Action research approach for gaining, and providing, feedback on domestic energy use to understand occupant behaviour, perceptions and expectations

Professor Rajat Gupta[1] and Dr Sarah Darby[2]
[1]Low Carbon Building Group, School of Architecture, Oxford Brookes University, Oxford OX3 0BP
Email: rgupta@brookes.ac.uk
[1]Low Carbon Futures, Environmental Change Institute, University of Oxford, Oxford OX1 3QY
Email: sarah.darby@ouce.ox.ac.uk

The paper outlines and discusses an integrated action research approach for gaining energy feedback from households and providing it to them, through an RCUK/ESRC project on evaluating low carbon communities (EVALOC). To meet the UK Government's 80% CO_2 reduction target by 2050, existing UK housing stock will need to undergo deep, rapid and large-scale retrofit in order to drive down energy consumption while maintaining or improving the quality of life provided to the occupants. It is recognised that success or failure of such low energy housing at achieving its design performance will not be independent of its occupants. To support the empirical understanding of the impact of occupant diversity and behaviour within low energy housing performance, a transition from classical scientific methods should be encouraged, in which researchers shift from a focus on detached observation to a more real-world based *action research* approach, in which they become participants as well as observers. The project aims to investigate the 'why' as well as the 'what' and 'how' of energy performance through this approach, and the paper outlines likely strengths and pitfalls of participant observation and analysis.

The 3-year ESRC funded EVALOC project has been developed with the aim of evaluating the impacts, effectiveness and long-term success of Government-funded low carbon communities on localised energy behaviours. Both authors are investigators on the project. The action research approach includes post-occupancy evaluation studies of low-carbon retrofitted houses from a technical and occupants' perspective, combined with energy display trials and feedback to occupants in 60 households, across six low carbon communities. Findings from the post-occupancy evaluation studies of UK houses will be compared with recent energy display trials to understand the challenges and complexity of using feedback in research. Ultimately such an evaluation of user perceptions and behaviour through feedback from, and to, occupants could be used to inform briefing and solutions (related to design, materials, construction, installation and commissioning practices) for low-carbon refurbishment of existing homes.

1. Introduction

Household energy consumption accounts for more than a quarter of all energy use in the UK, and a third of this energy is wasted in a typical household (POST, 2005). Reducing energy demand and carbon emissions in the domestic sector has a major role in dealing with climate change, fuel poverty and working towards UK's energy security .The domestic sector alone needs to reduce direct CO2 emissions by 29% on 2008 levels by 2020 to meet targets set by the Climate Change Act (LCC- IGT, 2010). UK's inefficient housing stock and low demolition rates mean that constructing all new homes to 'zero carbon' standards from 2010 to 2050 will only reduce housing emissions by 5% (CLGC, 2008). Given that at least 75% of the homes that will be standing in 2050 have already been built, if a significant reduction is to occur, then it will be necessary to undertake extensive refurbishment (retrofitting) of the current housing stock to improve the fabric as well as the energy-consuming services within domestic properties (Beddington, 2008; Gupta, 2009).

To address this, there are large scale programs of retrofit installation currently in various stages of preparation or implementation within the UK to demonstrate what solutions can be implemented with different designs, materials or technologies. In 2009 the UK government it announced its 'Great British Refurb' campaign in order to help people do full energy refurbishments of their homes. 'Warm homes, greener homes' strategy closely followed, which aimed that by 2015, every household should have loft and cavity wall insulation and by 2020, up to 7 million homes more substantial improvements such as solid wall insulation or renewable energy technologies (DECC, 2010). More recently Government's Technology Strategy Board has awarded funding to 86 successful applicants covering ~119 properties across the UK, as part of their Retrofit for the Future programme. The aim of this initiative is to drive innovation in 'whole house' retrofitting of poor performing dwellings using a multiple systems approach to reduce the carbon emissions emitted through each home by 80% or more. It is envisaged that the innovative approaches demonstrated through this programme could be scaled up, rolled out and copied, cost- effectively and in a widespread fashion.

Despite the increased impetus, retrofitting (or refurbishment) alone, of course, does not guarantee low-carbon results from a building or dwelling, even if it is carried out to a high standard. As a substantial body of research now shows, occupants use buildings in many ways. Not only does this lead to energy consumption that can vary by a factor of three or more in identical homes (Gram-Hanssen, 2010); it also means that the actual energy performance of a building often falls below predicted performance (Stevenson and Rijal, 2010). Post-occupancy evaluations (POE) have offered a much richer picture of energy use in buildings than is available from a purely technical approach (Gupta and Chandiwala, 2010), and POE plays an important role in the EVALOC project, described below.

Analysing the many factors that lead to a particular carbon outcome from a household is a massive task, and one which can, even so, only give a limited account of a dynamic process. We do not attempt it here. We do however examine one practice that has been shown to influence energy-use and the development of tacit knowledge - the use of feedback on consumption. Effective occupants' feedback provides objectivity and leads to action and insight improving the performance of the studied building as well as the services of the people involved in the building project and the wider knowledge base (Leaman et al, 2010). We also discuss the broader role of feedback in research and in the development of a community approach to energy, using the EVALOC project as an example of how these ideas are being tested through an action research approach in which expert and non-expert knowledge are developed together. Both authors are investigators on the project. To improve the uptake and effectiveness of household energy efficiency and low-carbon interventions, it is essential and inevitable to address this current gap in knowledge.

2. EVALOC project and action research approach

The EVALOC project brings social science and building science-based disciplines together to assess, explain and communicate the changes in energy use due to community activities within six selected case study projects under the Department of Energy and Climate Change's (DECC) Low Carbon Communities Challenge (LCCC), which is a government-supported initiative to transform the way communities use and possibly even produce energy and build new ways of supporting more sustainable living. These LCCC projects are evaluated 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).

Within this broad aim, we have five core research questions:

- How can community-based organisations best monitor and communicate their own effectiveness at energy demand reduction, and learn from their work? What are the limits and barriers?
- What are the effects and impacts of the LCCC interventions on behaviour change, energy use, and CO2 reductions, and how sustainable are they?
- How useful is DECoRuM for communities and policy makers in measuring, tracking, visualising and communicating CO2 savings to communities?
- How are energy displays used in a social context, and how can they be used to best effect to raise awareness and change practices?
- What is the role of social networks in promoting or suppressing the communication and take-up of new energy technologies, and how far do these interconnect with local community networks?
- What is the role of cross-learning within a broad 'community of interest', for energy-related change?

The EVALOC project was conceived as a means of assessing short- and longer-term developments in these six British communities that had been funded as Low Carbon Communities (LCC). Over a period of three years, it is also tracking and analysing what happens beyond the early stages of LCC funding (which lasted for nearly two years (2009-2011) and is now over), as the communities attempt to develop their material and social resources and their knowledge. Crucially, as the project involves action research, the EVALOC researchers are taking part in these developments at the same time as it investigates them. In this, the project is operating in some ways along the lines set out by Callon, Lascoumes and Barthe (2001) in their advocacy of hybrid forums where expert or 'secluded' researchers work together with non-expert or 'wild' researchers to develop useful and actionable knowledge and, at the same time, effective and inclusive decision-making processes for living in an uncertain world. The bid was developed in consultation with representatives from the communities, each community is represented on the project advisory group, and the work is discussed and negotiated at each stage. This involves great attention to detail on the part of the professional and 'lay' researchers, and negotiations on what is expected from each side in terms of time, effort, finance and other resources.

Some parts of the work are relatively controlled - for example, the thorough monitoring and post-occupancy evaluations of retrofitted homes, and the investigations into a small group of householders who use consumption feedback displays. For the first time, urban-scale energy and carbon mapping tools such as DECoRuM (Domestic energy, carbon-counting and carbon-reduction model) is used as a visual monitoring tool to provide real-time disaggregated feedback on energy consumption and energy reduction both on a household and community level. The consequent effect on inhabitants' habits, behaviour and practice, will be investigated. Others are more open-ended, such as the exploration of how knowledge and know-how are transmitted through social networks, and the organisation of community events followed by evaluation of their impact.

Such research enquiries are expressed through four inter-related work packages (WP).

- *WP1* focuses on action research with communities involving toolkit development and testing.
- *WP2* is about measuring, monitoring and mapping the actual environmental performance of low carbon communities, using monitoring equipment, post-occupancy evaluation techniques and a web-based monitoring tool.
- *WP3a* helps communities use their consumption and generation feedback to work towards low-carbon goals. It is linked with WP3b to facilitate sharing of results and reflection through social and community networks within and across communities.
- *WP4* focuses on the exchange of knowledge between different communities, which include the six selected communities as well as other community groups working on energy reduction. It also covers dissemination of the project findings through expert workshops, policy-relevant papers and conferences.

Figure 1 below shows the overall conceptual framework of the project and how the various work packages fit in with the overall theme of the project, along with their respective outputs.

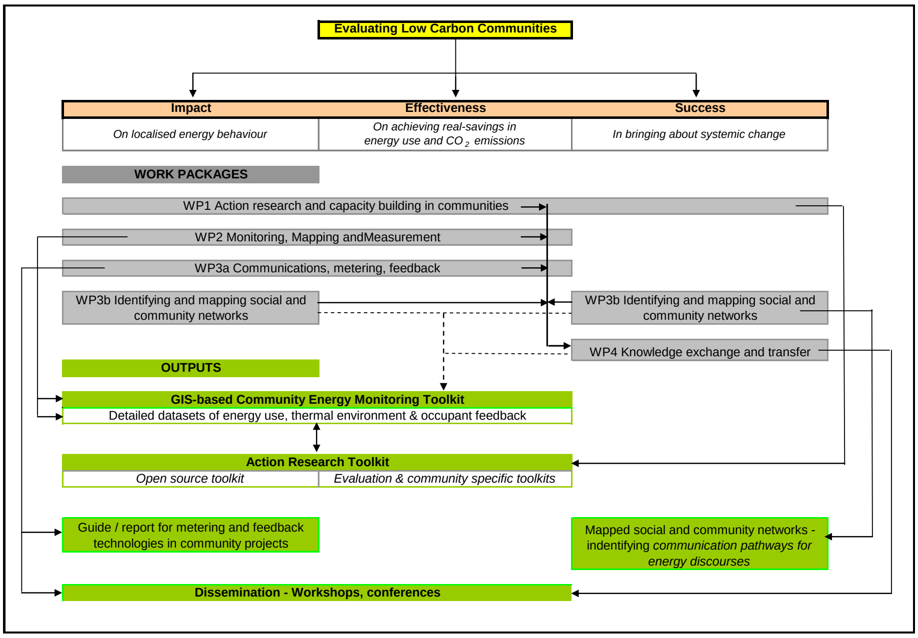

Figure 1 Conceptual framework of EVALOC project

3. Feedback and occupant behaviour in housing: creating a common language

The relationship between environment and behaviour in and around buildings has been a part of research that stretches back into the 1980s. In an attempt to link the more practical assessment of the physical performance of the building with occupants' behaviour and perception of comfort a series of approaches have emerged (Zimring and Werner, 1985, Kantrowitz, 1985) with the 'interactive adaptivity' socio-technical approach advocated by Cole et al (2008) outlining the debate. The latter recognizes communication and dialogue between inhabitants and elements as two dynamic and adaptive processes, necessary to achieve optimal building performance and adaptation into changing conditions. As such, this relation is influencing each other responding to inhabitant knowledge and action, and enhancing indoor environmental quality from the standpoint of the inhabitants.

Although internationally there has been research in housing regarding the relation between the user behaviour and the physical performance of the building (Andersen et al., 2009, Keller-Olaman et al., 2005), in the UK the occupant feedback methods related to energy use and behaviour remain relatively underdeveloped based primarily on satisfaction surveys and the occasional physical monitoring exercise (Stevenson and Rijal, 2010; Gupta and Chandiwala, 2009). Action research takes us into a new territory in terms of methods and analysis for occupant feedback surveys (POE). With its focus on change and process, as well as treatment of those involved in the project as research partners rather than objects of research, and with its ability to address the 'why' as well as the 'what' of energy performance, action research is particularly well suited to the demands of energy research in communities. Action research involves working interactively at both community and household level, in order to develop and test a 'toolkit' to empower communities to self-monitor, evaluate and communicate their moves in the direction of becoming low carbon communities. This will build on the experience of the professional researchers, and also on the experience and tacit knowledge in each community.

The social and cultural nature of energy demand may mean effective interventions are specific to a time and place, not universally applicable (Wilson and Dowlatabadi, 2007). At the same time, the nature of communities means that we are likely to see emergent properties of each. Theory based on ideas of individual agency does not prepare us for this. Given that each community is different from the others in many dimensions, and that 'secluded' and 'wild' researchers each have their own vocabularies, we clearly need some common language with which to evaluate and communicate experiences and developments in the course of the project. Hence the need to design plenty of interaction into the work, as well as intensive data-gathering. The plan is to develop an EVALOC toolkit with the help of a series of workshops with local residents using gaming techniques, visits to other low carbon communities, encounters with policy makers and energy providers and dissemination events.

We also see the use of 'feedback' as a means of developing a common language. The POE studies in selected houses is a form of feedback on the outcomes from physical changes to the housing fabric and/or low-carbon technologies, as is the use of DECoRuM to visualise and communicate the energy status of buildings. In order to map the occupants' behaviour and reactions against the new low carbon reality they experience in their house the use of feedback plays a key role. Further work programmes aim to help the communities use consumption and generation feedback from meters and display panels to work towards their goals, and to facilitate sharing of results and reflection through social and community networks.

4. Post-occupancy evaluation: gaining feedback from occupants on energy behaviours

The last few years there has been an increased interest in building performance assessment and a number of definitions of post-occupancy evaluation have emerged, all generally in line with the statement of Preiser et al (1988) that post occupancy evaluation is the systematic and rigorous way of assessing the buildings after they have been built and occupied for some time. Although housing has the largest number of buildings as a typology (accountable for 27% of carbon dioxide emissions in the UK) it has been underestimated in terms of post-occupancy evaluation mainly because of its highly diversified form in relation to relatively few users per dwelling (Stevenson, 2009). Findings from the recently-completed EPSRC/Carbon Trust funded CaRB project have re-confirmed that valuable new insights can be gained by collecting hard data, i.e. measurement, monitoring, questionnaires and surveys, in existing buildings (Lomas, 2009). In fact there is ample scope for learning in the average home, where there is huge variability in terms of the acquisition, default setting and day-to-day use of heating systems and appliances, and where occupant 'behaviour' is central to consumption levels (Lutzenhiser, 1993).

However the application of building performance evaluation in retrofitted and new low carbon housing has pointed out interesting findings on the importance of advanced feedback methods in the assessment and reduction of energy consumption. Gupta and Chandiwala (2010) stressed the importance of pre-refurbishment occupant feedback to measure a priori the factors that directly or indirectly impact energy use within the dwelling, engage the occupants with the retrofit process and generate energy awareness. Stevenson and Rijal (2009) developed an extended feedback methodology embracing user interactions and perceptions with building interfaces alongside physical monitoring indicating the importance of understanding occupants' behaviour at the design stage and communicating operational issues to them at the handover stage. A real time location system with ultra-wideband radio frequency technology was used in the case of an eco-house POE to track the occupancy patterns within the space and quantify the correlation between domestic energy consumption and occupant behaviour (Spataru et all, 2010).

Traditionally, building feedback was based on either qualitative evaluation of user behaviour and perception or quantitative physical monitoring, while nowadays these methods tend to blend and adopt a real-world based action research approach. A multi-modal method is being used in EVALOC for gathering information of the case of housing dwelling(s) that includes post construction fabric testing,

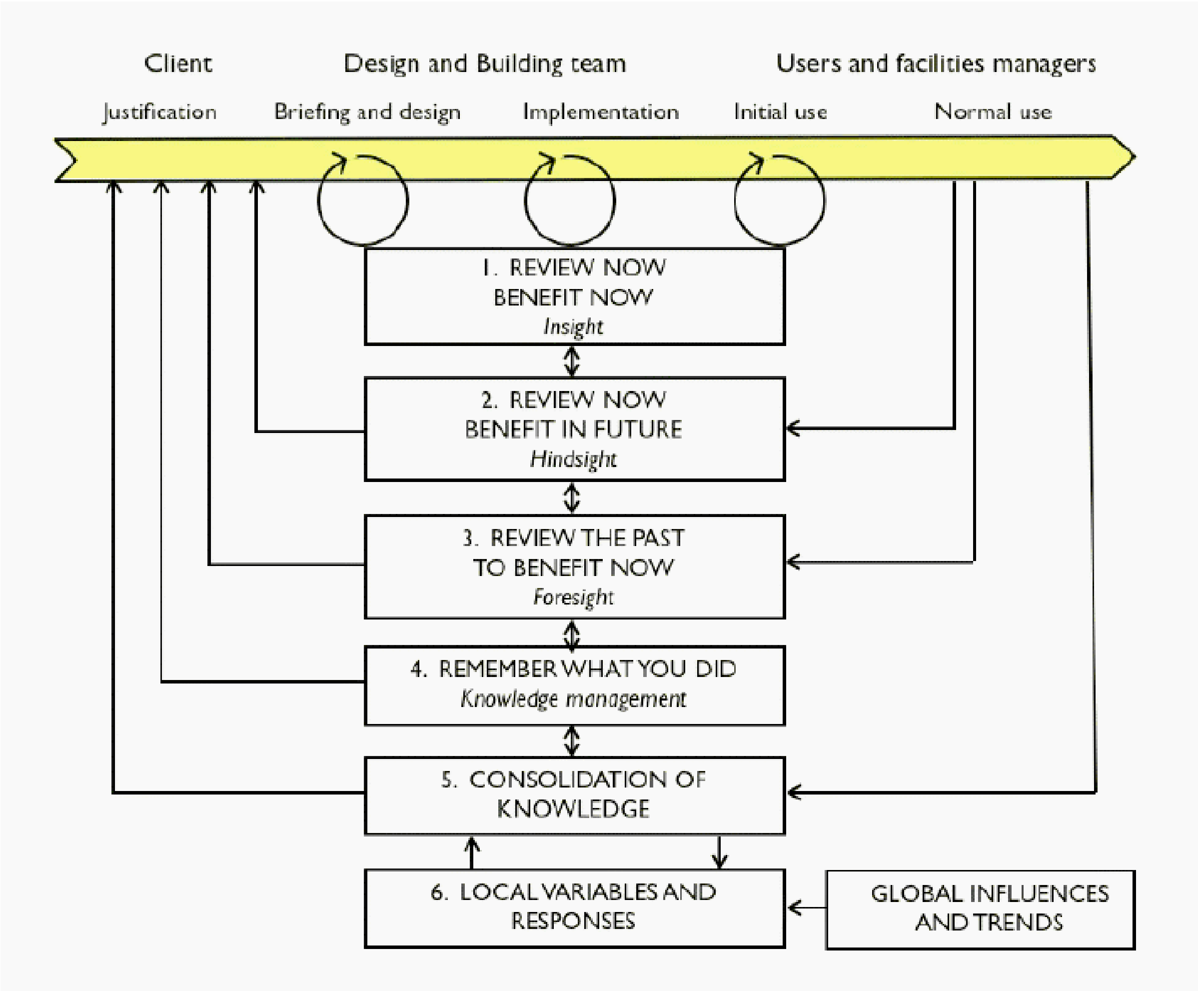

Figure 1: Layers of building feedback. Source: Leaman et al, 2010

energy assessment and benchmarking, in-use physical monitoring and a survey on the occupants' energy use and behaviour (Figure 2). Depending on factors such as the type, construction stage, availability of resources, demographics and the main research focus, some methods could be omitted while complimentary ones could be added. The methodological triangulation of the findings from these techniques highlight key issues and improvements concerning energy usage and occupants behaviour.

Building performance evaluation	Technique	Pre-refurbishment	Post-refurbishment
Post-construction fabric testing	Infrared thermography (external façade, openings, corners, junctions)		
	Co-heating test		
	Air-pressure testing (air permeability rate and pathways of air leakage)		
	Photographic survey		
Energy assessment and benchmarking	CIBSE TM22 Energy Assessment approach		
	Degree day analysis, control charts		
	Benchmarking energy use and CO_2 emissions		
	Detailed energy survey		
In-use measurement and monitoring of the physical environment	Delivered energy (gas, electricity)- weekly/10-minute/smart metering		
	Detailed metering-appliance energy using plug-in meters/whole-house kit		
	Detailed metering-domestic hot water using heat meter / whole-house kit		
	Water consumption		
	Internal temperature, lighting and humidity – living rooms / bedrooms / hall		
	Air movement using anemometer		
	External temperature, lighting, humidity, wind speed, solar intensity (weather station)		
	CO2 levels (internal air quality)		
	Daylight factor measurements using lux meter		
	MVHR system – electricity use of pump and air flow rate		
	Performance of low/zero carbon technologies - heat pump, micro-CHP, solar PV, solar thermal, micro-wind,		
Occupant feedback survey	Questionnaire surveys		
	Open-ended semi-structured interviews - occupants		
	Open-ended semi-structured interviews – design and build team		
	Activity log sheets of occupants – logging occupants activities		
	Heating schedule diary		
	Thermal comfort diary		
	Appliance energy usage questionnaire		
	Field observations of user behaviour		
	Occupants' video diaries		
	Focus groups		

Building performance evaluation	Technique	Pre-refurbishment	Post-refurbishment
Post-construction fabric testing	Infrared thermography (external facade, openings, corners, junctions)	×	×
	Co-heating test		×
	Air-pressure testing (air permeability rate and pathways of air leakage)	×	×
	Photographic survey	×	×
Energy assessment and benchmarking	CIBSE TM22 Energy Assessment approach	×	×
	Degree-day analysis, control charts	×	×
	Benchmarking energy use and CO_2 emissions	×	×
	Detailed energy survey	×	×
In-use measurement and monitoring of the physical environment	Delivered energy (gas, electricity) – weekly/ten-minute/smart metering	×	×
	Detailed metering – appliance energy using plug-in meters/whole-house kit	×	×
	Detailed metering – domestic hot water using heat meter/whole-house kit	×	×
	Water consumption	×	×
	Internal temperature, lighting and humidity – living rooms/bedrooms/hall	×	×
	Air movement using an anemometer	×	×
	External temperature, lighting, humidity, wind speed, solar intensity (weather station)	×	×
	CO_2 levels (internal air quality)	×	×
	Daylight factor measurements using lux meter	×	×
	Mechanical ventilation heat recovery (MVHR) system – electricity use of pump and air flow rate		×
	Performance of low/zero-carbon technologies – heat pump, micro-combined heat and power, solar photovoltaics, solar thermal, micro-wind		×
Occupant feedback survey	Questionnaire surveys	×	×
	Open-ended semi-structured interviews – occupants	×	×
	Open-ended semi-structured interviews – design-and-build team		×
	Activity log sheets of occupants – logging occupants activities	×	×
	Heating schedule diary	×	×
	Thermal comfort diary	×	×
	Appliance energy usage questionnaire	×	×
	Field observations of user behaviour	×	×
	Occupants' video diaries		×
	Focus groups		×

Figure 2 Techniques for measurement, monitoring, and occupant feedback during pre- and post- refurbishment of dwellings. Source: Gupta and Chandiwala (2010)

Figure 3 relates the occupant feedback survey techniques (given in Figure 2) and associated data to be collected within a household and at a community level.

Level of application	Feedback technique	Time of implementation	Data collected
Household	Self-completion questionnaire	Pre and post retrofit, once every heating season	Occupant satisfaction on a range of aspects- temperature, light, noise, air quality, controls
	Semi-structured Interview	Pre and post retrofit, once a year	Extended understanding on occupant satisfaction, positive and negative aspects of the house
	Walkthrough	Post retrofit, once a year	Emerging issues, key problems and any external factor which may influence strategies
	Activity log sheet	Pre and post retrofit: seasonal-weekly pattern	Influence of measures on occupants behaviour over a certain time duration, identification of discrepancies between individuals perception and requirements
Community	Focus group	Post retrofitting	Insights and experiences stimulated through interaction with householders who have experienced retrofitting

Figure 3 Occupant feedback techniques correlated with their applicability level, stage of implementation and type of data collected.

These techniques are complimentary to (forensic) photographic and thermographic surveys, in-use monitoring and energy assessment surveys. Some of the key occupant feedback techniques used in the EVALOC households and communities are described below:

Self-completion questionnaire

The questionnaire is a quick and thorough way of obtaining feedback data on building performance through a self-completion document and can be applied during the different stages of a building retrofit. It urges the occupants to think about a range of criteria related to their comfort levels and the internal environment of the house within a structured format which is easy to comprehend (Schwarz and Oyserman, 2001) and allows for comparisons to be made. Figure 3 shows a custom-made questionnaire developed for the TSB Retrofit for the Future case study buildings (Gupta and Chandiwala, 2010).

QUESTIONNAIRE SURVEY

OXFORD BROOKES UNIVERSITY

The survey is being conducted to help with future to help with future planning and design of buildings. All responses will be anonymous and the information collected will be treated as completely confidential by the survey team.

Name:		Sex: M / F	Location in the house:
Date:	Time:	Age:	

Section A: Occupancy

Number of occupants:

1. How long do you tipically spend in your house each week day? (hours) <4 / 4 to 8 / 8 to 12 / >12

2. How long do you tipically spend in your house each weekend day? (hours) <4 / 4 to 8 / 8 to 12 / >12

Section B: Comfort

3. How do you feel the temperature at this time?
Much too warm / Too warm / Comfortably warm / Comfortably neither warm nor cool / Comfortably cool / Too cool / Much too cool

4. I would prefer to be:
Much cooler / A bit cooler / No change / A bit warmer / Much warmer

5. How do you find the air movement in your house at this time?
Very high / High / Slightly high / Neither high nor low / Low / Very low

6. How do you find the lighting level at your house at the moment?
Very bright / Bright / Slightly bright / Neither bright nor dim / Slightly dim / Dim / Very dim

7. How do you find the noise in the surrounding areas?
Very noisy / Noisy / Slightly noisy / Neither noisy nor quiet / Slightly quiet / Quiet / Very quiet

8. How would you describe the air quality in your house at this time?
Very bad / Bad / Slightly bad / Neither bad nor good / Slightly good / Good / Excellent

9. At this time, how would you rate your overall comfort in your house? Considering all the above factors
Very bad / Bad / Slightly bad / Neither bad nor good / Slightly good / Good / Excellent

10. Clothing - tick all that apply
Short sleeve/blouse / Long sleeve shirt/blouse / Vest / Trousers/long skirt / Shorts/short skirt / Dress / Pullover / Jacket / Long socks / Tights / Tie / Boots / Shoes / Sandals

11. Activity level - What have you been doing in the last 15 min
Sitting (passive work) / Sitting (activework) / Standing relaxed / Walking indoors / Walking outdoors / Other(specify)................................

Figure 4 Occupant questionnaire survey form. Source: Gupta and Chandiwala (2010)

Interviews

Semi-structured interviews are used as a complementary and more 'qualitative tool' of mapping the reaction and perception of the occupants on their building low carbon features allowing them to contemplate and express themselves in a less restricted and open-ended framework. It is used to reveal not only the 'what' but also the 'why' and 'how' thus any unpredicted behaviour or system failure can be easily noticed and further justified.

Walkthrough

A whole house walkthrough ideally follows an occupant interview in order to identify and resolve emerging issues with retrofitting improvement. It acts as a 'spot check' on low carbon retrofitting and system elements, control interfaces and occupants' perception and actual use of space.

Activity logging sheets

The activity log sheets are used provide detailed information on occupants daily activities through the completion of a simple form. Occupants complete logging sheets for activities (eg. pattern of using heating system), occupancy levels and thermal comfort diary (Figure 3) approximately 3 times a day. The on-going logging of activities 'before' and 'after' retrofitting helps to understand the effect of low-carbon retrofitting on user behaviour.

Focus Groups

A focus group acts a form of interview between a trained researcher and a small group of occupants. It aims to facilitate an interactive discussion where participants are free to express their opinion, expectations and experiences gained through a certain occupancy period and talk with other group members.

perception of comfort, satisfaction, behaviour and expectations are combined with assessment of existing energy consumption and physical in-use monitoring, to inform both future briefing and solutions for achieving deep cuts in CO_2 emissions on a community level.

5. Energy display trials: providing energy use feedback to householders

Besides *gaining* feedback from occupants, there has been much recent research interest in the effects of *providing* better feedback to energy users on the scale, cost and impact of their usage, mostly focusing on real-time electricity displays. Clear real-time information has been associated with substantial reductions in usage compared with controls in the range 4-15%, mostly through raised awareness of what had been largely invisible (Darby 2006, 2010a and b; Ehrhardt-Martinez, Donelly and Laitner, 2010). The size of the range indicates that care is needed in interpreting and extrapolating findings. For example, the higher figures for savings typically come from small-scale studies with relatively motivated participants; advice accompanying the feedback also tends to increase the likelihood of savings. Evidence on the duration of savings is mixed but mostly positive (Ehrhardt-Martinez et al., op.cit.). Again, findings need to be interpreted in the light of the specific conditions of each trial. Overall, it is fair to conclude that feedback is necessary for effective learning about 'invisible' energy use, although it is often not sufficient. Hargreaves, Nye and Burgess (2010) and Van Dam, Bakker and Van Hal (2010) contribute valuable insights from their recent studies of home energy monitors in use, demonstrating how learning from household-level feedback is essentially a social exercise, within and sometimes beyond the household; that some householders are much more disposed than others to learn from displays, that one size (or design) does not fit all, and that for monitors to be effective, a deeper understanding of social factors, usability, and interaction design research is needed. In EVALOC, the aim is to build on earlier quantitative and qualitative studies by evaluating the use of energy displays in a community context. We aim to learn how households are using different types of energy displays, and also to track informal learning from energy feedback that goes on through word of mouth, through social network analysis (Carrasco et al., 2008).

6. Feedback in housing and energy policy: complexity and challenges

The multidisciplinary approach of POE combining empirical fieldwork with behavioural studies and physical measurements makes its outcomes beneficial for a series of cases especially under the pressure of carbon reduction targets and complex building technologies. Insight from the post-occupancy feedback helps to fine tune the dwelling performance and reduce energy consumption and its key benefits could be summarised in the following:

- Improve performance of the dwelling,
- Contribute to a wider knowledge base by helping architects, building managers, developers to improve their buildings and also occupants to understand the buildings the work or live in and efficiently 'use' them.

In case of community carbon reduction initiatives, the simplicity of a direct feedback mechanism demystifies the complexity of low-carbon technologies and gives the inhabitants a clear view of the impacts that their actions combined with the technological and design features may have with the energy performance of their house. This may also affect the extent of rebound effect in post-retrofitted dwellings. On a wider angle, the key lessons inform low-carbon buildings design in terms of briefing, materials, construction and commissioning processes having positive implications for large scale low carbon refurbishments and new low carbon homes helping to close 'the feedback loop' between the design aspiration and reality.

Research has highlighted the importance of having feedback mechanisms on the energy performance of a building, e.g. real-time energy consumption in order to inform and influence the inhabitants' behaviour. In the domestic setting, it has been shown that the provision of direct feedback can influence the awareness of the inhabitants and lead to a reduction of 5-15% (Darby, 2006) The establishment of a dual feedback indicator addressing both the inhabitants as well as the research community could lead to a direct reduction of energy consumption from the part of the users as well as the dissemination of learning to the wider design community.

In an ideal world, all participants in a built environment are guided by the information that they want and need in order to provide comfort and amenity with minimal environmental impact - and they are not inconvenienced with information that they do not want, that is misleading or confusing, or that breaches agreed conventions for privacy. Although housing may seem a fertile ground for the application of energy consumption feedback, an action research approach can face significant barriers when it is so closely linked with the individual's private life. Despite the benefits that they may have with the reduction of their energy bills and the increase of their comfort levels participants' enthusiasm for action may be limited by the fact that personal data are being accessed, processed and benchmarked.

Keeping in line with official ethics procedures where the methodological, technical and ethical aspects of the project as well as the expertise of the research team involved are approved is the one part of the solution. On the other side the willingness of building inhabitants both to accept and engage the feedback 'give and take' is of key importance. While the EVALOC research is approved by the ethics committees of both universities, we are aware that there are sensitivities about making energy-related data such as actual energy consumption of buildings publicly available. The emphasis is on using feedback data for the benefit of those directly affected, only making it public with their consent, and anonymising any that is published.

7. Conclusion

In this paper we have set out an action research approach to evaluating the use of energy in communities that respects the characteristics of different communities and tries to work with them. It represents a move away from individualistic methodologies and over-reliance on expert knowledge, and towards a more coherent view of the realities of daily social and individual practices and the development of tacit knowledge. Action research is, however, far from straightforward and entails frequent negotiation and adjustment. We have tried to show how the use of feedback at a number of levels may be used in developing a shared language for this type of research, based on experience and 'reality checks'. This matters not only for the conduct of the research, but for making the outcomes as useful as possible: for example, informing briefing and solutions (related to design, materials, construction, installation and commissioning practices) for low-carbon refurbishment of existing homes.

8. Acknowledgements

The authors acknowledge gratefully the support of the Economic and Social Research Council (ESRC), which funds the EVALOC project (Grant reference: RES/628-25-0012) under the RCUK Energy and Communities Programme.

9. References

Andersen, R. J., Toftum, J. and Olesen, B. W. (2009) 'Survey of occupant behaviour and control of indoor environment in Danish buildings',*Energy and Buildings,* 41(1), 11-16.

Beddington, J. (2008). Managing energy in the built environment: rethinking the system. *Energy Policy* 36, pp.4299-4300.

Bordass, B. and Leaman, A. (2005) 'Making Feedback and Post Occupancy Evaluation routine 1: a portfolio of Feedback techniques',*Building Research & Information,* 33(4), 347-352.

Callon, M., Lascoumes, P., and Barthe, Y. (2001) *Acting in an uncertain world. An essay on technical democracy,* Cambridge: MIT Press.

Carrasco, J. A. *e. a.* (2008) *Agency in Social activity Interactions: The Role of Social Networks in Time and Space*, Dutch Royal Geographical Society.

Cole, R., Robinson, J., Brown, Z. and O'Shea, M. (2008) 'Recontextualizing the notion of comfort', *Building Research & Information,* 36(4), 323-336.

Committee on Climate Change (CCC) (June 2011) *Meeting Carbon Budgets - 3rd progress report to parliament,* CCC [online], available: http://hmccc.s3.amazonaws.com/Progress%202011/CCC%20Progress%20Report_Interactive_2.pdf [accessed 06.07.2011].

CLGC- Communities and Local Government Committee (2008), Existing Housing and Climate Change, Seventh Report of The House of Commons -Session 2007–08.Available at http://www.publications.parliament.uk/pa/cm200708/cmselect/cmcomloc/432/432i.pdf (27th August , 2011).

Crosbie, T. and Baker, K. (2009) 'Energy-efficiency interventions in housing: learning from the inhabitants', *Building Research & Information,* 38(1), 70-79.

Darby, S. (2006) *The effectiveness of feedback on energy consumption: a review for Defra of the literature on metering, billing and direct displays*, Oxford: Environmental Change Institute.

Darby, S. (2010a) *Literature review for the Energy Demand Research Project,* Ofgem (Office of Gas and Electricity Markets) [online], available: http://www.ofgem.gov.uk/Sustainability/EDRP/Documents1/SD%20Ofgem%20literature%20review%20FINAL%20081210.pdf [accessed

Darby, S. (2010b) 'Smart metering: what potential for householder engagement?', *Building Research & Information* 38(5), 442-457.

Department of Energy and Climate Change (DECC) (2010a) *Digest of United Kingdom Energy Statistics (DUKES)*, London.

Department of Energy and Climate Change (DECC) (2010b) *Warm Homes, Greener Homes: A Strategy for Household Energy Management* London.

Department of Energy and Climate Change (DECC) (2011) *The Carbon Plan*, London.

Gram-Hanssen, K. (2010) 'Residential heat comfort practises: understanding users', *Building Research & Information,* 38(2), 175-186.

Guerra, S. (2010) *Actual energy consumption in dwellings, The effect of energy performance regulations and occupant behaviour,* Amsterdam: IOS Press BV.

Gupta, R. (2009) 'Moving towards low-carbon buildings and cities: experiences from Oxford, UK', *International Journal of Low-Carbon Technologies,* 4, 159-168.

Gupta, R. and Chandiwala, S. (2010) 'Understanding occupants: feedback techniques for large-scale low-carbon domestic refurbishments',*Building Research & Information,* 38(5), 530-548.

Hargreaves, T., Nye, M., and Burgess, J. (2010) 'Making energy visible: a qualitative field study of how householders interact with feedback from smart energy monitors ', *Energy Policy,* 38, 6111-6119.

Intergovernmental Panel on Climate Change (IPCC) (2007) *Climate Change 2007: Synthesis Report* [online], available: http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_synthesis_report.htm [accessed 20.12.2010].

Kantrowitz, M. (1985) 'Has environment and behavior research 'made a difference'?', *Environment and Behavior,* (17), 25–46.

Keller-Olaman, S. J., Eyles, J. D., Elliott, S. J., Wilson, K., Dostrovsky, N. and Jerrett, M. (2005) 'Individual and neighborhood characteristics associated with environmental exposure: exploring relationships at home and work in a Canadian city ',*Environment and Behaviour,* 37, 441-464.

Leaman, A. and Bordass, W. (2001) 'Assessing building performance in use: the Probe occupant surveys and their implications', *Building Research & Information,* 29(2), 129-143.

Leaman, A., Stevenson, F. and Bordass, B. (2010) 'Building evaluation: practice and principles', *Building Research & Information,* 38(5), 564-577.

Lomas, K. J. (2009). Carbon reduction in existing buildings: a transdisciplinary approach. *Building Research and Information* 38 (1), pp.1-11.

Lutzenhiser, L. (1993). Social and behavioural aspects of energy use. *Annual Review of Energy and Environment* 18, pp.247-289.

POST – Parlimentary Office of Science and Technology, (2005). Household energy Efficiency, POSTNOTE, October 2005 ,Number 249, Page 2. Available at http://www.parliament.uk/documents/post/postpn249.pdf(27th August , 2011).

Preiser, W. and Vischer, J. (2005) *Assessing Building Performance,* Oxford: Elsevier.
Preiser, W. F. E., Rabinowitz, H. Z., and White, E. T. (1988) *Post-occupancy evaluation,* New York: Van Nostrand Reinhold

Spataru, C., Gillot, M. and Hall, R. M. (2010) 'Domestic energy and occupancy: a novel post occupancy evaluation study', *International Journal of Low-Carbon Technologies,* (5), 148-157.

Steemers, K. and Yun, G., Y. (2009) 'Household energy consumption: a study of the role of occupants', *Building Research and Information,*38(1), 625-637.

Stevenson, F. (2009) 'Post-Occupancy evaluation and sustainability: A review', *Urban Design and Planning,* 162(3), 123-130.

Stevenson, F. and Rijal, H. (2010) 'Developing occupancy feedback from a prototype to improve housing production', *Building Research & Information,* 5(38), 549-563.

Schwarz, N. and Oyserman, D. (2001) 'Asking questions about behavior: cognition, communication, and questionnaire construction'. *American Journal of Evaluation*, 22(2), 127–160.

Technology Strategy Board (TSB) (2009) *Retrofit for the Future Phase 1, Technical and Energy Modelling guidance notes V1.0,* Technology Strategy Board [online], available: http://www.innovateuk.org/_assets/pdf/competitiondocuments/technical%20and%20energy%20modelling%20guidance%20notes%20v1%200%20(2).pdf [accessed 23.12.2010].

Van Dam, S. S., Bakker, C.A., and Van Hal, J.D.M. (2010) 'Home energy monitors: impact over the medium-term', *Energy Research & Information,* 38(5), 468-469.

Vischer, J. (2001) 'Post-Occupancy Evaluation: A Multifaceted Tool for Building Improvement' in *Learning from our buildings: a state-of-the-practice summary of post-occupancy evaluation*, Washington DC: National Academy Press, 23-24.

Wilson, C. a. D., H (2007) 'Models of decision making and residential energy use', *Annual Review of Environment and Resources* 32, 169-203.

Zimring, C. and Wener, R. (1985) 'Evaluating evaluation', *Environment and Behaviour,* (17), 97–117.