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# Exploring innovative community and household energy feedback approaches

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**ABSTRACT**

Most research to date on the provision of energy feedback to households has focused on assessing the efficacy of numeric-based feedback. This paper describes the application and evaluation of more visual energy feedback techniques (carbon mapping, thermal imaging) at different scales, alongside traditional methods (web-based energy and environmental visualization platform, home energy reports) delivered through community workshops, home visits and the internet, across six low-carbon communities in the UK. Overall, most of the feedback approaches were able to engage and raise awareness amongst the householders. Whilst carbon mapping was felt to be aimed more at community groups and local councils by providing evidence of past and future community action, displaying carbon maps at community workshops helped to show that others were also engaged in energy action. Thermal imaging was successful in engaging individual local residents through both community workshops and home visits, especially when included in the home energy reports. This stimulated discussions on future energy savings through building fabric upgrade. However, the data-driven web-based platform had limited uptake due to online log-in requirement and information overload. Such insights are useful for those involved in scaling up the deployment of energy feedback to encourage energy demand reduction.

**KEYWORDS**

behaviour change; carbon mapping; energy demand; feedback; household energy; thermal imaging; visualization

## Introduction

Whilst improvements in the building fabric and energy efficiency of household technologies are seen as key to reducing housing energy consumption (Ekins, 2009), studies have indicated that even with more efficient technologies installed, households do not necessarily consume less (Calì, Osterhage, Streblow, & Müller, 2016; TSB, 2014). A key factor in the variation of the energy demand is occupant behaviour, which has been recognized as influencing energy consumption in identical homes by a factor of three or more (Gram-Hanssen, 2010; Janda, 2011). Much social and environmental psychological research (Abrahamse, Steg, Vlek, & Rothengatter, 2005) has been undertaken to understand the reasons why this is so, and how such behaviours can be influenced in order to reduce energy consumption. Over the years, a large variety of interventions, from financial incentives and rewards to information and awareness campaigns, have been used in order to encourage households to change their behaviours and reduce their energy consumption. Although their success varies, several studies (Buchanan, Russo, & Anderson, 2014; Ehrhardt-Martinez, Donnelly, & Laitner, 2010; Steg, 2008) indicate that the provision of information through feedback can have a significant impact on domestic energy consumption through the prompting of changes in energy using behaviours.

For the purposes of this paper, the term 'information' refers to facts, figures or text provided to householders that is relevant to their context in order to influence energy-related behaviours or improvements to their dwelling. The provision of information has become increasingly common, particularly as a behaviour change-policy instrument, and aims to influence behaviours through the transfer of knowledge and increase the recipient's awareness of problems/barriers as well as solutions (Ek & Söderholm, 2010). Information relating to household energy consumption has been communicated in several ways: workshops (Anderson & White, 2009), mass media campaigns and tailoring (Ehrhardt-Martinez et al., 2010). Whilst mass media campaigns target a wide audience, but with general information, tailored information such as a one-off home energy audit

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targets often an individual or single household, and provides information that is highly personal and tailored to the preferences of the individual household (Ellegård & Palm, 2011). Studies on the effects and impacts of information on behaviour change indicate that tailored information is more effective than general information and workshops in terms of changing an individual's behaviours, but all three generally result in increase in knowledge (Abrahamse, Steg, Vlek, & Rothengatter, 2007; Gonzales, Aronson, & Costanzo, 1988; Steg, 2008).

The term 'feedback' refers to the provision of information using collected energy-related data specific to the householder's dwelling and behaviour. Effective feedback also allows consumers to monitor their consumption and to target energy and carbon savings (Lienert & Platchkov, 2012). The frequency of the feedback can vary, from continuous direct feedback (*e.g.* from energy display monitors (EDMs) and online and app-based visualizations) to weekly, monthly and/or annual indirect feedback (*e.g.* billing). Direct continuous feedback techniques can have a significant impact in terms of changing behaviours, as well as on actual energy consumption (Ehrhardt-Martinez et al., 2010). Darby (2006) indicates that direct feedback can result in 5–15% household energy savings, while an international meta-study of feedback approaches (Ehrhardt-Martinez et al., 2010) found this impact to be between 9% and 12%.

Figure 1 summarizes the types of information strategies and feedback approaches often used within the household energy sector. Feedback approaches can be divided into three delivery levels: individual, comparative and community. Whilst individual feedback can be specific to an individual or a home's unique consumption pattern, community feedback is often generalized or aggregated. Comparative feedback allows individual feedback information to be shared in a community, effectively blending the two levels. As an example, using social media to share energy data with friends or neighbours to inspire competition to reduce individual consumption (Petkov, Köbler, Foth, & Krcmar, 2011). The method of delivery of feedback can also provide a different learning environment for the recipient. Community and peer-focused information provision in the form of workshops and comparative feedback can overcome the failure to acknowledge social and cultural influences on human behaviour (Heiskanen, Johnson, Robinson, Vadovics, & Saastamoinen, 2010).

There has been a significant increase in energy feedback mainly on an individual level in the form of EDMs and home energy advice (DECC, 2012; Gans, Alberini, & Longo, 2013), through the precursors to the Energy Company Obligation: Community Energy Saving Programme (CESP) (2009–12) and the Carbon Emissions Reduction Target (CERT) (2008–12). Table 1 summarizes the different forms of energy feedback that have been provided to householders, as drawn from the literature.

There is little evidence showing the extent of impact or the effectiveness of these methods used in these programmes; however, 1.5% of total $CO_2$ equivalent ($CO_2e$) savings achieved is attributed to EDMs under CERT (Abraham, 2013) and less than 1% of total $CO_2e$ savings achieved is attributed to home energy advice packages (also known as home energy reports – HERs) under CESP (Duffy, 2013). Observations of the use of

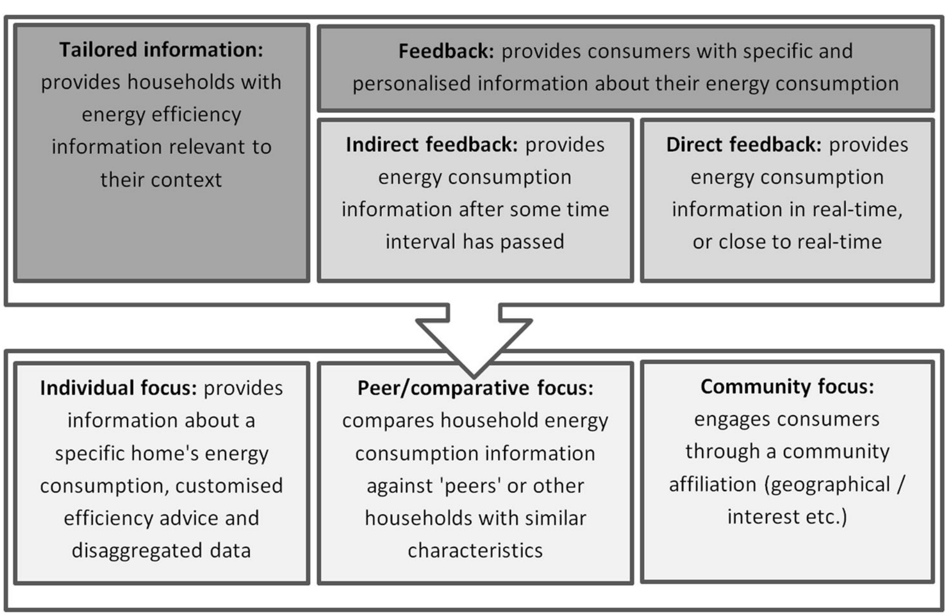


**Figure 1.** Types of household energy-related behaviour strategies and approaches.
Source: Based on Mahone and Haley (2011, fig. 1).

**Table 1.** Review of the feedback tools and feedback techniques used in this study.

| Level | Feedback method | Description of the feedback method |
|---|---|---|
| Individual | Paper bill | Standard form of feedback as provided by the energy company (Froehlich, 2009). Greater frequency of accurate reporting more effective at reducing consumption (Darby, 2006) |
| | Energy display monitors | Displays can provide energy consumption information for individual appliances or the whole house, *e.g.* kW, kWh/day, US$/£ per period of time *etc.* (Froehlich, 2009). Most useful if they show instantaneous usage, expenditure and history feedback (Darby, 2006). In one study, expressing energy use in monetary units (on a daily basis) was found not to be effective due to the small daily cost of the consumed energy. Similarly, $CO_2$e emissions and other environmental units to which home inhabitants are not accustomed were found to be ineffective influencers. Whilst kWh is more accepted, it is not entirely understood (Wood & Newborough, 2007). Petkov et al. (2011) found that in all cases interviewees considered temporal self-comparison (a history feature) essential |
| | Website/mobile application energy trackers | Similar to the energy display monitor but must login to a website to view the information – a higher level of analytical potential (Eisenbach Consulting, 2016; Froehlich, 2009) |
| | Peer educators | Point of contact to assist with specific individual questions on how to reduce (Carrico & Riemer, 2011) |
| | Personalized energy report/advice | Personalized advice regarding the energy and financial consequences of energy consumption behaviour (Midden, Meter, Weenig, & Zieverink, 1983; Rowe, 2014) |
| | Thermal imaging | Thermal imaging has been used to evaluate the performance of the building fabric during construction to avoid performance issues and manage construction quality (Taylor, Counsell, & Gill, 2013) and to promote energy-conservation behaviours (Goodhew, Pahl, Auburn, & Goodhew, 2015) |
| Comparative | Social sharing online (detailed or generalized) | Voluntarily sharing of energy data on social media, for example, is shown to create a pressure to engage in more efficient behaviour (Froehlich, 2009). Petkov et al. (2011) found that a majority of interviewees preferred the integration of energy data sharing with already used social media formats and that communication channels between comparing/competing parties is important for sharing information directly within a feedback tool<br>The Energy Saving Trust reported that, based on a survey, 45% of households want to compare energy consumption with similar households nearby (Rowe, 2014) |
| Community | Group e-mail list | General information on energy saving and information on how a group (*e.g.* an office) is performing as a whole (Carrico & Riemer, 2011). Community groups focused on energy management can also use this method |

EDMs showed backgrounding of the devices into everyday life, thereby gradually losing effectiveness in encouraging reductions (Nye, Smith, Hargeaves, & Burgess, 2010). Users appear to rapidly learn their consumption patterns in some considerable detail wherein monitors stop offering new or sufficiently detailed information (Hargreaves, Nye, & Burgess, 2010, 2013). Several studies indicate that feedback techniques that enable the consumer to visualize aspects of energy consumption are critical to increasing their awareness and understanding of energy consumption and efficiency, given the invisibility of energy use (Hargreaves et al., 2010; Steg, 2008). Web-based applications for customer feedback are favoured by utilities as they are relatively inexpensive, can be updated rapidly, ensure that the supplier has access to, and controls, all the information, and has the ability to alert customers to abnormal consumption patterns, but the information is largely numeric in content. A more visual approach of thermal imaging (TI) has been recently explored in the EViz project (Boomsma, Goodhew, Goodhew, & Pahl, 2016) to promote energy-conservation behaviours by showing to residents where improvement (*e.g.* insulation) is needed. However, there is limited research on investigating the impact of using more visual (as opposed to numeric) energy feedback techniques to increase householders' energy awareness. With the exception of the EViz project, there is lack of research that has applied and evaluated visual energy feedback techniques. Instead research has largely concentrated its efforts on assessing the efficacy of numeric based feedback such as billing, EDMs and web platforms. This provides the motivation and rationale for the study.

The present study explores the effectiveness of providing energy feedback to householders through more visual techniques (carbon mapping, TI) as well as standard methods (web-based platform, home energy reports) delivered through community workshops, home visits and the internet, across six low-carbon communities in the UK, so as to stimulate further energy behaviour change. The feedback techniques cover a variety of media (maps, TIs, web platform, reports) and scales (spatial and temporal), including carbon mapping of household energy use and potential for energy savings; TI showing heat loss from the building fabric; web-based energy and environmental visualization platform (WEEV) showing near real-time household energy use in relation to indoor and outdoor environmental conditions; and personalized home energy reports (HERs) accompanied by home visits.

## Visual approaches to energy feedback: the evidence

The invisibility of energy is seen as a reason why households, even if they do profess positive environmental attitudes, do not always behave in ways that conserve energy use (Burgess & Nye, 2008; Hargreaves et al., 2010). Buchanan et al. (2014) highlight the fact that energy is both physically invisible (the consumer cannot see what is being used) and consciously invisible due to the majority of household energy consumption being the result of routines and habits (Shove, 2003). It has been asserted that feedback is a learning process that enables the energy and environmental literacy gap to be closed (Froehlich, Findlater, & Landay, 2010). Evidence from literature reveals some of the qualities of successful feedback as clear, appealing, provides high granularity and frequency over a long period of time, is interactive (Fischer, 2008), provides social comparisons and is combined with other interventions (Hargreaves, Nye, & Burgess, 2013), gives access to relevant comparators (*e.g.* historic values) (Darby, 2010; Fischer, 2008), and makes recommendations (Froehlich, 2009).

Web-based applications attempt to address some of these aspects, but the extra effort it takes for people to access the online feedback can be a deterrent. Web-based platforms can vary in the format and the quality and extent of information provided, but international evidence has shown low usage rates of online feedback at 2–4% of customers (Darby, 2010). EDMs, HERs and WEEV have been reported to result in savings; however, through the observations of usual feedback methods, once equipped with new knowledge and expertise about their levels of consumption, behaviour may become harder to change as householders realize the limits to their energy-saving potential and become frustrated by the absence of wider policy, market support and wider social participation in energy conservation (Hargreaves et al., 2013). Interviews from the Visible Energy Trial conducted by British Gas (during CERT) indicated that there is a need for wider support and action to accompany real-time displays if domestic energy savings are going to be encouraged (Nye et al., 2010).

Although mainly used as a diagnostic tool, TI has begun to gain traction as a feedback tool for households enabling heat losses through the building fabric to be visualized, and the impact of building fabric upgrades that have been undertaken. Not only is TI visually informative, but also it is visually captivating (Darby, 2010). The EViz project and others (Burchell, Rettie, & Roberts, 2015; Morris-Marsham, 2014) have explored TI as a tool to improve the cognitive connection between conservation behaviour and consumption (Boomsma et al., 2016) and to demystify heat (Goodhew, Boomsma, Pahl, & Goodhew, 2015) in order to promote energy-conservation behaviours (Goodhew, Pahl, Auburn, & Goodhew, 2015). Thermographic images can be used in a number of ways to provide feedback through either individual household surveys or community-wide surveys (Fox, Goodhew, & De Wilde, 2016), and public display of the results to enable comparative feedback and information on potential issues and solutions.

Another feedback method for visual communication of energy information is through the use of spatial maps, typically using geographical information system (GIS). There are several cases of spatial mapping of energy and emissions information. In the UK, annual subnational energy and fuel-poverty data (DBEIS, 2017) are available at aggregated scales, *e.g.* lower-layer super-output area comprising 400–700 households (ONS, 2017), though not providing dwelling level detail. The national heat map (CSE, 2017) is freely accessible online for the planning and deployment of low-carbon energy systems; to help identify locations where heat distribution is most likely to be beneficial and economic (Figure 2). The City of Bristol provides a house-by-house-level view of the potential to install solar energy systems (BCC, 2017) (Figure 2). The Energy Saving Trust's (EST) Home Analytics (2017) provides information on the potential for energy-saving retrofit

**Figure 2.** National heat map (CSE, 2017) (left) and Bristol City Council (BCC) solar potential map (BCC, 2017) (right).

measures as a service to retrofit providers and energy companies. Beyond the UK, energy maps have also been developed internationally to assist utilities programme administrators in the US (Crowley & GL, 2014), energy policy-makers in Greece (Balta, 2014), and citizens, public administrators and government agencies to perform city-wide analyses on energy performance of the building stock in Italy (Di Staso et al., 2014). Kolter and Ferreira (2011) describe a methodology for the creation of energy consumption mapping in the US city of Cambridge for energy companies or retrofit providers to target homes for potential retrofits. Most of these methods provide aggregated results for targeting areas for energy improvements; and they are generally created for local authorities, retrofit providers or utilities, *i.e.* energy-savvy stakeholders, and are not intended to communicate dwelling-level energy feedback directly to householders.

For the first time the following work demonstrates the application and evaluation of more visual energy feedback techniques (*e.g.* carbon mapping and TI) at both individual and community levels compared with more traditional feedback methods (web-based platform, home energy reports). The research particularly takes the visual forms of energy feedback typically used by groups or people trained in energy analysis and uses these visualization techniques to communicate to householders to demonstrate the existing energy performance, and what the remaining potential is for further reduction.

## Methods

This study was conducted as part of a four-year action research project (entitled EVALOC) on evaluating the impacts of six geographically diverse low carbon communities (see Appendix A in the supplemental data online) that had projects funded through the Department of Energy and Climate Change's (DECC) Low Carbon Communities Challenge (LCCC). The main work streams took place on two levels: community and household, and used a variety of research methodologies including community events (14 events across the six communities), three rounds of focus groups, carbon mapping of 1659 homes and case study household monitoring of 88 households (having home energy improvements) over approximately two years (summer 2012 to summer 2014) (Gupta, Barnfield, & Hipwood, 2014). The 88 EVALOC households (occupying 88 dwellings) in the sample were recruited across the six case study communities by using a variety of techniques, comprising local community contacts and face-to-face dialogue with occupants at community events. The households were chosen to represent, as far as possible, the UK housing stock in terms of housing typologies (tenure, built forms and age groups), occupancy profiles and low-carbon communities (LCC) interventions.

The use and impact of a variety of energy feedback and information techniques (other than those undertaken by the LCC organizations themselves) was not initially part of the wider study. However, it was quickly apparent that the majority of EVALOC case study households actively wanted feedback from the research and from the LCC organizations themselves, not only in terms of advice on how to reduce further energy use but also in relation to monitoring progress during and after the project. More specifically, they wanted follow-up support and advice on the performance of the physical energy improvements they had undertaken as part of the LCC activities and funding. As an action research study, it was felt appropriate to trial different forms and scales of energy feedback techniques at both household and community level, as outlined in Table 2. These approaches included more visual techniques of carbon mapping and TI, as well as more traditional approaches of WEEV and HERs. As a consequence of this work being in addition to the aims of the EVALOC project, there was no follow-up to evaluate the change in energy consumption or actual behaviour change following the presentation of these feedback methods to the householders; however, success of the approaches was judged based on householder perception.

Three delivery methods were used for the four feedback approaches:

- community workshops: presentation to members of the communities showing analysis of carbon mapping and TI
- online (internet) access to WEEV
- home visits to discuss personalized HERs including TI

To learn from the application of the various energy feedback approaches in the case study LCCs, participants were surveyed and interviewed to understand their experiences and whether the feedback helped, from their point of view, in stimulating further behaviour change and motivation to reduce energy further. Questionnaire surveys were conducted at the end of the carbon-mapping workshops, which also had presentation slides and posters on carbon maps and TI surveys (Figure 3). Interviews were conducted during the home visits. Though no quantitative data were collected regarding the specific feedback approaches, the householders were asked to rate their level of response to the following statement:

**Table 2.** Characteristics of energy feedback techniques deployed in the study.

| Feedback technique | Level of application | Mode of delivery | Frequency | Duration | Sample size |
|---|---|---|---|---|---|
| Carbon mapping | Community[a] Household Comparative | Community workshops: presentation, posters | Indirect one-off | Annual | Five community workshops; 103 attendees |
| Thermal imaging | Household | Community workshops, HERs, home visits | Indirect one-off | Snapshot at a given time | Thermal imaging presented anonymously at five community workshops; 103 attendees/personal images presented to, and discussed with, 58 individual households as part of HERs |
| Web-based energy and environmental visualization platform (WEEV) | Household Comparative/peer | Online website with login | Direct continuous | Near real time | Details provided to 61 individual households (a subset of the 88 monitored households) |
| Home energy reports (HERs) | Household | Home visits | Indirect one-off | Months to years | Posted to and reviewed in person with 58 individual households (a subset of the 88 monitored households) |

Note: [a]Although in the workshops the carbon-mapping findings were shared with the community as a whole, the carbon maps contain information on individual households and also provided comparative feedback.

> *I feel capable of reducing energy use in my house* (Response to be selected on five-point range from strongly agree to strongly disagree).

Of the 88 EVALOC householders, a subset of 61 households (who agreed to have equipment installed in their homes for remote monitoring of energy use and indoor environment as part of the EVALOC project) were involved with the home visits and the WEEV trials; further details on the household characteristics can be found in Appendix A in the supplemental data online. In contrast, invitations to the community workshops were extended to the wider communities (outside of the 88 EVALOC households); however, no demographic information was collected at the workshops. When prompted to describe their feelings regarding climate change in a single word, 33 of 37 respondents expressed

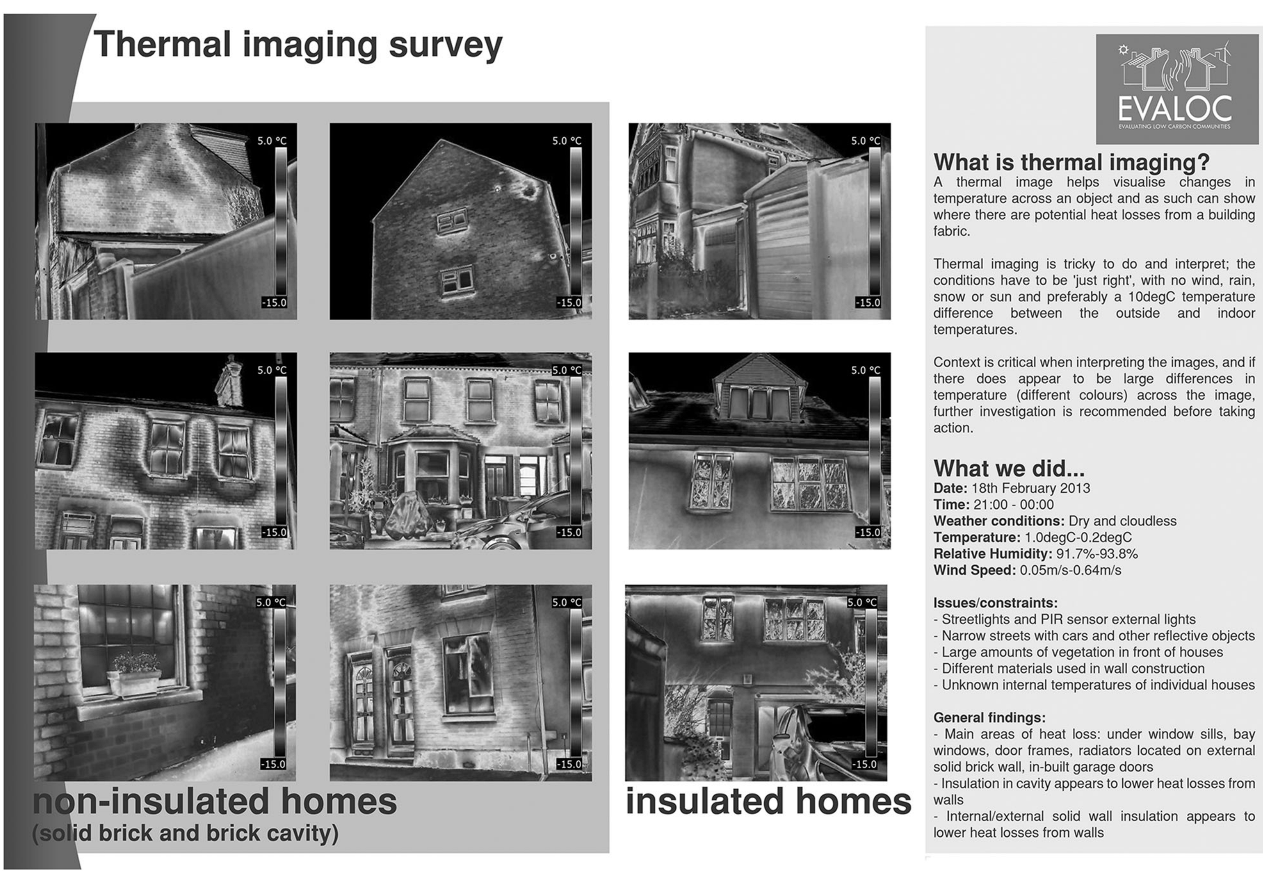


**Figure 3.** Example of a thermal imaging poster displayed at a carbon-mapping workshop.

it as important, challenging and most commonly 'concerned'. There was at least one respondent in each group who did not consider climate change a real concern.

The following subsections provide an overview of each energy feedback approach tested in the study. The intent is not to provide a detailed methodology behind the data gathering and development of each feedback approach specifically since these methods can be found in other sources of literature, *e.g.* carbon mapping (Gupta & Droege, 2008; Gupta, Barnfield, & Gregg, 2015), TI (BSEN13187:1999) (BSI, 1999; Pearson, 2011), and WEEV and HERs (Abrahamse et al., 2007; Ueno, Sano, Saeki, & Tsuji, 2006).

### Carbon mapping: community workshops

For the purposes of the EVALOC project, an urban energy modelling tool called DECoRuM[1] was used to bring together energy modelling and GIS to create colour-coded spatial maps showing (past and present) energy use and potential for (future) energy, carbon and cost savings on a house-by-house level, and also aggregated to the community level (Figure 4). DECoRuM modelling and mapping enabled the evaluation of longitudinal energy trends, *i.e.* pre- as compared with post-LCCC action. Gupta et al. (2015) present the method and application of carbon mapping for the wider purposes of the EVALOC project. As a feedback approach the novelty of carbon mapping lies in the provision of a wide variety of units for the interpretation of energy related information (*e.g.* energy, $CO_2$e, cost/unit, energy/$m^2$ *etc.*) and offers comparative evaluation between individual dwellings and between time periods for the same dwelling. Furthermore, the visual design enables carbon mapping to be easily shared socially for comparative purposes. Limitations are in the lack of data granularity and frequency of updating (Froehlich, 2009).

Carbon-mapping workshops were held in five of the six EVALOC communities (all but community B due to lack of resources, people and time in the area). The workshops were advertised among the communities by the community organizers, generally through e-mail, community newsletters or social media connections already established. As the advertising for the workshops was open as opposed to the other methods of providing or gathering information, the attendees were not limited to the subjects of the EVALOC project, nor were the subjects of the EVALOC project guaranteed to be present. At these workshops PowerPoint presentations displaying maps of baseline conditions (pre-LCCC action), current conditions (post-LCCC action) and potential areas for action on further reducing domestic energy use were presented to local residents by the researchers. The improvement measures were grouped as packages:

- fabric improvement package: wall, floor, roof insulation; draught proofing, and double-glazing
- fabric and heating upgrade package: fabric package plus new condensing boiler, hot water tank insulation, pipework insulation and heating controls

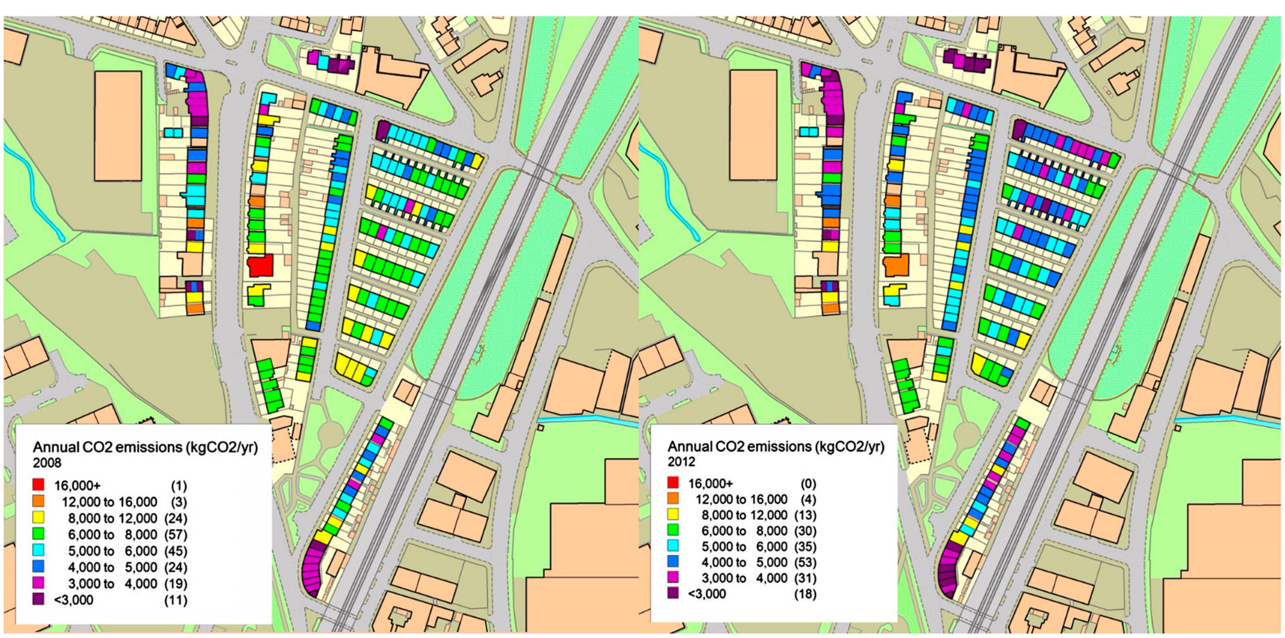


**Figure 4.** Carbon-mapping image showing, pre-Low Carbon Communities Challenge (LCCC) action, post-LCCC action, and potential reductions from suggested package.

- fabric, heating and electricity package: fabric and heating package plus energy efficient lighting and appliances, photovoltaic (PV) system and solar hot water

The case study LCCs helped to co-organize the carbon-mapping workshops, and invited key stakeholders and residents. The attendance of the workshops was influenced by the local context. For example, in one community it was felt that the carbon-mapping workshop was more appropriate for a local authority-led community meeting and was mainly attended by members of the local authority, councillors and local education, health and community providers, whilst in another the workshop was organized and attended wholly by local residents. The format of the workshop was a presentation (Figure 5) outlining the carbon-mapping findings, followed by a question-and-answer session with discussion. All maps provided data as annual $CO_2$ emissions and results were presented from a community perspective. Posters with the same information were also available to prompt discussion following the presentations. Questionnaires were given out to the attendees who were asked to self-complete and return them before they left the event. In total, approximately 103 people attended five carbon-mapping events across the case study communities, and 36 evaluation forms were completed by the attendees.

The follow-up survey asked the following questions:

(1) What motivated you to attend this event?
(2) What did you learn that was most useful?
(3) Has the event affected your motivation to reduce energy in your home?
(4) Has the event made you aware of more opportunities to reduce energy in your home?
(5) As a result of attending the event, do you intend to make any changes to reduce you energy use?
(6) Please write one word to describe how you feel about climate change (or global warming).
(7) Other comments

Due to the manageable number of responses, questionnaires were analysed in spreadsheet form.

### *Thermal imaging: community workshops and home visits*

TIs were used in the EVALOC project for both diagnostics (what has been done in terms of building fabric improvements to reduce heat loss) and awareness-raising (what can be done to improve the building fabric). Over six nights (one night per community) during February and March 2013, the 88 monitored case study households involved in the EVALOC project were subject to an external TI survey of which they were notified before the images were taken. The survey was undertaken using a FLIR T620bx TI camera by two researchers working together on foot. The researchers were trained in introductory to thermography using the same camera by the Infrared Training Centre and followed procedures set out in BSEN13187:1999 (1999) and Pearson (2011). External weather conditions were monitored throughout the surveys using a Vaisala Humicap HM40 relative humidity (RH) and temperature meter and an ATP DT-8880 anemometer; internal temperature and RH were accessed through the previously set-up environmental monitoring of the homes.

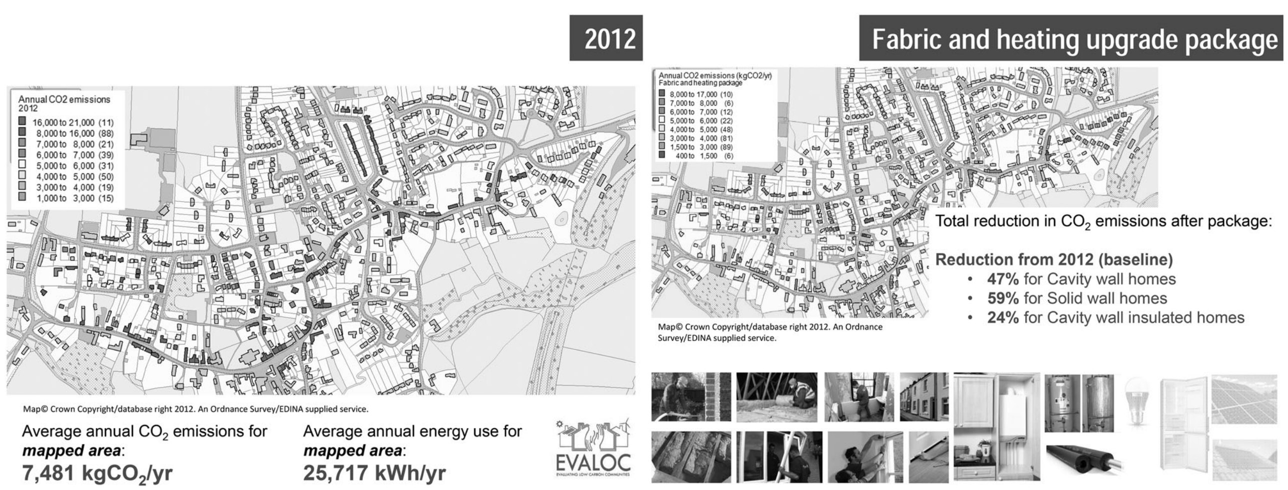


**Figure 5.** Slides from a carbon-mapping presentation showing the current conditions (left) and impact of physical improvements (right).

The images were edited using FLIR software to enable comparative scales to be made across the images. Limitations on the interpretation of the images were noted throughout the process, such as the effect of multiple materials upon one facade (with different emissivities) and contextual implications such as overshadowing buildings and vegetation. Such limitations were both explained at every opportunity to the householders. As a feedback approach, the novelty of TI lies in the visualization of dwelling aspects unavailable through any other source of feedback. TI can also be socially shared for comparative purposes. Limitations are in the cost, specifics of the process and frequency of updating (Froehlich, 2009).

Anonymous images were presented at community workshops through PowerPoint presentation and in poster format (from a community perspective), as well as to individual households as part of personalized HERs, alongside discussion with researchers. TIs of the relevant dwelling, key findings and comments were inserted into individual case study HERs, which were printed and sent to 58 EVALOC households (see Figure S1 in the supplemental data online). Approximately two weeks later, the researchers scheduled a home visit and took a further printed copy of the HER to discuss the TI results for the individual households face to face. The purpose of the presentation of TI during home visits was to identify and discuss discrepancies related to fabric improvements taken and to identify areas for further improvement.

### Web-based energy and environmental visualization platform (WEEV): online access

For the 61 (EVALOC) households (with an energy and environmental monitoring kit), the energy use (gas and electricity) and environmental monitoring (indoor and outdoor temperature, RH, $CO_2$ levels) data were uploaded onto a WEEV platform hosted by EnergyDeck (www.energydeck.com). Invitations were sent to 50 of the households by e-mail. Due to 11 households not having/providing an e-mail address, postal invitations along with a 14-page step-by-step guidance brochure on all aspects of the platform (see Figure S2 in the supplemental data online) were also sent to all 61 households. Beyond the guidance document no other information or training was provided to the householders on how to use the platform. The aim of the WEEV platform was to provide the householders with near real-time information on energy consumption and energy generation, as well as indoor and outdoor environmental conditions (temperature, RH, $CO_2$ levels). The platform provided comparative benchmarks and allowed the user to search for specific dates and times. It also allowed users to select different variables (*i.e.* gas data and living room temperature) and display these on one graph together. Householders had access to the WEEV platform for a total of three months before their opinions were assessed. As a feedback approach the innovation of WEEV lies in showing the link between energy use and the home environment at a detailed scale and the potential for comparative evaluation between individual dwellings and between time periods for the same dwelling (Froehlich, 2009). Some limitations of online platforms have been found to be the potential to overwhelm and to be inaccessible for some users (Darby, 2010).

### Personalized home energy reports: home visits

An alternative approach to the WEEV platform used within the study in order to feedback energy and environmental information to the individual households was the personalized HER (see Figure S3 in the supplemental data online). Using the findings from WEEV, the researchers aimed to develop a succinct and clear way of visualizing complex information on:

- household energy use (including over time and against benchmarks/national figures)
- environmental data (including temperature, RH and $CO_2$ levels)
- the performance of low-zero-carbon technologies and PV systems (if present)

As a feedback approach, the innovation of HERs lies in the provision of tailored information and recommendations (Froehlich, 2009). The main difficulty faced was the need to appeal to both non-technically and technically minded households. The HER was sent in draft form to 58 households (three households were unavailable for personal reasons or had moved dwelling) by post approximately one to two weeks prior to a scheduled visit by a researcher. During the visit, the occupants were asked whether or not they had read it, and if they wanted to discuss it further. For reference, the researcher carried an additional copy of the HER. Insights were gathered from householders about WEEV and personalized HERs during semi-structured interviews with the householders. The discussions were open to be driven by the householders; however, prompts were taken from the HERs in case discussion lagged or went off track. The discussion were recorded, transcribed and analysed in NVivo.

## Insights from the application of energy-feedback approaches

The main purpose of the feedback approaches was to communicate the findings of the project to householders, LCC groups and local authorities. In addition to this they were also expected to stimulate energy behaviour change which, in theory, would lead to further (not measured) energy reductions.

### *Carbon-mapping workshops*

Table 3 outlines the key findings from the carbon-mapping workshops held across five LCCs. Analysis of the evaluation survey forms (completed by participants) revealed that carbon mapping did not hold as much interest as the TIs (see below), though the interest varied among the communities. It was felt that this was possibly due to the fact that carbon is not a familiar concept to many people, and using costs or even kWh would perhaps have engaged people more (Simcock et al., 2014). Furthermore, the need for technical detail varied within different case studies, and highlights the need to ensure the presented information is edited and formatted to suit different requirements and contextual needs. In general, the presentations were found to be informative but possibly too technical. The majority of respondents, however, stated that they found the discussion more useful and left the workshop feeling motivated (31 of 36 respondents) to undertake either physical changes to their homes and/or change habitual behaviours such as turning the heating down.

In community F, feedback comments indicated people were not as interested in technical aspects of carbon savings and that communication of these concepts should be simplified. Elsewhere, however (communities D and E), participants felt that the colour-coded spatial maps effectively communicated the carbon reductions that took place due to community-based home energy improvements as compared with the baseline (no one mention of difficulty with measuring change using carbon emissions). In community A, it was felt that the aggregation of the data, concentration on community mapping, rather than individual house comparison, was not appropriate for the audience. On the other hand, the information provided through carbon mapping to community E's local council helped in justifying funding for the PV panels and 'will help guide future

**Table 3.** Findings from the five carbon-mapping workshops held across five communities.

| Community | Attendees | Approach | Responses from participants |
|---|---|---|---|
| A | 12, mostly local residents | Presentation, posters, Q&A and group discussion | Information presented was too technical with not enough detail on individual households<br>Three of four respondents stated they felt more motivated to reduce energy further following the event<br>Two of four respondents more aware<br>Three of four respondents left with intentions to change (physical measures and behaviours) |
| C | 25, six local residents; others were representatives of local professional organizations, *e.g.* housing association, council | Presentation, posters, Q&A and group discussion | Presentation and group discussion valued equally by the respondents<br>Eight of 10 stated they felt more motivated to reduce further energy following the event<br>Five of 10 felt more aware<br>Seven of 10 left with intentions to change (physical measures and behaviours) |
| D | 30, mostly local residents | Presentation, posters, Q&A and group discussion | Most respondents stated they learned most from the mapping of impacts of potential measures<br>All respondents (13) stated they felt more motivated to reduce further energy following the workshop<br>Eleven of 13 felt more aware<br>Nine of 13 left with intentions to change (physical measures and behaviours) |
| E | 16, local authority and community representatives (no local residents present) | Presentation, Q&A and group discussion | Presentation was useful as it was found to help justify previous activities and guide future investments in the area |
| F | 20, mostly local residents | Presentation, posters, Q&A and group discussion | Most commonly cited things learned from the workshop were the use of thermal imaging to identify heat losses and energy saving gained through LED lighting<br>Seven of nine stated they felt more motivated to reduce further energy following the workshop<br>Four of nine were more aware<br>Eight of nine left with intentions to change (physical measures) |

Note: Q&A = question and answer.

investment of the community fund generated by the PV panels'. Community C's local council found value in using carbon mapping to encourage private landlords to carry out similar work by demonstrating carbon benefits of improvements in social housing dwellings.

### *Thermal imaging: community workshops and home visits*

Though the TI presented at the carbon-mapping workshops was anonymized, attendees found the images visual stimulating, inspiring a number of requests from householders to have their homes thermally imaged. A particularly useful aspect of the presentation method was that it allowed the researchers to show the householders 'good' and 'bad' examples of similar dwellings that had been thermally imaged, further emphasizing the potential of physical measures, and also highlighting issues of which to be aware. In response to the open question 'What did you learn that was most useful?', eight out of 28 respondents stated that the use of TI for identifying heat losses from building fabric was most useful.

During the personalized home visits to discuss the HERs, TI was found to be a successful engagement tool in engaging with householders and increasing their awareness to seek solutions to minimize heat loss, especially when combined with expertise in interpreting the images. The householders appreciated the opportunity to discuss details of the TIs with the researcher. Although there was no follow-up to establish specifically whether changes were made as a result of gaining feedback through TI, as part of subsequent household interviews some householders reported on actions following the provision of the TIs:

> By the way, the unidentified cold spot on the corner of the front bedroom window was the result of dampness caused by crumbling pointing between the stones. Thanks to you I can have it restored – I would never have known about it otherwise.
> (householder comment)

> I took the pictures into the local housing trust because the flat below, it had a big light spot under the window … .
> (householder comment)

During the home visits, TI was also used to provide clarity and peace of mind to householders that fabric measures had been undertaken successfully (where appropriate), and provoked interesting discussion when any apparent anomalies in the fabric improvements were indicated by the TIs. As part of household interviews, 10 out of 50 respondents stated that TI was the most useful activity they had participated in as part of the EVALOC study.

### *WEEV: online access*

Of the 61 households that were invited to use the WEEV platform, only 22 signed up to access it, with approximately five requiring significant help from the researchers. It was realized that a web-based feedback approach is not suitable for all individuals and that feedback methods should be carefully thought through in terms of accessibility and readability. The level of interaction appeared to be due to the type of individual and their familiarity with computers and the internet rather than to which community they belonged. For example, high and low interactions were both observed in communities B and D.

Of those who did not sign up to access the platform, the main reason for not using the site appeared to be lack of time and motivation to log in to 'yet another' website, but many stated that they were simply unaware of the website. This suggests that the means of contacting the households (through post and via e-mail) were not always successful.

> I think probably the access to the online data should have been the most useful if I got round to actually looking at it.
> (householder comment)

Regardless, a simple yet potentially effective suggestion was that personalized reports should be generated weekly (or monthly) and automatically sent to the individual's e-mail address, thus providing the individuals with a direct prompt, rather than requiring them 'actively' to seek the information. For those who accessed it, when queried about the use of the website, few said that they had looked at it more than once, with many overwhelmed by the wide variety of options and perceived complexity of the site (even though they found the guidance helpful). Whilst some stated that it needed simplifying, others appreciated the options available and were disappointed more by the fact that it was not 'real time'. It was notable that these were generally households with high levels of energy-management knowledge (indeed, some worked in the energy sector themselves).

### *Personalized home energy reports and home visits*

The HER was found to be a useful way of provoking discussion between the researcher and householders on their energy use. It also prompted the householders to discuss the reasons why their energy use and/or indoor environmental conditions were the way they were. An example of this was the use of a graph showing annual energy use from 2008 to 2011. This generally acted as a trigger for the occupants to remember relevant contextual details that had otherwise been forgotten and not mentioned when they were asked about any changes in household over the years.

Many of the occupants also stated that they found the report interesting, but often it was found to be too technical and simpler graphs were required:

> Yes I've read it but I don't understand everything in it.
> (householder comment)

> I'm not very good at numbers and sums, and so a lot of it was just dancing in front of me and not meaning anything … I was very interested and very taken with that infrared photography.
> (householder comment)

Yet for some, the HER did not go into enough detail:

> I would have wanted to see that on a more regular basis so it's not kind of crammed into one report so maybe a quarterly breakdown if not a monthly breakdown so that I could more easily relate consumption patterns to actions that I know I've taken. At the moment I think in that form the data is too aggregated to be useful.
> (householder comment)

Furthermore, it appears that many who did not understand the graphs tried to view them in terms of 'good' and 'bad' (*i.e.* better or worse than it 'should' be), but the graphs had no comparative data in them to give the occupants this information, and so the occupants were unable to understand what the graphs were supposed to be telling them. A number of households had not looked at the HER at all, stating that they had simply been too busy or had forgotten about it. Yet even in these households, when the HER was shown to them during the researcher's visit, it prompted discussion and interest. This indicates the significance of physical presence in ensuring information is transferred and communicated fully. It is appreciated, however, that physical presence to explain HER documents would be a resource-intensive approach. Therefore, other approaches could be considered that involve considerable design of documentation and presentation materials that allow layered revelation of highly visual and appropriate-to-audience information based on the comprehension of the recipient. As an example, revelation of information could follow a framework similar to the 'choose your own adventure' literature, where based on interest or comprehension a recipient can proceed to dig deeper into the material.

## Discussion

The study has provided useful insights into householder experiences of more visual energy feedback techniques (carbon mapping, TI) at different scales, alongside traditional methods (web-based, home energy reports), delivered through community workshops, home visits and the internet. Findings of the study corroborate previous work (Abrahamse et al., 2007; Gonzales et al., 1988; Steg, 2008) that face-to-face interaction/provision of feedback and information is most appreciated by recipients. This was evident through the positive experience of the householders with the home visits which used TI and HERs to stimulate discussion on household energy use and potential for energy savings through improvements of the building fabric. The visualization and communication of house-by-house carbon emissions in the form of colour-coded spatial maps through community workshops was found to provide evidence about the impact of community action on household energy use and show that 'others' were also actively engaged in energy action. Although in one community householders felt carbon mapping to be too impersonal because of the scale, overall it emerged as a useful technique for scaling-up LCCs' action for both community members and local councils. Despite being data driven, the WEEV platform had mixed reactions: some individuals were overwhelmed by the platform, while others were disappointed with the limitations of the analysis.

It was also realized that energy feedback alone may not be enough to stimulate further energy reduction, particularly for people who are already careful in their habits:

> It's got to the point where it's difficult to reduce it right down without cutting out everyday things that we use or that we enjoy. The only real way to do anything more now is quite expensive changes.
> (householder comment)

> being an electrician I know where the money goes but you get to the point where you start penny-pinching … the effort overcomes the gains.
> (householder comment)

Instead, the most effective forms of feedback are likely to include both products (be it maps, TIs, reports or online platforms) and services (compilation of data, targeting and tailoring of recommendations) that provide householders with timely and detailed information that is presented in multiple ways, tailored to the consumer, and contextualized to provide meaning and motivation. In the delivery of such feedback, some degree of personal contact was needed to make the most of what the feedback was able to provide in the way of information.

It is important to remember that overall the number of participants involved in this study is relatively small, and the findings cannot be treated as statistical generalizations. It is also worth noting that the 61 households who participated in the trial of WEEV and HERS were part of the EVALOC project who had agreed to have their homes monitored. The participants, therefore, formed a motivated sample which may not typically be representative of the general population. This motivation may have influenced their interest and willingness to take up feedback and advice. In contrast the carbon-mapping workshop, attendees were potentially more mixed as these events were more publically advertised through community newsletters to households outside the EVALOC project.

Despite the limitations, the findings of the present study do have implications for the UK's smart meter rollout (expected to be delivered by 2020; DCLG, DWP, DECC, & Ofgem, 2015) and EDMs, which have the capability to enable energy consumers to see energy use, costs and to gain control over saving energy and money. Face-to-face interaction could be integrated as a potential behaviour-change mechanism into smart meter policy at the time of (or just after) the installation of smart meters and EDMs, when the resident(s) could be trained to use the EDM and/or online tool, and even personalized energy advice could be provided. Such an integrated approach combining feedback technology and personal contact is likely to be welcomed given the experience in this study.

To enable policy-makers to engage actively with these visual and traditional energy feedback methods as part of the smart meter rollout, reflections are made on the costs associated with each approach in terms of time, expertise, equipment required to examine which approaches are potentially scalable and which offer good value for money. Table 4 describes the data-collection process, equipment (or data sources) and expertise required for the corresponding feedback approach.

The feedback approach of carbon mapping is highly scalable from single dwellings to a street, a neighbourhood or even a town/city. The typical costs for setting up carbon maps can range from an estimated average of £5000 (two weeks) for a mapped assessment of 10,000 homes using open public data (on energy and housing such as subnational energy consumption data from the Department for Business, Energy and Industrial Strategy (DBEIS), 2016), energy performance certificates – EPCs) to £12,000–£15,000 (two months) for a more detailed version including dwelling data collection and assessment. In addition, where active community groups exist, the community group members can help with the data-collection process. On the other hand, TI and HERs can be time intensive since they are traditionally performed on a house-by-house level. The cost of a TI camera can range from £300 (a thermal camera attachment for smart phones) to £20,000 (a high-end wide-angle lens camera), although there are opportunities to rent or hire a professional to perform assessments. Moreover, thermography-equipped drones are now being used to increase speed, lower cost and simplify the process of TI inaccessible points such as high facades and roofs (Jung & Liebelt, 2015).

HERs and visits can be resource intensive but can work where there is an active community group or where already trained EPC assessors can be used, in which case the value for money is expected to be high. WEEV

**Table 4.** Feedback approaches and associated data-collection processes and expertise required.

| Feedback approach | Level | Data-collection process | Equipment, data source | Expertise required |
|---|---|---|---|---|
| Carbon mapping | Street, cluster, neighbourhood, town, city | Depending on the desired level of precision, data-collection time and cost can vary | Energy performance certificates, subnational energy data and housing statistics, home questionnaires, and home assessment | A large amount of useful data on dwellings can be collected by community/householder; however, energy calculations require knowledge of energy software such as the standard assessment procedure (SAP) and mapping requires geographic information system (GIS) |
| Thermal imaging | House by house | Capturing the street-facing facades of houses using a thermal-imaging camera and processing of images | Thermal-imaging camera | Thermal imaging requires a certain level of expertise; however, training or hired professionals are available |
| Web-based energy and environmental visualization platform (WEEV) | Traditionally house by house, though clustered energy data can be collected | Wired or wireless connection between sensors (collecting data) and web-based software for data cleaning, analysis and reporting | Sensors such as smart meters and environmental sensors. Hub for data collection and transmission. Web-based software for analysis and reporting | A high level of expertise is required to set up a WEEV platform; however, there are many formats already available. Some expertise is also necessary to explain how to use the software |
| Home energy reports (HERs) and home visits | House by house | Assessment and reporting of monthly/annual-level data | Energy bills, meter readings, smart meters | Expertise can vary (from community group to energy assessor to specialist researcher or consultant) depending on the data source and equipment used and the desired level of detail to report |

platforms need a third party to install the sensors, design the interface, conduct analysis and manage data, which proved to be time consuming and expensive. Though a WEEV platform is neither cheap nor easy to do, once set up it does have potential if it can be linked with time-of-use tariffs (Ward, 2017). Using the community workshop approach to provide collective feedback can cost around £1200 – an example cost of organizing a community energy and feedback learning event in this study. Given that potentially a large number of people can be engaged with through community-based events or workshops, these offer good value for money and are potentially scalable where active community groups exist.

## Conclusions

This study has empirically tested both traditional and more visual methods of energy feedback at different scales (spatial and temporal) across six low-carbon communities in the UK. The feedback gathered from householders showed that the majority of the feedback approaches were able to engage with the householders, raise their awareness on household energy and, in some cases, motivate them into taking action. Due to the qualitative nature of the evaluation process and small sample numbers, the findings are more illustrative than conclusive, but they do provide insights into the types of feedback that can be used as well as provide recommendations for future research studies and feedback activities undertaken at a community level.

The traditional approach of HERs tended to be forgotten or 'put in a drawer for later'. Yet, when combined with a researcher's visit, they created the opportunity for discussion using the feedback as a prompt by creating an awareness of energy on a very personal level for the household. This increasingly personal approach has to underpin the delivery of any future energy feedback approach.

The more visual approach of carbon mapping was found to be useful in providing evidence of past and future community energy action, thereby helping to scale up community energy action. Despite this, carbon mapping was felt to be aimed more at community groups and organizations rather than at individual householders and, as such, did not engage the local residents as much as TI. A potential solution to this problem would be to integrate carbon mapping with the TI results to create carbon-thermal mapping, wherein carbon-inefficient homes could be shown to be also thermally leaky. This could be an area of further investigation in future.

## Note

1. DECoRuM (Domestic Energy, Carbon Counting and Carbon Reduction Model) is a GIS-based toolkit with the capability to estimate current energy-related $CO_{2e}$ emissions and to test the effectiveness of a number of best-practice energy-efficiency measures and low/zero-carbon technologies in homes. The background calculations of DECoRuM are performed by BREDEM-12 and SAP 2009, both of which are dynamically linked to create the model and perform the calculations. The aggregated calculation method and map-based presentation allows the results to be scaled up for larger application and assessment. To inform the model, actual home and neighbourhood characteristics are gathered from historic and current maps, on-site assessment, home-occupant questionnaires, and literature describing home characteristics based on age and typology (for more information, see Gupta (2009).

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