Evaluating the impact of low carbon communities on household energy behaviours

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ABSTRACT: This paper describes a collaborative action research based approach and emerging findings of a 3.5-year research project (EVALOC) on evaluating six Government-funded low carbon communities (LCC) in the UK in terms of their IMPACTS (on changing individual and community energy behaviours), EFFECTIVENESS (on achieving real-savings in energy use and carbon emissions) and SUCCESS (in bringing about sustained and systemic change). Action research is undertaken on both community and household levels, using a variety of research methodologies and survey instruments, including community events and household level monitoring and surveys.

To understand the impact of low carbon communities on household energy behaviours, a robust graduated measurement, monitoring and evaluation (MME) approach is applied to gather quantitative and qualitative data on energy use and practices for 88 households across UK covering two heating seasons. These households are segmented into three groups depending on their LCC intervention type (technical, behavioural and none). By using a variety of methods, we are able to discover 'what', 'why' and 'when' energy is used, and help us uncover the complexities surrounding energy practices in UK households.

The first round of MME has uncovered a number of unintended consequences associated with both technical and behavioural household interventions, such as inappropriate operation and maintenance of low carbon systems due to lack of understanding and knowledge, changes in environmental conditions and energy behaviours following fabric improvements; all of which highlight the difficult balancing act between intent and outcome. Ultimately, the research seeks to create a body of evidence to help inform future strategy implementation for meeting national CO_2 targets.

Keywords: low carbon community, post-occupancy evaluation, household energy

INTRODUCTION

The UK is committed to an 80% reduction in carbon emissions by 2050 (from 1990 levels). With household energy use accounting for more than one-quarter of all energy use in the UK [1] and the rate of growth in the domestic sector in Great Britain only at 0.85% [2], the need for low-energy retrofitting of existing homes is immediate and urgent. However, reducing energy demand in individual homes is a 'wicked' problem characterised by radically different views from stakeholders [3], changing resources, a range of physical, technical and environmental variables, socio-economic factors and the behaviours of occupants. All of these have an impact on actual energy savings, which are often lower than anticipated [4].

Whilst research into low carbon technologies (LCTs) and renewables has revealed a gap between theoretical and actual (in-use) performance [5], refurbishment programmes to reduce energy demand in homes also have the potential for other unanticipated impacts relating to many areas including population health, deterioration of the building fabric and content, as well as economic, social and cultural viability [6]. Known possible side effects within the homes themselves include indoor air quality (IAQ) problems, higher fuel prices, overheating, changes to the hygrothermal properties of the building fabric and health and safety issues such as increased fire risks [6]. In addition to these, energy efficient 'improvements' have been found to potentially result in increased energy use and carbon emissions due to the 'rebound effect'.

The impact of occupant's behaviours and their interaction with their home cannot be ignored in the expected energy savings of energy efficient measures and is widely documented [8; 9]. Moreover, recent research has found that often, there is no set pattern to the type and number of energy behaviours relating to high household energy use, therefore behaviours cannot be grouped or characterised as associated with 'high energy use' [10]. Thus the contextual data surrounding energy behaviours is critical to understanding a household's overall energy use.

Due to their familiarity with the contextual factors that shape an individual's behaviours, low carbon community groups/organisations (LCCs) are often best placed to influence and communicate energy action to individuals (downstream), as well as other community organisations (midstream) and decision-makers (upstream). Whilst there has been an upsurge in community energy action in recent years, there is a lack of robust evidence-based evaluation of the impacts and effectiveness of such programmes, on both localised energy behaviours and actual energy savings [11]. This, amongst other reasons can lead to a gap between the *intentions* and the *outcomes* of community energy actions and initiatives that ultimately affect how successful a community energy project appears to be.

This paper seeks to outline the measuring, monitoring and evaluation approach used in a current research project that focuses on establishing the impact (intended or not), effectiveness and success of low carbon community interventions on localised energy behaviours and actual energy use in existing and retrofitted homes, with the critical aim of suggesting change strategies for reducing energy use in homes.

EVALOC LOW CARBON COMMUNITIES PROJECT

Research presented in this paper is part of the ongoing EVALOC low carbon communities project, an RCUK funded research programme with the key aims of assessing and evaluating the impacts of Government-funded low carbon communities (LCCs) on individual and community behaviours and energy use; as well as the LCCs success in achieving sustained and systemic change within their community.

The MME framework developed within the EVALOC project enables the assessment of the outcomes of physical and behavioural interventions in homes, in terms of both the LCCs intentions as well as quantifying their impacts in line with national carbon reduction targets on an individual household level and works at both community and household level (Fig. 1).

The project brings together an interdisciplinary team of researchers from Oxford Brookes University and the University of Oxford to undertake an action research based approach within six case study communities across the UK. The action research is carried out on both community and household level, with a variety of research methodologies and survey instruments being used; focus groups and community events (community level research), household monitoring, occupancy feedback surveys and social network analysis (household level research).

At the household level, the impacts and effectiveness of community-led energy renovations and behaviour initiatives are evaluated through a comprehensive measuring, monitoring and evaluation (MME) study of 88 households throughout the six case study communities; split into 3 groups, A, B and C. The grouping of a household was based on the following selective criteria in order to help understand the differences in household behaviours and their motivations for consuming more/less energy across the three distinct groups, as well as the appetite for community-led energy actions:

- **Group A:** households that have received some kind of physical treatment (demand or supply side) from the LCC, as a result of Government funding
- **Group B:** households that have received some support from the LCC, such as an energy display monitor or behavioural intervention
- **Group C:** households that have had no intervention or support from the LCC, and will act as 'control'

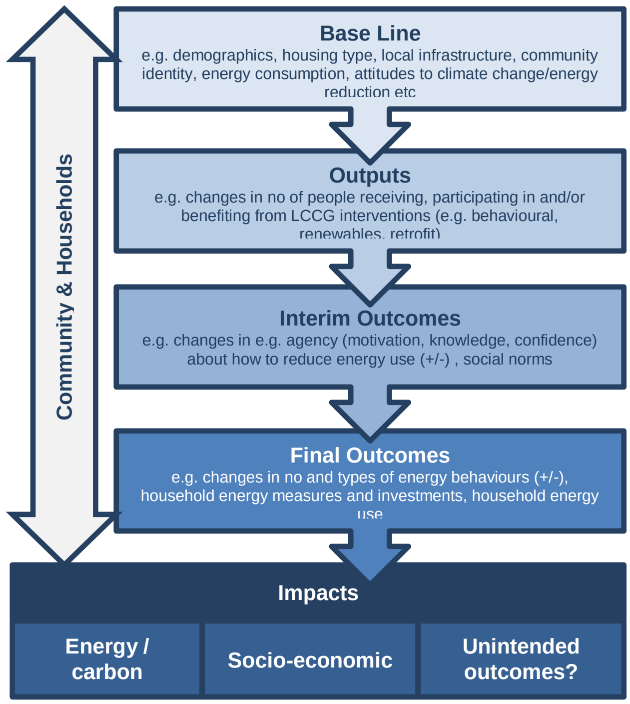

Figure 1: EVALOC overall framework.

EVALOC CASE STUDY HOUSEHOLDS

Recruiting Case Study Households

The aim was to recruit approximately 90 households across the six communities, split into the groups described above. Due to some drop-outs, the current number of participating households is 88. These are split into; 30 Group A households, 33 Group B households, and 25 Group C households. In reality, it was often difficult to recruit 'pure' samples within these groups, as a vast majority of households had 'standard' physical interventions such as double glazing and energy efficient appliances/lighting within their homes. As such, a distinction was made between 'typical' physical measures and 'intensive' physical measures such as solid wall insulation and low-carbon technologies.

Due to the objectives and varying focus of the individual case study communities, it was also impossible to recruit 'pure' Group A and B households;

with many LCCs offering both physical measures hand-in-hand with behavioural interventions. As such, there are sub-groupings within Group A and Bs.

EVALOC Household Sample Profile

The households were selected to represent, as best possible, the housing stock of the UK in terms of house and occupancy type e.g. dwelling age and type, number, age and gender of occupants etc. The focus tenure of the study is owner-occupied (no. 74 households) but a sample of social housing has also been included, notably in the communities with a high proportion of social housing.

Out of the 88 households for which data is readily available, 54 are predominantly cavity wall construction (49 of which have partial or full cavity insulation). Thirty-three are solid wall, with only three having partial internal/external insulation. The majority of households have loft insulation (to recommended levels) and double glazing. In terms of low-carbon technologies in the Group A households, there are 19 solar PV systems, 6 solar thermal systems and 5 air source heat pump systems. All households have central heating systems, with the fuel typically being gas despite two out the six communities not being on mains gas supply (other fuels being oil, coal and electricity). The vast majority of the households are naturally ventilated (but with intermittent extract or portable fans) but two Group A households have MVHR systems installed as part of their retrofit strategy.

DEVELOPING AN MME APPROACH

To add to the growing body of evidence relating to the impacts and understanding of household energy use and energy behaviours, the EVALOC team has developed and applied a robust measurement, monitoring and evaluation (MME) framework to gather quantitative and qualitative data on energy use and energy behaviours within the 88 EVALOC households.

Overall Approach

The household MME approach is designed to provide a holistic understanding of energy use and energy behaviours at an individual household level by covering the three fundamental aspects of energy use in the home; a) **the physical environment**, b) **the technical context**, and c) **the occupant**, and *assessing the interactions and relationships between them*. By both measuring and monitoring existing homes, comparative analysis of the 'sayings' and the 'doings' of the occupants, and the establishment of correlations (or not) between technical and physical household measures and the behaviours of the occupants can be undertaken. This is critical to understanding the impact of behaviour on energy use (both short- and long-term) as well as evaluating the impact of physical measures, and establishing any unintended consequences of the LCC interventions, at both household and community level.

A mixed method approach has been adopted to provide cross-tabulation of both quantitative and qualitative data. Whilst the quantitative (numeric) data provides detailed information on the actual energy use, behaviours/interaction as well as performance of the physical building, the qualitative (narrative and images) allows further probing into the reasons, understanding and motivations behind household energy use and behaviours. It was felt important to combine both building and social science methodological approaches to ensure the socio-technical aspects of household energy use were covered in depth. As such, the survey tools and techniques include building performance evaluation and energy audits, semi-structured interviews (occupancy feedback) and social network analysis. The data collection takes the form of both spot (one-off) measurements and continuous monitoring. The combination of building and social science methodologies provides a novel and robust approach to assessing community energy action, and highlights the unique added value an academic-community partnership can bring to understanding the impacts and successes of community energy action projects.

The use of 88 individual households allows us to complete indepth evidence-based case studies and provide contextual insight into household energy use, but it must be noted that as the number of cases explored is relatively small, the findings cannot be extrapolated or treated as statistical generalisations.

Elements of Study

The MME framework developed is based on studying; a) the physical aspects, b) the technical context, c) the occupant, and d) the interaction (between occupant and technical). To achieve this, six key elements of study comprise the measurement, monitoring and evaluation of:

- Energy consumption
- Internal and external environmental conditions
- User interaction with physical environment
- Occupancy
- Performance of building fabric
- Long-term performance of low-carbon technologies and on-site renewables

A graduated MME approach using a variety of survey instruments has been taken within the study, based on the grouping of the households. As Fig. 2 shows, Group Cs have least involvement; whilst Group As have whole-house monitoring systems installed in their homes to monitor energy, environmental and interaction data every 5 minutes.

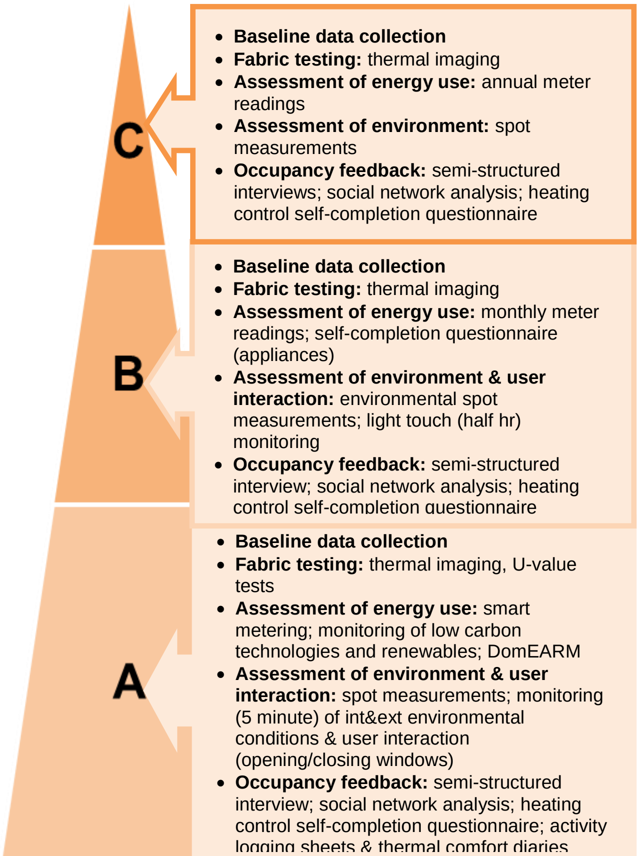

Figure 2: Graduated MME approach used in the EVALOC project.

Application of MME to EVALOC Households

The first round of MME was undertaken between May and August 2012, and involved a baseline characteristics survey of the physical and occupancy characteristics of the recruited households, a semi-structured interview that included themes such as a) heating and hot water systems, b) home improvements, c) lighting and appliances, d) general views of the home, e) thermal comfort, f) energy behaviours, g) energy displays (if applicable), h) community involvement and i) social network analysis. Spot measurements of external and internal environmental conditions and meter readings were also undertaken whilst light touch monitoring (temperature and humidity data loggers) was installed in Group B households.

Following on from the first round surveys, the whole house monitoring equipment was installed into 30 Group A households during September and December 2012, to provide a minimum of 12 months data, including two heating seasons.

FIRST ROUND MME: EMERGING FINDINGS

As a consequence of the data gathered in the first round of MME, evidence relating to the impacts and outcomes (expected and unexpected) of both physical and behavioural interventions is emerging. However, due to the early stages of analysis, these findings are yet to be corroborated and so must be considered perceived impacts and outcomes.

The following sections outline some of the outcomes and potential impacts (both positive and negative) of, first, physical interventions and latterly behavioural interventions, in relation to comfort, health, energy use and performance of building fabric measures as well as LCTs and renewables.

Physical Interventions – The Building Fabric

Using thermal imaging, expected findings such as heat loss through un-insulated (hard-to-treat) solid walls are appearing, as are improvements through wall and loft insulation (Fig. 3). However, these surveys also identified inconsistencies across the façade of homes with 'full' cavity wall insulation on more than one occasion; suggesting the need for further investigation into the overall performance of the building fabric, and potential lack of uniformity of the U-Values across the façade (Fig. 3).

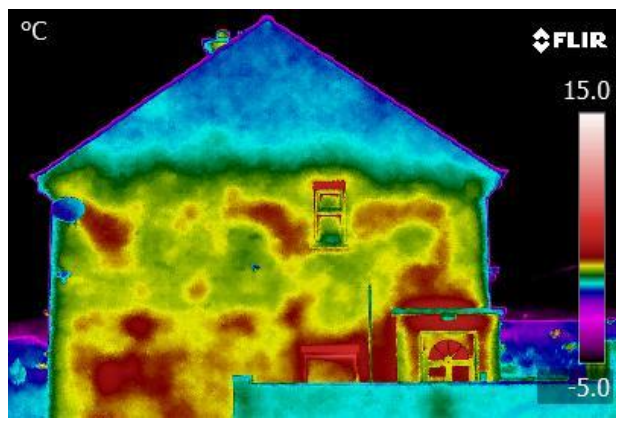

Figure 3. Inconsistencies across wall façade apparent. Note distinction across joist-line corroborating installation of loft insulation

In terms of the impact of increased insulation and air-tightness of their homes, few respondents noted a decrease in their fuel bills since the refurbishment. However, a large majority described a change to their internal environmental conditions, which appear to have a positive impact on their comfort, health and behaviours; *"We felt as if it was warmer and so we could indeed turn the radiators down a little after that time…"*. Despite this, there were examples of unintended negative consequences of increased insulation, particularly in terms of health and behaviours; *"…free insulation but since they did that*

I've started [to notice] mould on my ceiling." And; *"RF: I've got double glazing and I've wall insulation…to keep the heat from going out…RM: Then you get too hot and you have to open a window and out it goes anyway.".*

Using the emerging data from households with improved insulation and air-tightness measures, increased CO_2 levels (an indicator of poor indoor air quality) appear to be present, particularly in relation to similar households with no insulation. In addition to this, higher, but more stable (during occupancy) temperatures in refurbished households can be found. This could point to both negative and positive impacts from such physical interventions; stable temperatures can indicate better comfort levels, whilst higher temperatures could demonstrate the potential of the home to overheat (even in the winter), as well as adaptive behaviours relating to changed comfort levels.

Physical Interventions – LCTs and Renewables

Households with LCTs and renewables reported mixed views on the impact of the installations on their energy bills. However, from the monitored data, in nearly all cases, the solar PV systems are exceeding their expected output. A number of households demonstrated a lack of knowledge relating to their systems, in terms of control, and how best to use and maintain the system, but overall felt positive about their technologies; *"…you pick your heat and it stays there…there aren't any hot or cold areas anymore.".*

In terms of behaviours, the emerging findings have highlighted discrepancies between peak daily usage times by the occupants, and peak generation/performance times of their solar systems. In addition to this, whilst some occupants have reported adaptive behaviour to make the most of the 'free' electricity, in some cases the installation of LCTs and renewables appears to have changed the occupant's energy behaviours in other ways; *"…we didn't use a dishwasher for a couple of years but now we do because we've got the solar PV."* And; *"…But now with this air pump I leave all the doors in the house open…".*

During the installation of the whole-house monitoring systems, issues relating to the installation, commissioning and maintenance of various technologies have come to the fore, which suggest that some systems are potentially underperforming, and would benefit from further investigation.

Behavioural Interventions

The type of behavioural intervention ranged between communities, and as such, at this stage of analysis, key contextual cross-correlation has yet to be made. The vast majority of Group A and B households agreed that the behaviour programmes undertaken in their areas are having an impact on the wider community, and people 'like themselves'; not only in terms of energy but also social and environmental benefits, thus hinting at the 'other' benefits of LCCs to their local communities and individuals within the communities.

Throughout all communities, and household groupings, the level of concern for global warming and climate change is very high. In addition, awareness of the impacts of small energy-saving behaviours such as turning lights off when not in a room in households is high also. Yet this awareness does not appear to fully translate into sustained energy behaviour change. The reasons for this are varied, but the following factors have been provisionally identified; comfort, health, costs, the 'hassle-factor' involved as well as daily routine; *"…I just couldn't do that, I would not feel comfortable in my own home if I tried to do something like that."* And; *"I tried that [washing clothes at 30degrees] and it worked for a while but then you have to put them on a hotter wash because otherwise…eventually they do start to smell…".*

Despite this, increased awareness in some households due to their involvement in their LCC has led directly to them installing physical measures, from energy efficient appliances to solar PVs, despite being aware that they themselves would be unlikely to benefit, economically.

In relation to specific energy behaviours, among respondents who answered that they 'always close windows before turning up the heating', it has been discovered that, of those being monitored, CO_2 levels of over 1,000ppm are being achieved. Whilst unlikely to be the only reason, such a practice can contribute to poor indoor air quality in many refurbished homes and highlights the potential unintended impacts of certain energy saving advice given to/believed by individual households.

EMERGING UNINTENDED CONSEQUENCES AND IMPACTS

The emerging unintended consequences of the interventions at household level are key to understanding the 'balancing act' between intent and impacts over the long-term; the relationship between the physical performance gap (individual building, technologies and services, and behaviours) and the wide-reaching, often less tangible intentions of LCCs (community-wide social norms, socio-economic, cultural and environmental). The following Table 1 outlines some of the emerging unintended consequences of the first round of household level research.

Table 1: Positive and negative unintended consequences of interventions within EVALOC households

Positive	Negative
Improved comfort levels following building fabric improvements *(P)*	Increase in poor internal environmental conditions following building fabric improvements *(P)*
Increased positive attitude towards environmental and energy concerns *(P&B)*	Occupants not adapting habitual behaviours to suit LCTs & renewables *(P)*
Change in energy behaviour profile to suit 'free' electricity *(P&B)*	Increase/no change in energy bills following installation of physical measures *(P)*
Technical interventions (LCTs) providing kick-start to energy behaviour changes *(P)*	Adaptation of LCT and renewable systems to suit habitual behaviours (reduced comfort levels and potential unnecessary energy use) *(P)*
Physical interventions leading to increased personal capacity & knowledge *(P)*	Increased energy-intensive behaviours following installation of physical measures *(P)*
Increased personal capacity & awareness leading to installation of further physical interventions *(B)*	Larger appliances bought due to higher energy efficiency rating (but with increased energy consumption) *(B)*
Increased sharing of energy saving information within social network *(P&B)*	Over-exposure of energy-saving related advice potentially resulting in energy lethargy *(B)*
Wider community recognition for physical and behavioural measures *(P&B)*	Potential segregation of wider community (socio-economic, values & attitudes) *(P&B)*
Increased acceptability and use of advanced technologies and controls *(P&B)*	Lack of knowledge into maintenance of LCTs and renewables (potential early degradation of systems) *(P)*
B = from behavioural interventions; P = from physical interventions; P&B = from both behavioural & physical interventions	Incomplete installation of physical measures (under-performance of systems/energy savings potentially not as expected) *(P)*

CONCLUSIONS

The MME framework produced as part of the EVALOC project is enabling detailed analysis of behaviours and practices within existing homes in relation to their impacts on localised energy use. With predicted energy savings informing the economic sustainability of current funding schemes such as the Green Deal, a greater understanding of factors mediating the gap between predicted and actual outcomes is vital. By using a mixed-method approach, both the 'hard' (what and when) and 'soft' (why) data can be discovered, helping us uncover the complexities and unintended outcomes of energy behaviours and use in UK households. With the current lack of robust MME of community energy action, such data is providing unique insights into which projects work as well as establish the complexities of refurbishment programmes.

Further analysis of the data is required, however, both negative and positive consequences of household interventions are being identified. Whilst many are indicative of known, but little researched unintended consequences of physical interventions on health, internal environmental conditions and energy use, other emerging outcomes relate to wider community impacts such as increased awareness and concern. The preliminary findings substantiate the need for increased knowledge, understanding of and adaptation of behaviours in line with installed technologies in order to maximise energy use reductions. Yet they also reveal the difficulties in achieving long-term changes to energy behaviours in the face of many other socio-cultural, environmental, and economical factors, at both household and community level. Ultimately, the research seeks to create a body of evidence to help LCCs understand the impacts of their interventions as well as inform future policy formulation and the implementation of community energy strategies.

ACKNOWLEDGEMENTS

The authors are grateful to RCUK's Energy Programme for financially supporting this project under Grant reference: RES-628-25-0012. The authors would also like to acknowledge the EVALOC research team, in particular Tara Hipwood. In addition to this, thanks must go to the EVALOC case study communities and individual households for their support and continued interest in participation within the research project.

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