (Dowson et al., 2012). In 2013, the Energy Company Obligation (ECO) replaced CERT, CESP and Warm Front as a single policy covering supplier obligation to improve domestic efficiency and is the largest domestic energy efficiency programme in Great Britain (DECC, 2014). The ECO is due to be upgraded in spring 2017 to sharpen its focus more on fuel poverty. Whereas the ECO is largely focussed on solving the hard-to-treat and fuel poverty issues, the Green Deal was a renovation scheme for able-to-pay domestic customers. In 2015, the Green Deal was abandoned due to the lower than expected uptake; however, a replacement programme is expected to be resolved in 2017 to cover the able-to-pay and private renter portion of the domestic sector (Pratt, 2016).

Along with an inefficient housing stock, the UK has one of the highest fuel poverty ratings in Europe, though it is a country with some of the lowest energy prices (ACE, 2015). It is the poor state of the housing condition which is the lead cause for inefficiency and fuel poverty (ACE, 2015).

MASS-RENOVATION SCHEMES

Most of the innovation in energy renovation work to date has been focussed on individual house demonstrators (Gupta et al., 2015). However in order to meet UK's legal target of 80 % emission reductions by 2050, against

1990 levels (CCC, 2015), scaling up in the form of mass energy renovation is necessary. Mass-renovation is the process of improving the energy performance of multiple dwellings at a community or city scale. Due to economies of scale, mass-renovation is considered to reduce capital costs, although there can be significant barriers, such as not all private dwellings agreeing to participate (Cityfied project, 2015). Despite this, mass energy renovation has several benefits versus an individual house approach that include:

- Due to the relative homogeneity of urban/suburban neighbourhoods/streets in many areas of the UK (Gupta and Gregg, 2013), theoretically renovation packages can be developed for large clusters or streets, simplifying the process.
- Economy of scale can reduce costs, e.g. required capital for tools and machinery, bulk material buying (Ariffin et al., 2016; Cousins, Gitsham and Joss, 2010); lower costs offer substantial motivation to homeowners (Cityfied project, 2015).
- Potentially higher rate of shared information: willingness to participate in comparative social sharing of energy consumption following retrofit with neighbours with like-dwellings and like-retrofit works (Cabinet Office, 2011).

It is also recognised that large-scale energy renovation schemes can help alleviate fuel poverty (Webber, Gouldson, and Kerr, 2015), meet national carbon targets and improve the local economy (DECC, 2014), but they need to be better targeted, more cost-effective and result in a higher uptake. Following the shift of involvement and action to reduce emissions from the central government to local government and community based groups (Wade et al., 2013); local government and community groups now require the tools to assess their local housing stock in order to improve it.

Within this context, this paper describes the methodology and application of a new localised and data-driven energy mapping approach for targeting and modelling energy interventions in urban areas. This study was undertaken as part of a 15-month UK Government (Innovate UK) funded research project (LEMUR – *Local Energy Mapping for Urban Retrofit*) on develop and deliver a service for local authorities and housing associations using data to better plan and deliver area-based energy efficiency programmes. This service is designed to be offered to local authorities and housing associations on the basis that they would save money overall by targeting those most in need. The overall approach of the LEMUR project (Figure 1) is to rapidly identify the local areas most in need of energy improvements using publicly available data along with local authority's own data; assess the dwellings where maximum and cost-effective energy savings would be made; and then record to delivery of the energy improvements.

Methodology of the study

The approach of the study was tested in Bicester (a town in Oxfordshire, UK) and involves the following steps:

1. Rapid energy assessment: to identify the local area to be targeted
2. House-level data collection for enhanced modelling: to build the baseline model of the targeted area
3. Options appraisal to identify what measures are suitable for the targeted area on a house-by-house level (includes standalone measures or packaged measures)

Following the installation of the measures, the actual household energy use can be fed back into the neighbourhood model to keep an up-to-date energy assessment of the area.

RAPID ENERGY ASSESSMENT

The rapid assessment approach involves spatial mapping (using GIS) and superimposing a variety of publicly-available top-down (aggregated) and bottom-up (house level) datasets to identify the local area having dwellings with high energy consumption, and/or high fuel poverty, and dwellings in need of energy improvements. The datasets/data sources used in rapid energy assessment include:

- *Ordnance Survey (OS) MasterMap Topography layer* and *OS Address-Point*: OS MasterMap Topography layer and Ad-

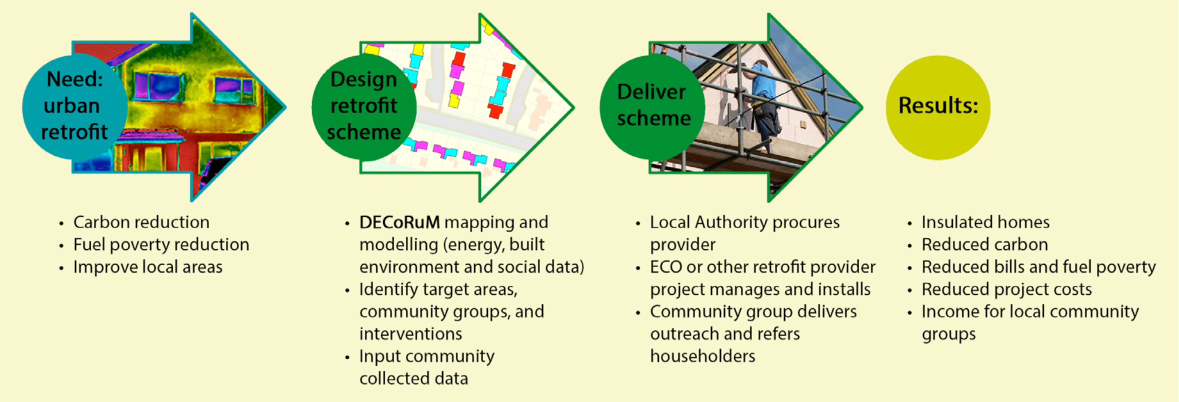

Figure 1. Overall approach of the LEMUR research project.

dress-Point are needed to identify dwelling characteristics (e.g. building form). The Topography layer also forms the base map on which mapped outcomes are presented.

- *Energy Performance Certificate (EPC) dataset*, over 6,000 dwelling EPCs in a single spreadsheet, obtained from the Department for Communities and Local Government (DCLG, n.d.) via Cherwell Council. This dataset includes dwelling energy related information (e.g. wall type, insulation, heating system, annual energy use) compiled through domestic energy assessments at address level by trained individuals. The data collection process began in 2008 and is ongoing.
- *Sub-national energy consumption statistics* (DECC, 2016) and sub-national fuel poverty statistics (DECC, 2015a), obtained from the Department of Energy and Climate Change: Sub-national datasets are free to use publically available datasets of metered consumption collected from fuel transporters (DECC, 2015b). The data are aligned with Lower layer super output area (LSOA) covering approximately 400–700 dwellings.

The topography layer forms the base map, EPCs and sub-national datasets were then geo-linked to the base map to be visualised: EPCs were connected via the OS Address-Point at each individual address point and LSOAs were manually outlined, then linked to sub-national data. The findings, energy consumption, fuel poverty rate, renovation need, e.g., cavity wall insulation, are then identified for clusters of LSOAs and at LSOA level.

After a rapid assessment is performed, a local area for detailed focus is selected based on specific renovation goals which may be energy reduction, fuel poverty elimination or deployment of renewables. For this study, an LSOA with high energy consumption and fuel poverty was selected for detailed focus. In summary, a combination of energy consumption and fuel poverty data from EPCs and Sub-national datasets were mapped in GIS, overlaid, and isolated in order to make a selection.

FURTHER HOUSE-LEVEL DATA COLLECTION FOR ENHANCED MODELLING

To prepare for renovation options appraisal of the selected area, a detailed bottom-up energy analysis is helpful to 1) fill in the dwelling characteristics data gaps (i.e. where EPCs do not exist) and 2) provide estimated energy consumption data for every household. To undertake this detailed energy analysis of the selected area accurately, more primary data are collected for modelling. This data collection involves both desktop research and home energy surveys gathered through various techniques of community engagement.

Desktop research

The DECoRuM[2] model is used for assessing dwelling level energy use and CO_2e emissions (Gupta and Gregg, 2013). DECoRuM is a GIS-based energy model with the capability to estimate current energy-related CO_2e emissions and test the effectiveness of a number of best practice energy efficiency measures and low/zero carbon technologies in homes. The model aggregates the results to a street, district or city level. The background calculations of DECoRuM are performed by BREDEM-12 (Building Research Establishment's Domestic Energy Model) and SAP 2009 (Standard Assessment Procedure) both of which are dynamically linked to create the model. For context, there are more inputs than that required for EPCs; however, the data are collected based on dwelling statistics, external observations, and ideally where possible, occupant-completed home energy surveys. To inform the DECoRuM model and satisfy BREDEM-12 and SAP calculations, actual house characteristics are gathered from the following in Table 1.

Examples of assumptions made in the model: heating set-point, unless known, is assumed to be 21 °C (as default in the BREDEM-12 model and SAP), occupancy, unless known, is calculated from floor area using the BREDEM-12 method; street-facing windows and frames are directly observed but all other unseen windows are assumed to be the same; 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).

Calibration of the energy model is done by aligning the mean CO_2e emissions of all dwellings calculated using DECoRuM with the mean of the total CO_2e emissions as calculated from the sub-national energy consumption data at LSOA level. Where heating set-point is not known (gathered only through survey), the assumed heating set-point is reduced to align the CO_2e emissions results.

---

[2] Domestic Energy, Carbon counting and carbon Reduction Model.

Table 1. Data sources.

Method	Source	Example data collected
Historic and current maps	Historic Digimap, Ordnance survey, Google maps	Dwellings age, dwelling form, floor area, roof area, roof orientation, existing solar energy systems, window size and type, etc.
On-site assessment		
Home energy surveys		Number of occupants, insulation details, boiler type, secondary systems, heating set-point, solar energy systems, etc.
Dwelling statistics	literature describing home characteristics based on age and typology (e.g. English House Condition Survey (DCLG, 2009), BREDEM-12 reference tables (Anderson et al., 2001), UK Housing Energy Fact File (Palmer and Cooper, 2013))	

Home energy surveys and community engagement to collect data

Home energy surveys are helpful in gathering real data about home characteristics that cannot be gathered from observation of the dwellings. Some points of data and results collected from the home energy surveys for the dwellings, which were included in the mapped study area, are listed below.

- Built form: 39 % semi-detached, 34 % detached, and 27 % terraced
- Built age: 15 % 1920–1945, 79 % 1946–1979, 4 % 1980–1995, and 2 % 1996–2005
- Construction: 94 % brick construction, 6 % timber construction; 92 % full double glazing
- Mean occupants: 2.7 occupants
- Mean annual energy bills cost: £968
- Mean heating set-point: 19.3 °C

As part of the study, a range of community engagement activities were used by the local authority, to promote the study locally and to maximise the number of home energy surveys completed. These methods included:

1. *Door-stepping*: project team members approached residents at their homes to explain the study and get the surveys filled. The completed surveys were manually entered into the LEMUR platform.
2. *School engagement:* three primary schools in the neighbourhood were asked to promote the project by sending home letters (with link to online survey) with children.
3. *Day centre (activity space for elderly)*: two representatives from the local authority attended a day centre in the neighbourhood to explain the study to the visitors (local residents) and complete the energy surveys.
4. *Church group meeting*: two representatives from the local authority attended a group meeting for middle-aged generation at a local church to have surveys filled.
5. *Local library:* a member of the local authority approached the library visitors (mainly local residents) to have surveys filled on a single day in August.
6. *Community action group:* The research team also collaborated with the local low carbon community group – worked to promote the project to the local residents and get energy surveys completed.
7. *Facebook campaign:* The local authority team also created a Facebook post to promote the project and get local residents to complete the energy surveys.

MODELLING AND OPTIONS APPRAISAL

The baseline energy model/map

The DECoRuM baseline energy model generates a large number of results including annual CO_2e emissions, annual energy consumption, and annual running costs. In addition, any number of inputs or assumptions can be mapped, e.g., which dwellings have or need cavity wall insulation, loft insulation, photovoltaics (PV), etc. The results for each household are displayed on a map using GIS; in this instance, MapInfo and ArcGIS.

Examples of some basic model assumptions include:

- If the home has double glazing which is easily observed, then the home has at least 100 mm of loft insulation (this is to reflect the large amount of homes which have up to 100 mm of loft insulation installed (over 90 %) (Palmer and Cooper, 2013). EPC information or survey data on loft insulation supersedes this assumption.
- If the home has a solar hot water system, then the domestic hot water tank (assumed) has foam insulation (at least 35 mm).

Renovation measure/package recommendations

Single renovation measures and or renovation packages are recommended via maps showing the impact of the renovations on the dwellings. The initial success of measures, i.e., reduction of CO_2e emissions, is evaluated by creating model variants which run scenarios for each dwelling. As examples, insulation levels are set to current building regulation levels, double and triple glazing, boilers are upgraded to 88 % efficiency, alternative heating systems are tested, and solar energy systems are tested. Because the DECoRuM model is built to evaluate existing conditions, for example, whether there is cavity wall insulation present and the total energy use given existing conditions, the model is capable of estimating the reduction in total annual energy use (kWh), annual CO_2e emissions and estimated running costs due to any changes. To formulate packages, best performing measures are selected and combined. To establish whether a measure is valid the following 'reduction assessment method' steps are taken in the model:

1. A simple payback (c) is calculated based on a static reduction in annual running costs (b) and current cost to install a measure (a).

$$a / b = c. \qquad (1)$$

2. Install potential (yes / no) must fulfil the following:

- Is there a reduction in energy use?
- Is there a reduction in running costs? (includes Feed-in Tariff (FiT) and Renewable Heat Incentive (RHI) payments).
- Is the simple payback period less than the life of the measure?

Results

RAPID ENERGY ASSESSMENT

For the rapid energy assessment, sub-national energy data and EPCs were mapped for the town of Bicester. Figure 2 shows the sub-national energy and fuel poverty data mapped for Bicester. The boundaries represent LSOAs. The data show that the southwest quadrant contains some of the LSOAs with the greatest energy consumption and the greatest fuel poverty. It is interesting to note also that the LSOAs with the lowest percentage of fuel poor dwellings are on the perimeter of the town.

Figure 3 shows examples of EPCs mapped. For the town of Bicester there were a total of 5,453 dwellings with valid EPC data. The EPC data revealed that:

- Only about 1 % of dwellings in the entire EPC dataset for Bicester lack double glazing.
- There are almost 500 uninsulated cavity wall dwellings and almost 250 uninsulated solid wall dwellings in the entire EPC dataset for Bicester; i.e. about 14 % of dwellings need wall insulation.
- The south west quadrant of Bicester (Figure 3) contains the most dwellings in need of wall insulation: 198 cavity wall houses with no insulation (40 % of total uninsulated cavity wall)/47 solid wall houses with no insulation (21 % of total uninsulated solid wall).
- Over 50 % of the dwellings with known roof insulation levels in the EPC dataset for Bicester have less than or equal to 150 mm of roof insulation; these dwellings could possibly double their insulation levels.
- Over 85 % of the Bicester EPC dataset is heated by gas boiler system with radiators.
- LSOA Cherwell 014C (figure 3) has the greatest percentage of dwellings with annual energy consumption above 300 kWh/m^2.

When the EPCs for the dwellings per LSOA were averaged and compared to the sub-national figures for the LSOAs in the southwest quadrant, an over-estimate of between 3,000–4,000 kWh/yr in the mean energy figure was found in the EPCs. The potential older age of EPCs versus the single year sub-national data and the modelled EPCs versus actual metered sub-national data may be some of the reasons for the discrepancy between sub-national energy data and EPCs.

Superimposing the two datasets, considering highest fuel poverty, relatively high energy consumption, and highest percentage of annual energy consumption in the EPCs, an area called Highfield in Bicester was selected for building the house level energy model. The neighbourhood of Highfield covers LSOA Cherwell 014C (Figure 3) and a little of surrounding LSOAs.

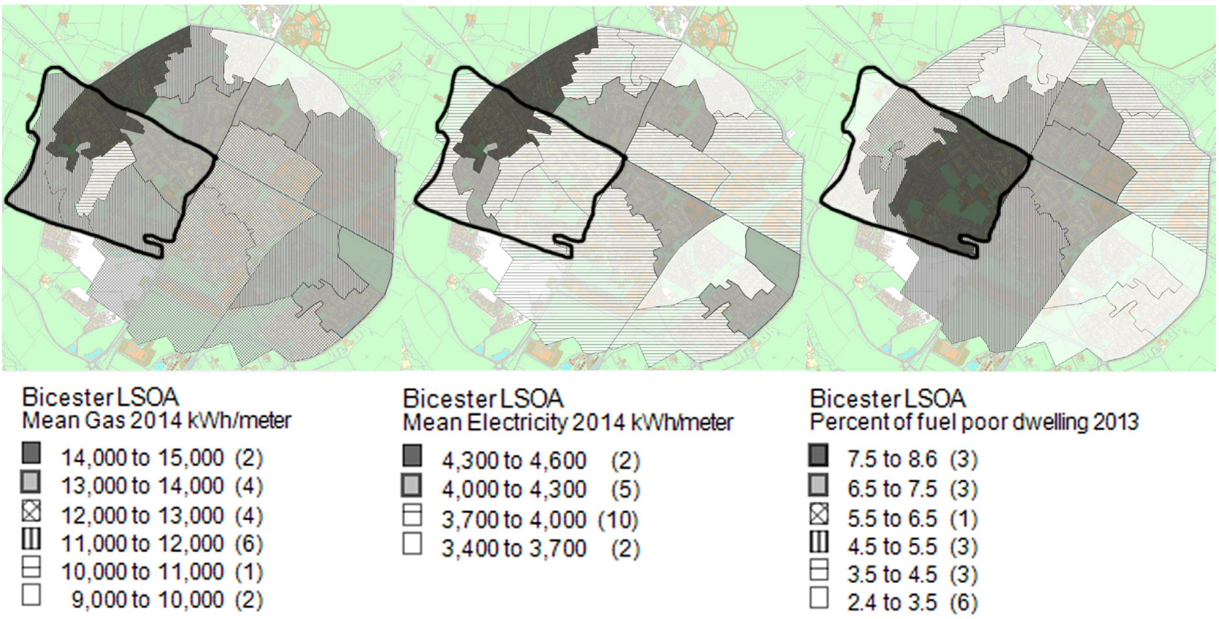

Figure 2. Maps of mean gas consumption 2014 (left); mean electricity consumption (centre); percent of fuel poor dwellings 2013 (right). Note: the black lines indicate LSOA divisions. Background maps© Crown Copyright and Database Right 2016. Ordnance Survey (Digimap Licence).

MODELLING RESULTS

Following the selection of the Highfield area from the rapid assessment, an overlay of completed surveys in the area, and limiting the map to roughly 550–650 dwellings, a boundary for mapping baseline consumption was selected (Figure 4). The modelled area included 58 completed surveys and 222 valid EPCs.

The modelled area as compared to the town of Bicester has a greater representation of semi-detached dwellings (59 %) and is mostly made up of dwellings built from the 1930s to the mid-70s though dwellings range in age from 1920–2010 (Figure 5). Note: though 'Highfield' is the name for a much larger community in Bicester, the modelled case study area is referred to as Highfield throughout the remainder of the study.

Baseline maps

The annual energy consumption in Highfield varied between 6,000 kWh to 42,000 kWh with 110 dwellings consuming between 21,000–26,000 kWh per year (CO_2e emissions of 5.4–6.8 tonnes/year). Energy use and CO_2e emissions by most common dwelling types in the selected neighbourhood are listed in Table 2.

Figure 6 shows a baseline map of dwelling annual energy use in the selected neighbourhood. Note that only a close-up of a section of the map is shown for greater clarity. Figure 6 also shows the solar potential of the dwellings by assessing the available roof area, orientation, ornamentation of the roof and hot water to indicate the potential for deploying solar thermal and/or solar PV systems.

Options appraisal

The final step is to create recommendations for energy renovation in the form of improvement packages. Solid wall insulation and cavity wall insulation produced the greatest mean reduction in carbon emissions (30 % and 25 % respectively). Loft and floor insulation, new condensing boiler, heat pumps and PV panels resulted in mid-range reductions with means ranging

Figure 3. Map of dwellings with EPCs and close-up of total energy consumption (kWh/m^2) figures from EPCs for dwellings. Note: the black lines indicate LSOA divisions. Background maps© Crown Copyright and Database Right 2016. Ordnance Survey (Digimap Licence).

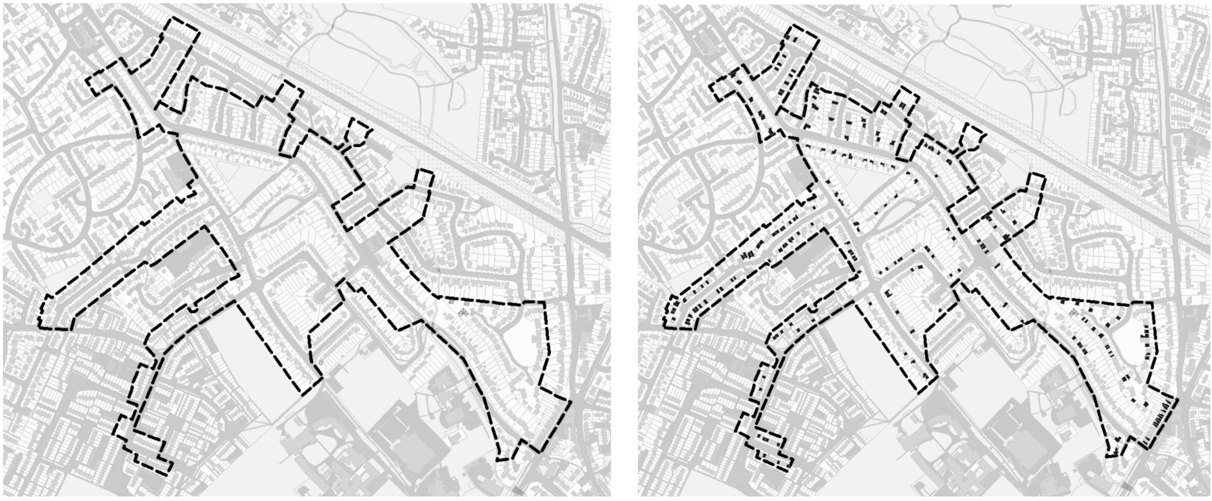

Figure 4. Selected boundary of modelled area (left); selected boundary with dwellings with EPCs marked (right). Background maps© Crown Copyright and Database Right 2016. Ordnance Survey (Digimap Licence).

Contents Keywords Authors

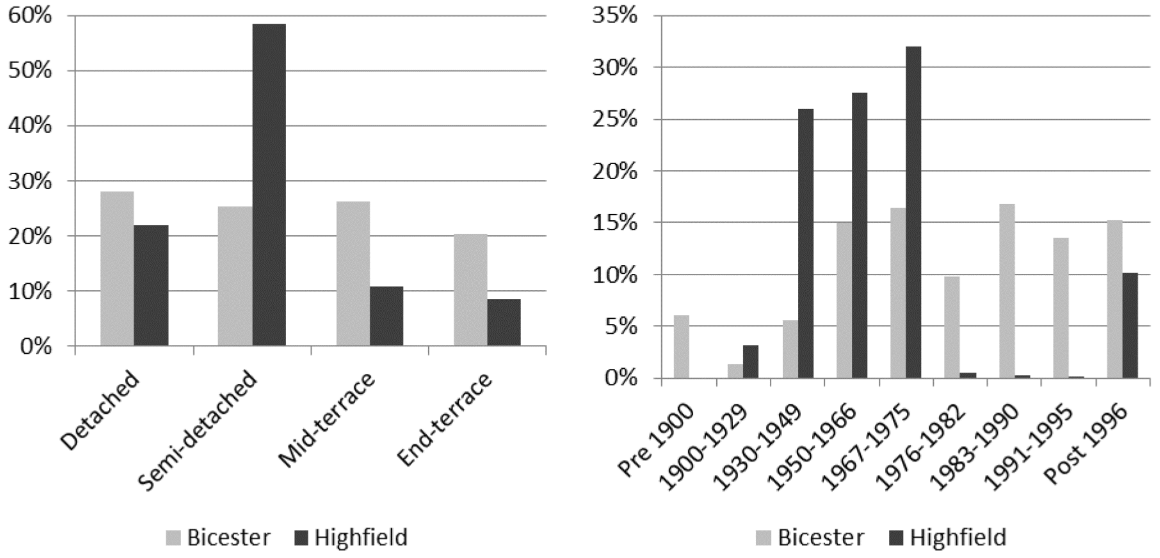

Figure 5. Dwelling form make-up of the modelled area as compared to the entire town of Bicester (left); age-band make-up of the modelled area as compared to entire town of Bicester (right).

Table 2. Most common dwelling types.

Type designation	Dwelling type	Percent of dwellings in Highfield	Percent of dwellings with uninsulated walls	Energy use (kWh/m^2/yr)	CO_2e emissions ($kgCO_2$/m^2/yr)
A	1930–1949 semi-detached	23 %	72 %	279	59
B	1950–1965 semi-detached	19 %	64 %	197	54
C	1966–1976 semi-detached	15 %	57 %	196	55
D	1966–1976 detached	9 %	61 %	210	58

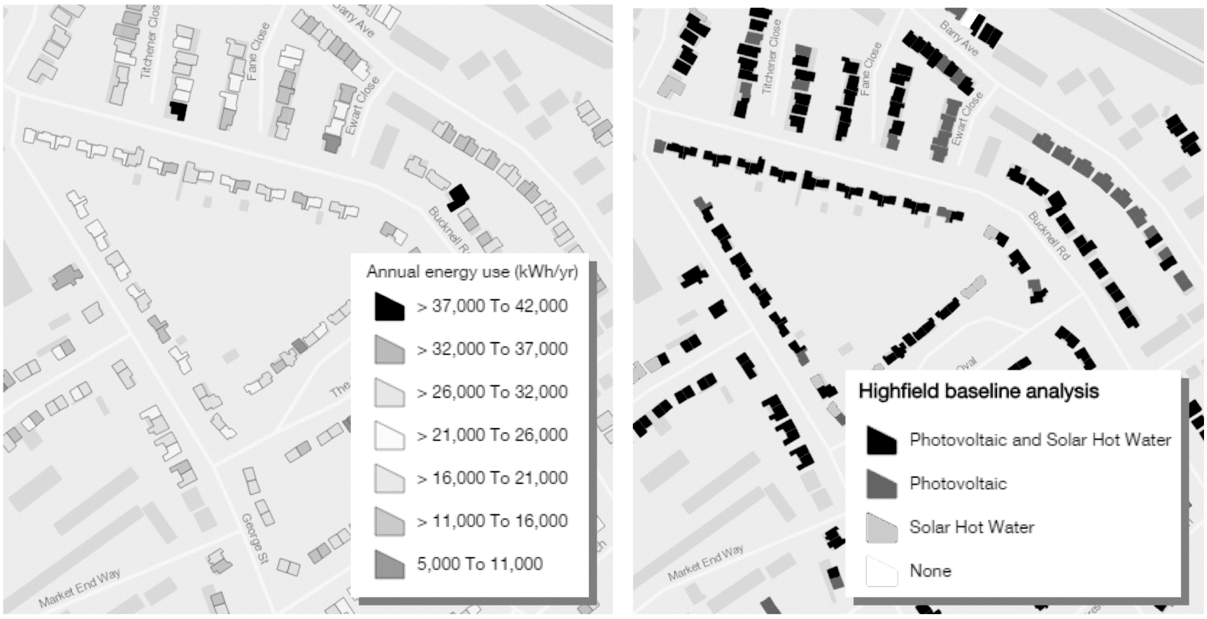

Figure 6. Total annual energy consumption (left); solar energy system installation potential (right). Maps contain OS data© Crown Copyright and Database Right 2016.

Contents Keywords Authors

from 12–17 %. Three hundred and sixty-three dwellings could potentially install cavity wall insulation and 542 homes could potentially install ground floor insulation. Only about 4 % of the dwellings could pass the reduction assessment method to install heat pumps. This is mostly due to the gas dominance of the area and the seven-year limit on the RHI. However, PV systems still appear to be an effective measure even when considering the significantly reduced FiT payments.

The recommended measures tested were therefore, grouped into the following packages:

1. Fabric package: wall, loft, and floor insulation, double glazing and draught proofing
2. Fabric and heating package: fabric package + new condensing boiler or heat pump, hot water cylinder insulation and thermostat, and pipework insulation
3. Fabric, heating and solar package: fabric and heating package + PV system and solar hot water system

The reduction assessment method revealed that six dwellings in total could install the complete fabric, heating, and solar package. Four of these dwellings are 1930s–1960s semi-detached (types A & B). Older dwellings, e.g. 1930–1949 semi-detached (most common type in the area), have shorter payback periods due to greater need for improvement, and are therefore more likely to benefit. Overall, a full fabric, heating and solar package emerged as the most effective with regard to CO_2e emissions reduction on an induvial dwelling basis (Figure 7); however, as stated above, only six dwellings meet the installation approval of the reduction assessment method. This emphasizes the need to resolve the up-front cost issue of materials and systems.

Discussion

Outputs from DECoRuM, maps of estimated energy use and CO_2e emission reduction potential of individual households, can provide useful feedback on renovation need and progress to community groups, residents, and local authorities. Whereas it is traditionally up to the householder to seek out energy renovation or accept offers for renovation from salespersons or grants from local authorities on an individual house-by-house basis which could require serving randomly spread dwellings throughout a town or city, the proposed approach provides community groups and local authorities with the information needed to rapidly pin-point local areas of high energy use and to identify potential grouped areas for renovation (Williams et al., 2013; Gupta, Gregg and Barnfield, 2015).

After the local area is energy mapped, a number of approaches can be adopted to decide where to focus renovation, including:

- Focus on common dwelling types which are likely to require the same type of renovation package; maps can be used to pin-point specific dwelling types,
- Focus on common measures required; maps can pin-point dwellings that need a particular measure or combination of measures,
- Focus on clusters, e.g. hot-spots of high energy consumption.

The maps make energy use visible by highlighting areas of heat loss and potential areas for energy improvements. Other benefits include: use as a communication tool for planning change and funding, visual source for tracking renovation progress and change. Such a local energy mapping approach would also be beneficial for implementing any national energy renovation programme and the ECO upgrade planned for 2017 (Pratt, 2016), by enabling renovation providers and community groups (acting as mediators between householders and renovation providers) to communicate and evaluate the need for energy improvements and track any improvements made. The method assists in prioritising action by providing ECO providers or energy assessors with an overview of homes most in need, estimated consumption and a complete tool for testing potential success of measures or packages.

Figure 7. Fabric, heating and solar package reduction in annual CO_2e emissions: entire map of Highfield (left); close-up of centre (right). Background maps© Crown Copyright and Database Right 2016. Ordnance Survey (Digimap Licence).

Because the method is intended to simplify the process and aggregate data, some expected limitations exist (to overcome these, dynamic simulation would be recommended):

- Desktop data collection and entry (e.g. entries from façade observations) can be time intensive.
- Behaviour assessment is limited: occupancy times, heating schedules, window opening schedules, etc. cannot be modelled; however, temperature set point can be modelled and collected via survey.
- Different scenarios must be calculated separately and cannot vary within a given timeframe; calculations are static.
- The model does not calculate where specifically a homeowner should insulate walls and whether internal or external insulation is ideal (insulation is simply either solid wall or cavity).

Table 3 indicates the demographic findings of the community engagement/outreach efforts. It also shows the relative success and the number of surveys filled.

The most effective engagement was found to be a combination of church group, community action group and Facebook campaign. In the case of the community group, the research team worked with the low carbon community group to promote the project to their members. The strength behind the success for the community group was in the way the message and request held more legitimacy by being communicated by familiar or known individual. The Facebook post reached over 8,000 people, with almost 400 clicks to the survey resulting in 109 survey completions. The Facebook method was found to be highly successful in terms of effort and cost for return. The total budget was £100 (not including the prize incentives) which resulted in £0.26 per click. The Facebook method required little staff time, is easy to monitor results, and allows for targeting of specific demographics and locations. It is expected that an ideal approach would combine Facebook with other local group engagement to reach particular demographics that do not use social media, whereas, the church group and community group allowed the older demographic to be represented.

In contrast, door-stepping is considered the least effective approach considering the effort for return. The approach is labour intensive, requires several members of staff or volunteers knowledgeable about the project, and involves the uncomfortable cold-call scenario. It is recommended that door-stepping be conducted by community or neighbourhood groups so that residents are familiar with the visitors. The library was also highly unsuccessful considering the large amount of time invested. The general feeling was that residents were too busy to stop and had no interest in completing a survey. They were often with children and were focussed on their purpose for being at the library. The school approach was more effective and less intensive than the door-stepping campaign but overall not successful considering the considerable printing, sorting and packing of letters to be sent home with the children. The schools were provided with an incentive for participation regardless of surveys returned. One question remains whether rate of return would have been increased if the incentive was dependent on the rate of survey return. Also, it is possible that sending printed surveys with the busy parents would have improved the return. The day centre approach was considered a worthwhile approach to reach an older demographic; however there were a few limitations, such as the need to sit, explain and assist the resident with the survey, a large number of residents for which the surveys were difficult to answer or inapplicable (individuals with early signs of dementia or sheltered housing residents). The exercise in reaching the older demographic was ultimately, however, considered worthwhile to educate and raise awareness for measures to achieve affordable warmth and energy savings. It is suggested that pre-screening individuals for applicability be done in these cases. Overall, as engagement efforts took place during the late spring and summer, it is theorised that warmth and energy concerns are not at the forefront of people's minds as they would be in the winter, thereby potentially limiting the response rate.

Future research and development of the presented approach includes linking energy mapping with smart-meter data (given the expected smart meter roll-out in UK by 2020). This would enable evaluation of area-wide trends in energy use (demand

Table 3. Outreach results.

	Survey format	Incentive	Demographic	Success*	Surveys filled (total = 234)
Door-stepping	Printed survey	None	Mixed	Very low	55 (24 % of total)
Schools (x3)	Promotional letter with link sent home with children	For school	Younger generation with children	Low	40 (17 % of total)
Day centre	Printed survey	For day centre	Older generation	Moderate	5 (2 % of total)
Church	Printed survey	For church	Middle age	High	12 (5 % of total)
Library	Printed survey	None	Younger generation with children	Low	1 (0.4 % of total)
Facebook	Link to survey online	Drawing for ten vouchers of £25	Expected to exclude older generation	Very high	109 (47 % of total)
Grassroots Bicester	Printed survey	For group	Mix	High	12 (5 % of total)

** Success qualitatively measured as effort and cost versus rate of survey return.*

profiles) which can be useful for introducing local (time of use) energy tariffs, heat networks or community energy systems. Tracking energy consumption either before or after renovation coupled with detailed data on dwelling characteristics collected through the methods described, can provide a more complete picture of renovation requirements or progress than simply using smart meter data alone. A potential limitation to this approach can be data protection, privacy and security; however, where local authorities or energy companies are teamed-up with active community groups or renovation providers to incentivise participation of the homeowners, this can be resolved. Linkage with smart-meter data can also constantly track energy consumption (and generation) in almost real-time, thereby helping to increase the local penetration of distribution generation and smart storage to locally manage demand and supply of energy.

Conclusion

This study has shown how the challenge of enabling mass energy renovation in towns and cities, can be tackled by local authorities and community groups, using a systematic assessment of publicly available and spatially based data. This new local energy mapping approach has the capability to facilitate wider roll out of energy improvements measures by rapidly identifying and targeting appropriate local areas and dwellings. The process to collect data, model, map and ultimately aggregate energy improvements in a local area can also help to minimise installation costs. Also, spatially mapping the potential for energy improvements in a geographical area is found to be visually effective in providing energy feedback to householders, community groups and local authorities to encourage take-up of improvement measures.

This new data-driven approach can also help local authorities, community groups and householders prepare for mass-implementation of renovation programmes. Modelling interventions could be also cross-examined with socio-economic data to track the effect of renovation on fuel poverty. Future application of this approach would be to collaborate with a mass-renovation provider and assess the potential cost reductions in identifying appropriate dwellings with the LEMUR approach.

References

Anderson, B. R., Chapman, P.F., Cutland, N.G., Dickson, C.M., Henderson, G., Henderson, J.H …Shorrock, L.D., 2001, BREDEM-12 Model description: 2001 Update. Watford: BRE.

Ariffin, S., Sulaiman, S., Mohammad, H., Khalijah, Y.S., and Yunus, R., 2016, February, Factors of economies of scale for construction contractors. Paper presented at the International Congress on Technology, Engineering and Science (IConTES 2016), Kuala Lumpur, Malaysia.

Association for the Conservation of Energy (ACE), 2015, The cold man of Europe – 2015. Association for the Conservation of Energy. Available from: http://www.ukace.org.

Boardman, B., 2007. Examining the carbon agenda via the 40% House scenario. Building Research & Information, 35 (4), pp. 363–378.

Bonfield, P., 2016, Each Home Counts. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/578749/Each_Home_Counts__December_2016_.pdf.

Cabinet Office, 2011, Behaviour change and energy use. Available from: http://neweconomists.org/files/Behaviour_and_Energy.pdf.

Cityfied project, 2015, Building solutions for boosting the energy retrofitting of buildings and districts in the cities of Valladolid and Malaga (Spain). Available from: http://www.cityfied.eu/News/Press-Releases/Finding-Solutions-For-Boosting-The-Energy-Retrofitting-Of-Buildings-And-Districts-In-The-Cities-Of-Valladolid-And-Malaga-Spain.kl.

Committee on Climate Change (CCC), 2012, How local authorities can reduce emissions and manage climate risk. Available from: https://www.theccc.org.uk/archive/aws/Local%20Authorites/LA%20Report_final.pdf.

Committee on Climate Change (CCC), 2015, The Fifth Carbon Budget: The next step towards a low-carbon economy Committee on Climate Change. Available from: https://www.theccc.org.uk/wp-content/uploads/2015/11/Committee-on-Climate-Change-Fifth-Carbon-Budget-Report.pdf.

Cousins, A., Gitsham, M. and joss, A., 2010, Retrofit at scale: Refurbishing homes in Bristol. Available from: https://www.forumforthefuture.org/retrofit-scale.

Department for Business, Energy & industrial Strategy (DBEIS), 2016, Sub-national consumption statistics: methodology and guidance booklet. Available from: https://www.gov.uk/government/publications/regional-energy-data-guidance-note.

Department of Communities and Local Government (DCLG), 2009, English House Condition Survey – 2007 Annual Report. http://webarchive.nationalarchives.gov.uk/.

DCLG, no date, Domestic Energy Performance Certificate Register, Department for Communities and Local Government. Available from: https://www.epcregister.com.

Department of Energy & Climate Change (DECC), 2014, UK National Energy Efficiency Action Plan. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/307993/uk_national_energy_efficiency_action_plan.pdf.

DECC, 2015a, Fuel poverty sub-regional statistics, Department of Energy & Climate Change, Available from: https://www.gov.uk.

DECC, 2015b, Sub-national consumption statistics: Methodology and guidance booklet, Department of Energy & Climate Change, Available from: https://www.gov.uk.

DECC, 2016, Sub-national consumption statistics, Department of Energy & Climate Change. Available from: https://www.gov.uk.

Dowson, M., Poole, A., Harrison, D. and Susman, G., 2012. Domestic UK retrofit challenge: Barriers, incentives and current performance leading into the Green Deal. Energy Policy, 50, pp. 294–305.

Gupta, R. and Gregg, M., 2013. Preventing the overheating of English suburban homes in a warming climate. Building Research & Information, 41 (3), pp. 281–300.

Gupta, R., Barnfield, L. and Gregg, M., 2015, June, Effectiveness and impacts of community-based action on household energy reduction. Paper presented at European Council for an Energy Efficient Economy (eceee) 2015 Summer study proceedings, Hyères, France, pp. 535–547.

Gupta, R., Gregg, M., Passmore, S. and Stevens, G., 2015, Intent and outcomes from the Retrofit for the Future programme: key lessons, Building Research & Information, 43 (4), pp. 435–451.

HM Government, 2011, The carbon plan: Delivering our low carbon future. London: DECC.

Iorwerth, H.M., Lannon, S., Waldron, D., Bassett, T. and Jones, P.J., 2013. A sap sensitivity tool and GIS-based urban scale domestic energy use model. In Building Simulation 2013 (BS2013): 13th International Conference of the International Building Performance Simulation Association.

Palmer, J. and Cooper, I., 2013, United Kingdom housing energy fact file. London: DECC.

Pratt, 2016, Green Deal replacement scheme pushed to 2017, Available from: http://www.cleanenergynews.co.uk/news/efficiency/green-deal-replacement-scheme-pushed-to-2017.

Shnapp, Sitja and Laustsen, 2013, What is a deep renovation definition?: Technical report, Available from: http://www.gbpn.org/sites/default/files/08.DR_TechRep.low_.pdf.

Webber, P., Gouldson, A. and Kerr, N., 2015, The impacts of household retrofit and domestic energy efficiency schemes: A large scale, ex post evaluation. Energy Policy, 84, pp. 35–43.

Williams, K., Gupta, R., Hopkins, D., Gregg, M., Payne, C., Joynt, J.L., Smith, I. and Bates-Brkljac, N., 2013, Retrofitting England's suburbs to adapt to climate change. Building Research & Information, 41 (5), pp. 517–531.

Acknowledgements

The authors would like to thank Innovate UK for funding the LEMUR research project under the *Solving urban challenges with data competition*. The authors are also grateful to Bioregional (project partner) for their assistance in data collection and Cherwell District Council (project partner) for providing access to the EPC dataset and their exceptional efforts in community engagement.