Department of Energy & Climate Change

Feasibility study on Green Deal & ECO customer behaviour

Working Paper to scope the feasibility of research into how consumer behaviours influence the impacts of the Green Deal and ECO programme.

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Executive Summary

Purpose and process

This working paper considers options for research into how consumer behaviours influence the impacts of the Green Deal and Energy Companies Obligation (GD/ECO) programme. It was commissioned under ICF International's contract with DECC to evaluate the programme and was a collaborative effort by a team drawn from ICF International, Brook Lyndhurst and Heriot-Watt University.

The objective of the study was to provide DECC with a list of research projects that could be undertaken to test hypotheses on household energy consumption and related behaviours in households that have had measures installed after a Green Deal assessment or by ECO. The primary focus was on what was feasible in the initial phase of the evaluation but the study also looked forward to longer term options.

The first step in the study process was to consult with DECC officials to identify the topics of interest relating to household energy consumption and related behaviours in households that have had measures installed after a Green Deal assessment or by ECO. In the next step the study team identified potential research hypotheses that would contribute to DECC's understanding of these issues. A strategic appraisal of existing research was undertaken to identify gaps in evidence and lessons on research design. Project options were then developed.

Context

The way in which consumers manage energy in the home (or rather their consumption of services that use energy, such as heat, light and power) after installation of the kind of measures supported by Green Deal and ECO determines the net impact of the programme on comfort levels, energy savings, bills, avoided carbon emissions, etc. There are therefore potentially important interactions between the consumer (household) behaviours and overall programme results but these interactions are not well understood. DECC models assume 15% of theoretical savings will be lost to such 'comfort-taking'. This adjustment is grounded in empirical evidence but there is significant uncertainty about whether it is a true reflection of the reaction of contemporary households to installation of measures under the Green Deal and ECO programme. Better information about the interaction between behaviours and home energy use in general, and about the interactions between the Green Deal and ECO interventions, consumer behaviour and energy use would help DECC to reduce the uncertainty in its estimates of the impacts of the programme and understand how the programme might be adjusted to improve its efficacy and efficiency.

Hypotheses and evidence

The overarching hypothesis for further research projects focusing on post-installation responses is: *post-installation behaviour of households affects the extent to which expected Green Deal energy savings are realised (which is crucial to meeting the Golden Rule).* We can further state that: o*n the basis of existing theory, knowledge and emerging evidence, an array of hypotheses about behavioural influences on post-installation energy use can be identified and clarified.* We are thus interested in: (i) the extent of comfort-taking and how it varies across consumer types/situations (to help DECC enhance its predictions of the scale of impacts and variations);

and (ii) why it occurs and what behavioural factors underpin consumer responses. Working within this framework, a set of research hypotheses were developed drawing on behavioural economics, social psychology and sociology.

The evidence scan[1] found wide variation in how key terms relevant to this study are used and understood. 'Energy consumption', 'behaviour' and 'comfort' mean different things to different authors, reflecting their diverse theoretical backgrounds. While 'rebound' is generally understood to mean achieving less energy saving than predicted, the basis on which rebound effects are identified varies widely. Energy-relevant behaviours at the household level have been studied extensively. A key focus of past research has been rebound effects, comfort, and comfort-taking, although reviews of such studies have pointed to limitations and a need to further disentangle behaviour responses and their role in comfort-taking. Research shows that user behaviour is central to understanding post-installation outcomes but there are significant gaps in the evidence available to address this study's hypotheses.

Hypotheses relating to the extent of comfort-taking are suited to formal quantitative testing. Those relating to the behavioural underpinnings of comfort-taking are more amenable to qualitative research approaches where the hypotheses are used as the exploratory framework for generating insight. However, the evidence shows clearly that the determination of the scale and cause of comfort-taking associated with installations is methodologically very challenging. There is a need for creative research methods that are capable of considering the complex interactions between daily life, personal identity, technological change and context. In particular, attention needs to be paid to the monitoring period (heating seasons before/after), sampling (including issues of access, size, study population and selection bias); the range of measures installed (recognising variation in response to different measures); and monitoring techniques.

There are a number of active research projects in the UK that are looking at energy use in the home but none provide a substantial sample of Green Deal / ECO participants with pre/post installation monitoring.

This feasibility study concludes that there are no quick fixes; gaining an understanding of the scale of comfort-taking associated with Green Deal / ECO and the impacts of the programme on energy savings would be a long term, complex undertaking. Rather than a generating a list of feasible short term projects, it concludes that the best investment at this stage is to lay the foundations for success by: conducting preparatory qualitative research on Green Deal and ECO programme customer behaviours, forging partnerships with parallel research projects and reviewing aspects of the current programme delivery model and support contracts that make it more difficult and expensive to conduct research on the issues of interest. The proposed qualitative research project would generate useful results in the shorter term as well as supporting the development of a longer term solution. A follow-on quantitative project is described in outline.

Other short term research projects were considered in the course of the feasibility study but were discounted on the basis that the constraints imposed by the programme model and available timescale, and design deficiencies of the type identified in chapter 4 significantly reduced their robustness and value.

The specific options are, therefore, for:

[1] The rapid evidence scan looked at the coverage of the research hypotheses in the literature and at the way problems are framed and key terms interpreted. The scan was not constructed as a formal Rapid Evidence Assessment (REA), though some of the techniques used in REA were applied

- A project to conduct **user-centred research on post-installation behaviours and practices**, potentially followed by a longer term quantitative behaviours project to develop a behaviour scale/index for use in quantitative modelling;
- A supporting action to **engage with the lead researchers in specific university-led research projects** to explore the potential for those projects to contribute to the agenda outlined in this paper by incorporating a Green Deal/ECO component into their designs.
- A supporting action to **build a better platform for research on the programme.** This would involve identifying aspects of the current programme delivery model and support contracts that increase the cost and difficulty of conducting research on programme impact. It would also assess and recommend remedies to those issues and then re-appraise the potential for a comprehensive solution based on the revised set of opportunities/constraints provided and the capabilities available from research partners.

These could be proportionate steps to address the gaps in the current research evidence and for primary research to add value in the short term whilst establishing the arrangements that should provide answers to the longer term strategic questions facing the programme.

1: Conduct user-centred research on post-installation behaviours and practices

The purpose of this project would be to develop an in-depth understanding of behavioural practices relevant to energy use in the home, with a specific focus on how households have responded to the installation of Green Deal type measures. It would explore underlying influences on behavioural practices, interactions with technology and programme design.

The first part would consist of in-depth qualitative research to build an explanatory account of how and why energy savings are achieved (or under-achieved) in the Green Deal, to inform outputs from its impact modelling and, potentially, to provide foundations for improved modelling/prediction in the future. It would build on the DECC High/Low study (DECC, 2012a). Links could be made to one or more of the current[2] university-based research projects for collaboration on quantitative follow-up depending on how those projects develop. Findings will be of immediate use to flag ways to help customers maximise savings from Green Deal or other energy efficiency measures. Interviews could be built into further rounds of the Green Deal evaluation.

The suggested approach is a programme of quasi-ethnographic, in-home interviews. The approach would be based on a purposive sample. The research hypotheses would be used to inform design of interview guides. A pragmatic approach would be taken to sample structure recognising the pattern of take-up of Green Deal plans, Green Deal assessment and ECO.

A possible second phase would use the outcomes of that qualitative research to develop a behaviour scale/index for use in quantitative modelling. It would seek to explain variance in comfort-taking with reference to aspects of customer behaviour responses, in addition to other known factors such as technology, building type and socio-demographics. It would require a large-scale quantitative consumer survey of households exposed to GD/ECO.

[2] Such as the ORIGIN project involving Heriot-Watt University or the IDEAL project run by the University of Edinburgh.

2: Establish research partnerships

This feasibility study concludes that planned and current research projects being managed by UK universities have the potential to make a contribution to the research questions identified in this paper. Questions on comfort-taking in the home before and after installation of energy efficiency measures could be addressed through partnerships with, and expansion of the scope of, existing research projects.

None of these projects directly addresses the programme at present but there is the potential to forge mutually beneficial partnerships. They have access to research subjects, monitoring and other technologies, and analytical tools that are relevant to the current context. The Green Deal and ECO programme could, with some adjustments, relieve some of the constraints on recruiting households into research on energy use in the home.

Two of the projects identified (IDEAL and ORIGIN) have designed state of the art monitoring devices to collect data on indoor temperature, indoor air quality, electricity and gas demand, which are combined with metadata about the weather, building characteristics and household composition. These potentially offer the opportunity to combine highly advanced physical monitoring with qualitative methods to gather evidence on causes behind outcomes and variations in energy use, comfort and other household behaviour. Integrating a GD/ECO component into other projects would give DECC outputs from a nationally representative study, albeit with some delay.

Working with these projects is necessarily a long-term endeavour. The projects are not currently configured to address GD/ECO programme specific issues. Setting up any collaboration would take time, as would design and recruitment of the sample and then installation of monitoring arrangements. The identified projects have not as yet gathered data. Information on pre-installation consumption would therefore either require a period of monitoring (ideally summer and winter months with one full heating season) before installation of measures or access to via historical bills or (if possible) the National Energy Efficiency Data-Framework (NEED). Multi-annual funding arrangements would be required.

The initial step would be to make contact with researchers currently designing these projects to explore the possibility for the addition of Green Deal/ECO elements to their current research design, and under what terms. The approach is therefore conditional on outcomes of those consultations. If initial consultations are positive the next step would be to work up project specifications based on the target hypotheses and associated funding arrangements. Some of the projects are themselves in a scoping and development phase and the potential to partner with them will be influenced by decisions made on their future, independent of the Green Deal and ECO research agenda.

3: Build a better platform for research on the programme

The aim of this project would be to look beyond the current evaluation study and to address the barriers to, and expand the opportunities for, cost-effective research on the programme. This would build a better platform for future research, both direct and collaborative, and help DECC to respond to the challenge set by the House of Commons to monitor the programme's impact[3].

Some aspects of the current programme make the establishment of a cohesive impact monitoring system more difficult and expensive than it need be. There is currently no

[3] House of Commons Energy and Climate Change Committee. The Green Deal: watching brief. First Report of Session 2013–14. HC 142 Incorporating HC 966, Session 2012-13. Published on 22 May 2013. http://www.publications.parliament.uk/pa/cm201314/cmselect/cmenergy/142/142.pdf (accessed 21 February 2015).

mechanism to solicit customer consent to participate in a programme of research that is in the public interest. The telephone numbers of households that have a Green Deal assessment are not captured such that researchers appointed by DECC need to write and/or door-knock to engage those programme customers in research, significantly increasing the time and cost of engagement. DECC does not have access to all the Energy Performance Certificate (EPC) data lodged by assessors that are potentially of interest for research purposes.

There is the scope to increase the opportunities for the programme to support powerful, long term research on its impacts. An example is to adjust the delivery model to facilitate recruiting early stage customers into an in-home monitoring programme using the smart technologies now available.

This project would involve workshops to: (i) identify aspects of the current model (including support service contracts) that increase the difficulty and cost of research, and reduce access to data; (ii) identify and evaluate potential remedies to those barriers, taking into account data protection safeguards. The second step would be to work with research partners and programme delivery agents to examine the scope for adjusting the delivery model to support long term research, e.g. the early stage recruitment of Green Deal and ECO programme participants into long term monitoring programmes.

1. Introduction

This chapter describes the study objectives, context and approach

Objectives

1.1. This is the final report of a short study on the focus and feasibility of research into how consumer behaviours influence the impacts of the Green Deal and Energy Companies Obligation (GD/ECO) programme. It forms part of the first phase of the evaluation of the Green Deal and ECO programme (hereinafter 'the programme') led by ICF International. The study was conducted by ICF, working with the support of Brook Lyndhurst and Heriot-Watt University.

1.2. The core objective of the study was to scope research that could be undertaken within the Green Deal and ECO evaluation to test hypotheses on household energy consumption and related behaviours in households that have had measures installed after a Green Deal assessment or by ECO. It is set in the context of the challenge laid down by the House of Commons Energy and Climate Change Committee in its report *The Green Deal: watching brief*[4], such as to conduct, "expert monitoring of Green Deal installations to assess the quality of work and to measure actual energy usage and expenditure on energy bills" and to follow the customer experience through to post-installation.

1.3. The focus was on research that would provide insights into:

- consumer behaviours that relate to energy use in the home, e.g.:
  - whether consumers make effective use of energy efficiency measures installed via the programme and what influences this;
  - the level of comfort-taking (behaviours that offset energy/carbon savings);
  - whether consumers are more conscious of energy efficiency after the installation of new measures (and what influences this);
  - whether consumer behaviour relating to heating and use of energy changes after installation of new measures (and why);
- consumers' experiences of the installation and how their homes and lives were changed by the installation of GD/ECO measures;

[4] House of Commons Energy and Climate Change Committee. The Green Deal: watching brief. First Report of Session 2013–14. HC 142 Incorporating HC 966, Session 2012-13. Published on 22 May 2013. http://www.publications.parliament.uk/pa/cm201314/cmselect/cmenergy/142/142.pdf (accessed 21 February 2015).

- the extent to which GD/ECO installations addressed consumers' needs and expectations;
- evidence on consumer behaviour assumptions relevant to the impact assessment as modelled by DECC economists (e.g. health, comfort-taking);
- whether - for those taking out Green Deal Finance - experience is consistent with the Golden Rule (the balance of energy savings versus repayments).

1.4. While the subject of investigation was the end of the GD/ECO customer journey (i.e. post-installation), factors along the journey which influence post-installation behaviour were also taken into account.

1.5. The primary focus was on activities that could be undertaken within the initial phase of the evaluation. Consideration was also given to how to develop a longer term strategy for tackling the key research questions. This assumed additional importance once the scale of the constraints on what was achievable within the available research window became clear.

1.6. The study was required to take note of the ambition to foster collaboration between DECC and the community of researchers working on relevant issues in the UK. Beyond the evaluation project there are many behavioural and technical research projects, concluded or on-going, studying the effects of energy efficiency installations on consumers' behaviour and their comfort/health. Connecting the Green Deal evaluation questions to this community is potentially a useful means of increasing the information and evidence brought to bear on the Green Deal as well as leveraging additional public benefit from the investments made in these other projects. The House of Commons Energy and Climate Change Committee report[5] makes a specific recommendation that DECC, "…*should attempt to coordinate its own evaluation studies with research being carried out by other institutions in this area, in order to maximise the utility of any data being collected*" (para. 24).

Context

1.7. The way in which consumers manage energy in the home (or rather their consumption of services that use energy, such as heat, light and power) after installation of the kind of measures supported by Green Deal and ECO determines the net impact of the programme on comfort levels, energy savings, bills, avoided carbon emissions, etc. There are therefore potentially important interactions between the consumer (household) behaviours and overall programme results.

1.8. These interactions are not, however, well understood. Current models cannot explain large parts of variance in energy use between apparently similar households. Findings from the literature confirm that a) this is a gap in knowledge and b) the variation can, to some extent, be attributed to 'behaviours'. These behavioural influences on energy use at the household level are recognised but

[5] ibid

not well understood. Previous research for DECC[6] – which looked at similar houses – showed that behaviour patterns contributing to the difference were highly idiosyncratic and probably not predictable on the basis of home or household type.

1.9. It has been recognised that behavioural factors are likely to reduce the energy savings and carbon savings delivered by Green Deal and ECO. This phenomenon is widely referred to as comfort-taking which means that part of the theoretical savings are taken in improved householder comfort (i.e. higher in-door temperatures). The model that is used by DECC to estimate the impacts of the Green Deal and ECO programme assumes that 15% of theoretical energy saving (and associated reduction in carbon emissions) delivered by installation of the energy efficiency measures is lost to comfort-taking[7].

1.10. Fifteen per cent is a 'rule of thumb' adjustment: it is grounded in empirical evidence but there is significant uncertainty about whether it is a true reflection of the reaction of contemporary households of varying types to installation of measures under the Green Deal and ECO programme. Better information about the interaction between behaviours and home energy use in general, and about the interactions between the Green Deal and ECO interventions, consumer behaviour and energy use would help DECC to:

- Reduce the uncertainty in its estimates of the impacts of the programme;
- Understand how the programme might be adjusted to improve its efficacy and efficiency.

Approach

1.11. The study was structured around four main tasks:

- Identification of potential research hypotheses that contribute to DECC's understanding of household energy consumption and related behaviours in households that have had measures installed after a Green Deal assessment or by ECO (Chapter 2);
- A strategic appraisal of research to identify gaps in evidence (Chapter 3) and lessons on research design (Chapter 4);
- Definition and development of research options (Chapter 5);
- Presentation of findings to inform ongoing and future research programmes (Chapter 6).

1.12. The method adopted is described in Annex 1. The research review was not constructed as a formal Rapid Evidence Assessment (REA) according to Government Social Research Services guidelines[8] (due to time and budget constraints), though some of the techniques used in REA were applied. The

[6] DECC (2012) Domestic energy use study: to understand why comparable households use different amounts of energy. Brook Lyndhurst for DECC.

[7] Interviews with DECC officials.

[8] The Rapid Evidence Assessment toolkit is available at http://www.civilservice.gov.uk/networks/gsr/resources-and-guidance/rapid-evidence-assessment

study team’s judgement was used in determining relevance and the scan was not to be as systematic as a formal REA.

2. The research hypotheses

This section describes the research hypotheses developed from DECC's statement of requirements

Definition of purpose

2.1. In consultations DECC officials provided a consistent message that a principal issue of interest to the department is comfort-taking (rebound effect) in homes that have had measures installed after a Green Deal assessment or under ECO. There is interest in the scale of the effect as well as behavioural factors that lead to comfort-taking. There is also interest in other impacts on residents' lives, including effects on health and alleviation of the consequences of fuel poverty.

2.2. For the purposes of the GD/ECO impact assessment, DECC analysts discount energy savings delivered by installations by 15% to allow for comfort-taking, i.e. 15% of the energy savings one would expect to see are not observed. This 'behaviour' adjustment factor is, in DECC calculations, considered in addition to the in-use adjustment factors which account for the technical 'under-performance' of measures when installed in real homes – e.g. loft insulation does not insulate as well as the models suggest it should.

2.3. Comfort-taking reduces carbon savings but is assumed to be a consequence of consumer preferences for warmth. Past studies have tended to explain comfort-taking responses in terms of rational economic responses - consumers are spending some of their savings on buying more energy. Other social science traditions (e.g. behavioural economics, social psychology and sociology) suggest that explanations for apparent comfort-taking are more complex and multi-dimensional than economic models would suggest.

2.4. Factors of interest that contribute to comfort-taking include: consumer needs and behaviour practices; the variation of behavioural response across consumer groups; and how the process of installation of energy efficiency measures impacts on how people use and heat their homes post-installation, and hence energy use. Questions and issues being raised in DECC include:

- How much confidence can there be in the 15% comfort-taking assumption, with respect to Green Deal and ECO?
- To what extent does comfort-taking vary by household types (including the fuel poor) and demographics?
- Is comfort-taking constant or does it vary over time post-installation?
- How significant is the role of behaviours as an influence on comfort-taking? How do behavioural factors relate to any observed differences?
- How does human-technology interaction affect performance of measures?

- How long do people persist with trying to get the best out of their heating controls, if they are having problems making them work properly?

2.5. There was recognition by the DECC consultees that:

- relatively little is known about how people actually use energy in their home, how they respond to the installation of new efficiency measures and ultimately how this affects their energy use;
- concepts of full information/skills and 'rationality' on the part of consumers (for example the notion of a conscious and deliberate 'preference for warmth') are unlikely to yield accurate representations of consumer behaviours and energy consumption.

Development of hypotheses about behaviour effects in comfort-taking

2.6. In light of the understanding above, the overarching hypothesis for further research projects focusing on post-installation responses is: *post-installation behaviour of households affects the extent to which expected Green Deal energy savings are realised (which is crucial to meeting the Golden Rule[9]).* We can further state that: o*n the basis of existing theory, knowledge and emerging evidence, an array of hypotheses about behavioural influences on post-installation energy use can be identified and clarified.* We are thus interested in:

- **The extent** of comfort-taking and how it varies across consumer types/situations (to help DECC enhance its predictions of the scale of impacts and variations); and
- **Why it occurs** and what behavioural factors underpin consumer responses (to help DECC develop explanatory accounts of behaviour responses which could help it enhance the design of energy efficiency programmes, including Green Deal, and potentially support further development of impact models).

2.7. The former is amenable to energy monitoring and/or predictive modelling (which has generally been the standard approach to measuring post-installation 'behaviour' so far). Both monitoring and modelling approaches tend to treat 'behaviour' as a black box (e.g. a model residual) and a singular entity where 'behaviour' may be inferred from before/after comparisons of energy consumption. This framing tends to equate energy behaviour with energy consumption.

2.8. The latter opens up the possibility that behaviour response is in fact multi-dimensional and that energy consumption is a secondary outcome of other behavioural responses to the adoption of energy efficiency measures (for example as shown in Figure 2.1). In this perspective, we can only understand (and improve predictions of) energy consumption outcomes if we understand the full range of behavioural factors or practices that are implicated in post-installation responses.

2.9. Hypotheses relating to the extent of comfort-taking are suited to formal quantitative testing. Those relating to the behavioural underpinnings of comfort-taking are more

[9] The 'Golden Rule' says that expected financial savings from energy efficiency measures for which Green Deal finance is provided must be greater than the costs attached to the energy bill.

amenable to qualitative research approaches where the hypotheses are used as the exploratory framework for generating insight.

2.10. Evidence and insight from a range of disciplines and perspectives was drawn upon in the development of hypotheses for possible future projects to be considered in the context of the evaluation of the Green Deal and ECO programme. A scan was conducted of recent and current research activity - with a focus on DECC-sponsored projects and the centres funded through the UK Energy Research Council (described in chapter 3). The team's own extensive knowledge of behaviour theories and practice in the energy and environment field was also applied, drawing insights from three schools of thought:

- Behavioural economics
  - noting in particular the approach taken in the MINDSPACE report[10];
  - including non-(economically) rational influences on choice; choice architecture and specific nudges.
- Social psychology
  - including Defra's pro-environmental behaviours research portfolio[11];
  - including values, attitudes, skill, agency, identity, norms, habits.
- Sociology
  - including the work of the DEMAND centre[12] led by Professor Elizabeth Shove;
  - with its focus on social practices and questioning of the individual behaviours perspective.

2.11. While these academic disciplines have fundamental disagreements about the foundations of behaviours/practices, they share a common underlying premise that, rather than being a discrete behaviour, energy use is actually an outcome of interlocked and evolving factors. This calls for a pragmatic approach to framing hypotheses which recognises both the *individuals* and the *contexts* in which they are organising their lives[13]. Their interplay is illustrated in Figure 2.1 overleaf. This conceptual framing is central to the list of hypotheses that follow.

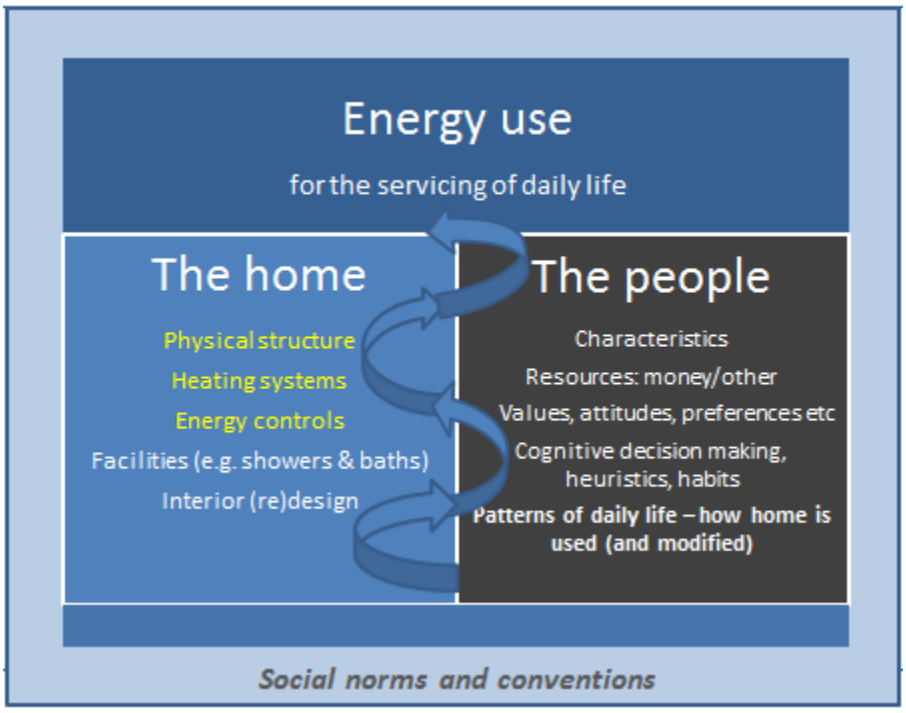
[10] MINDSPACE: Influencing behaviour through public policy. Institute for Government and the Cabinet Office. 2010.

[11] Outcomes from Defra's progamme of research on pro-environmental behaviours and sustainable consumption are summarised in: Defra (2008) A framework for pro-environmental behaviours; Defra (2011) A framework for sustainable lifestyles; and S. Eppel, V. Sharp, L. Davies (2013) A review of Defra's approach to building an evidence base for influencing sustainable behaviour, Resources, Conservation and Recycling, Volume 79 , October 2013, Elsevier.

[12] The DEMAND Centre (Dynamics of Energy, Mobility and Demand) is funded by the ESRC/EPSRC with support from ECLEER (EDF R&D), Transport for London and the International Energy Agency. The centre started work in May 2013 and will continue until 2018. http://www.demand.ac.uk/

[13] This kind of pragmatic approach was suggested in Chatterton (2011) *An introduction to Thinking about 'Energy Behaviour': a Multi Model Approach*. DECC. It is also central in the Scottish Government's ISM (Individual, Social, Material) behaviour model, summarised in Annex 4.

Figure 2.1 Observed energy use can be seen as a function of the interplay between the home, its occupants, and the social norms and conventions of the society in which they live



2.12. A set of headline hypotheses were developed; each headline hypothesis had an accompanying list of supporting hypotheses which elaborated the main idea for each. These more detailed aspects could be a useful starting point when designing specific research instruments, such as interview guides. The following is a summary list of the headline hypotheses; the supporting detail is produced at 0. The identifiers (H1 etc.) in the table are used as reference numbers throughout this report.

2.13. H1 and H2 below are the hypotheses most directly related to the *extent* questions about comfort-taking while the rest of the hypotheses are central to questions of *why* and *how.* For DECC to develop a more accurate and sophisticated understanding of post-installation responses any new research projects would need to include more than one of these hypotheses, depending precisely on what research outcomes are required. The options outlined in chapter 5 indicate which hypotheses are relevant to each and how they could be used (e.g. for quantitative testing and/or research frameworks for qualitative insight research).

Table 2.1 Research hypotheses

Ref	Hypothesis description
H1	Perceptions of comfort, and hence comfort-taking, will be influenced by who lives in the house and their starting level of comfort pre-installation (and how that interacts with bundles of behaviour factors identified below).
H2	Behaviour responses, including comfort-taking, may be influenced by the mix of measures taken up and (if relevant) the order in which they are adopted, and how people interact with them.
H3	Emotion and mental short-cuts are implicated in decision-making about energy and can result in non- (economically) rational choices and strategies which can result in unintentional comfort-taking.
H4	Habits and behaviour lock-in can lead to unconscious or unintentional comfort-taking.
H5	Salience and defaults – exposure to the GD through assessment and/or finance raises salience and the likelihood of people making an effort to maximise savings, but households may return to default behaviours over time.
H6	Norms play an important role in determining perceptions of 'acceptable' levels of comfort, and therefore propensity for comfort-taking.
H7	Values, attitudes and identity will influence active management of energy and paying attention to maximising benefits from installed measures.
H8	The social dynamics of households influence who controls comfort and how they do it which will affect the pattern of comfort-taking.
H9	The scheduling of daily life and heating routines affects opportunity and willingness to take comfort/maximise savings from energy efficiency measures.
H10	Human/technology interaction affects the effectiveness of GD/ECO measures – which is particularly relevant to unintentional comfort-taking and perverse effects. This includes the role of skills and agency.
H11	The customer journey prior to installation has an influence on the behaviour outcome and resulting energy saving. This includes the role of 'messengers' (assessors/installers) and influences on customers' skills, agency and commitment.
H12	There is potential for both positive and negative behaviour spill-over from the GD/ECO – that is, taking up GD measures encourages or discourages one or several other energy related behaviours[14].

[14] For example: installation of GD measures might inspire customers to acquire further energy saving measures or adopt other pro-environmental behaviours (positive spillover); alternatively, individuals feeling virtuous about energy saving from GD measures might be less inclined to consider other energy, water or waste saving actions *or* changes in individuals' physical experience of the building (e.g. it's hotter or damper) encourages new behaviour patterns (e.g. using air conditioning) which leads to extra energy use (negative spillover). For an in-depth review and exploration of behavioural spill-over see Austin et al (2011), Catalyst Behaviours, Defra.

3. The evidence

This section considers the findings from the rapid evidence scan and the gaps that new research projects might focus on

3.1. The rapid evidence scan looked at the coverage of the research hypotheses in the literature and at the way problems are framed and key terms interpreted.

Framing – key definitions relevant to understanding post-installation behaviours

3.2. The scan identified wide variation in how key terms of interest to this study are used and understood. Notably 'energy consumption', 'behaviour' and 'comfort' mean different things to different authors, reflecting their diverse theoretical backgrounds. While 'rebound' is generally understood to mean achieving less energy saving than predicted, the basis on which it is identified varies widely.

3.3. It is important that key terms are clearly defined for the purpose of developing research options. The following box highlights key insights from the literature and how the implications for the proposed research designs have been interpreted.

Energy consumption is "the tangible result of a combination of user behaviours" (Gill et al 2010), including the interaction of attitudes, behaviours and the material and social context (McMichael and Shipworth 2013, Huebner et al 2013a, Dolan and Metcalfe 2013). People do not consume energy directly: they consume the services provided by energy, for example, comfort; energy consumption is an indirect effect of every-day life (Brook Lyndhurst/DECC 2012a). The idea of household energy 'practices' (Guy and Shove 2000) captures the idea of the human-social-technological-material interaction and the limitations of considering rational decision-making by individuals as central to energy outcomes.

Implications: 'Consumption' is used to refer to the observable *amount of energy consumed* which enables consumers to service their daily living requirements. It is not a discrete 'behaviour'. The notion of 'energy-*relevant* behaviours and practices' is more appropriate than 'energy behaviours'. This includes not only 'direct' behaviours, such as turning the heating on and off, but also if and how residents use their homes differently after installation of measures (e.g. because warmth is distributed differently, heating controls are not fully understood, or people stick with defaults and habitual patterns).

Comfort is 'the state of mind that expresses satisfaction with the environment.' 'Comfort' includes thermal, visual, air quality, and psychological dimensions (American Society of Heating, Refrigerating, & Air-Conditioning Engineers, cited in Huebner et al 2013a). Thermal comfort is cited by research participants as the most important aspect of comfort (Huebner et al 2013a), but these other dimensions are also relevant to energy efficiency installations (e.g. Caird et al 2008). Comfort means different things to different people – it is not necessarily related to specific room temperatures and individuals may be satisfied with comfort at lower temperatures than technical models assume (Huebner et al 2013; Milne &

Boardman 2000). Societal framings of comfort influence how individuals perceive acceptable levels of comfort, and these change over time (various works from Elizabeth Shove and her work through the DEMAND centre). Individuals within a household may have differing perceptions of comfort so that the use of heating has to be negotiated (DECC 2012b).

Implications: In the context of investigating behaviour influences on post-installation energy consumption the qualitative dimension of how consumers understand and perceive comfort is central. Comfort cannot be determined entirely from technical estimates and temperature monitoring.

Rebound is an umbrella term that covers a number of effects, including direct effects (more intensive use of equipment due to lower effective unit cost of energy); income effects (spending savings on other energy); and composition effects (shifting from energy extensive to energy intensive goods) (Van den Bergh 2011). The rebound effect is the most researched area of post-installation behaviours (see Van den Bergh 2011, Sorrell 2007, Milne and Boardman 2000; Galvin 2014; Chitnis et al 2013, Chitnis et al 2014 for reviews). The estimates found in the literature for the magnitude of the rebound effect vary widely because studies look at different aspects/types of rebound, and are inconsistent in terms of system boundaries, time spans, and long-term household dynamics (e.g. changing preferences) (Van den Bergh 2011). Rebound mechanisms and effects depend on the technology installed (Sorrel, 2007). There are also technical issues with measurement of the performance of installations that may obscure true effects, including assumptions made about energy consumption prior to the installation of measures.

Implications: Quantitative studies to measure rebound effects need to identify reliable ways of measuring energy consumption accurately before, soon after installation of measures, and in the longer term (taking into account external factors such as energy prices). Qualitative research could usefully provide insight on why/how direct and income effects occur. Both quantitative and qualitative studies need to have clear statements of scope and sampling strategies that ensure internal consistency.

Validation of hypotheses and evidence to support research designs

3.4. The following observations drawn from the evidence scan make reference to the list of hypotheses in chapter 2. They have been used to refine the focus for project research options in chapter 5. Details of the texts reviewed in the evidence scan are provided at Annex 8.

3.5. Energy-relevant behaviours at the household level have been studied widely, most often from sociological and social psychology perspectives and more recently from researchers concerned with behavioural economics. A central focus of energy / behaviour studies has been voluntary action to reduce energy consumption through ‘everyday’ actions, including some experimental intervention studies. Others have used a behavioural lens to explore differences in energy use between homes that are physically similar (DECC, 2012; Gill et al, 2010).

3.6. Specifically with respect to post-installation impacts, the evidence scan confirmed that user behaviour is central to understanding outcomes (for example, Gill et al

2010, Abrahamse et al 2005, Linden et al 2006, Caird et al 2008, Lopes et al 2012, Carlsson-Kanyama and Lindén 2005, Ekins and Spataru 2012, Huebner et al, Huebner et al 2013a,b,c, Spataru et al 2010, Gauthier and Shipworth 2013, Linden et al 2006, Gram-Hanssen 2010) but also flagged a lack of detailed understanding of behaviour aspects. Researchers commonly recommend better coverage of behaviour responses alongside physical monitoring and technical building performance.

3.7. Some studies currently underway (e.g. the DECC supported Solid Wall Insulation Research Project and research projects in UK Energy Research Council centres[15]) will provide new evidence on post-installation behaviour responses but findings will not be available for several years in many cases (a summary of on-going research projects can be found in Annexes 6 and 7).

3.8. No studies were found during the scan that formally linked energy-related behaviour responses to households' interactions with the design of the energy improvement programme or the way in which they had accessed it [H11].

3.9. Looking across both types of evidence (general energy behaviours and those focused on post-installation outcomes) the evidence scan provides support for the importance of the following topics that were identified in the initial list of hypotheses:

- How people use their homes and service their daily lives, in general and in response to the installation of energy efficiency measures (see references under 'energy consumption' in the box above) [H9];
- Attitudes, values, norms (Huebner et al, 2013; Dolan and Metcalfe, 2013; Gill et al, 2010; Abrahamse & Steg, 2009) [H6, H7];
- Information and knowledge (general, e.g. environmental issues, and specific, e.g. how to work heating controls) (Gill et al 2010; Abrahamse et al 2005; Munton et al, 2014) [H3, H5, H7, H10, H11];
- Skills and agency, perceived behavioural control, unintentional comfort-taking (Combe et al, 2010; Huebner et al, 2013a; Van den Bergh, 2011; DECC, 2012; Munton et al, 2014; Woosey, 2012) [H2, H3, H5, H10, H11];
- Habit, and the opportunities for behaviour change provided at moments of change in people's lives, e.g. moving house (Darnton et al, 2011; DECC, 2012; Huebener et al, 2013b; Marechal, 2010; Linden, 2006) [H4, H5, H3];
- Salience, visibility of usage and of savings, the importance of direct feedback and lack of awareness of energy use or bills (DECC, 2012; Willis et al, 2010; Dolan and Metcalfe, 2013) [H5, H4, H3, H11].

3.10. With respect to comfort, there was some consensus that comfort-taking is typically greater in low income households [H1], though comfort responses are recognised to be diverse [H2] (Huebner et al, 2013a). Comfort responses can include energy-saving behaviour such as turning the heating down. The ability to achieve desired comfort levels may be affected by individuals' knowledge and skills (e.g. of heating systems) [H10]. Perceptions of comfort are not fixed and often socially determined.

[15] See Annex 7 for more details.

Understanding comfort as a subjective experience and desire [H3], as well as a physical condition, is therefore important to understanding behaviour responses.

3.11. Two aspects have been covered in specific studies but were not widely mentioned elsewhere: social dynamics within households [H8] and possible spill-over effects [H12].

3.12. The scan also confirmed the importance of identifying key socio-demographic characteristics of households alongside behaviour [H1] (though behaviour effects cannot, yet, be predicted on the basis of these characteristics alone[16]). The following are frequently flagged as explanatory factors in the context of energy use:

- Income
- Age (elderly/small children)
- Health
- Household size
- Tenure (owner-occupiers vs tenants)

3.13. Table 3.1 summarises how the evidence maps onto the hypotheses (in a general context) and summarises the evidence gaps that are relevant to the evaluation.

Table 3.1 Hypotheses, evidence and gaps

Hypothesis	Evidence relevant to hypothesis (and strength)	Evidence gaps / research agenda
H1 Demand for and perceptions of comfort Perceptions of comfort, and hence comfort-taking, will be influenced by who lives in the house and their starting level of comfort pre-installation (and how that interacts with bundles of behaviour factors identified below).	Widely researched from both quantitative and sociological perspectives. Estimates vary widely, often related to research design. Broad recognition that the behaviour dimension needs to be 'disentangled' to better understand comfort responses.	How perceived comfort changes as a consequence of installation, mapped to household composition, ex ante preferences, and how energy-relevant behaviours respond to the new environment Outside the confines of fuel poverty households, the drivers of rebound effects are not well understood. Even with the fuel poor the understanding has been based on limited datasets.
H2 Mix of measures and differential behaviour response Behaviour responses, including comfort-taking, may be influenced by the mix of measures taken up and (if relevant) the order in which they are adopted, and how people interact with them.	Rebound effects are known to vary according to technologies installed. Evidence tends to be technology specific. Both technology and behaviours are implicated. Gaps identified for different mixes of measures.	Whether the mix and/or sequencing of measures has an impact on the behavioural determinants of energy savings.
H3 Mental short-cuts leading to unintentional comfort-taking Emotion and mental short-cuts are implicated in decision-making	Well documented in wider behaviour change literature, less evidence in relation to the installation of energy-efficiency measures. Aspects such as 'mental accounting' flagged as needing more	How household awareness and 'management' of heating changes on the customer journey, especially post-installation. Evidence on whether the

[16] On-going studies outlined in annexes 6 and 7 attempts to model the 'behaviour' dimension of energy use, some with a view to developing predictive models.

Hypothesis	Evidence relevant to hypothesis (and strength)	Evidence gaps / research agenda
about energy and can result in non- (economically) rational choices and strategies which can result in unintentional comfort-taking.	exploration for comfort responses (Boulanger 2013).	programme model recognises and seeks to 'reset' short-cuts and so increase benefits from installation
H4 Habits and behavioural lock-in Habits and behaviour lock-in can lead to unconscious or unintentional comfort-taking.	Well documented in the wider behaviour change literature, especially in relation to changes in everyday EE behaviour (e.g. turning lights off, using heating controls). Some preliminary evidence with respect to role of habits post-installation (Huebener, 2013)	How household awareness and 'management' of heating changes on the customer journey, especially post-installation. Evidence on whether the programme model is an effective 'disruptor' to 'reset' household practice and so increase benefits from installation
H5 Salience and defaults Salience and defaults – exposure to the GD through assessment and/or finance raises salience and the likelihood of people making an effort to maximise savings, but households may return to default behaviours over time.	Well documented in wider behaviour change literature. Some field experiments (UK and US) to test feedback interventions: including Newcastle heating controls advice trial and IDEAL. Some qualitative evidence on home visits and salience from programme evaluations. Not applied specifically to Green Deal context and specifics of the programme design.	How far GD / ECO customer journey changes salience/defaults. Evidence on whether impacts are sustained over time
H6 Norms Norms play an important role in determining perceptions of 'acceptable' levels of comfort, and therefore propensity for comfort-taking.	Well documented in wider behaviour change literature, including 'sustainable lifestyles' research. Some evidence on social norms (e.g. Dolan & Metcalfe, 2013; McMichael & Shipworth, 2013) with respect to energy consumption. Emerging evidence on influence of norms on post-installation behaviour.	The diversity and determinants of norms and associated 'comfort'. Evidence on the role of norms in supporting or blocking changes in energy-relevant behaviour post-installation. Where norms originate from – family, friends community, region, celebrity
H7 Values, attitudes and identify Values, attitudes and identity will influence active management of energy and paying attention to maximising benefits from installed measures.	Often considered alongside norms in wider behaviour change literature. Some evidence on energy use – e.g. Huebener, 2013. This perspective has not been widely applied to the study of post-installation behaviour responses.	The diversity and determinants of energy management Evidence on the extent to which the programme model engages in a way that connect with customer values/attitudes/identity and whether the engagement supports realisation of the potential benefits of installation
H8 Household social dynamics The social dynamics of households influence who controls comfort and how they do it which will affect the pattern of comfort-taking.	Identified in the DECC DEUS study; known from other fields (e.g. recycling). Tends to flag gender dynamics in household management which could be a potentially important influence on post-installation responses, also related to skills and know-how effects.	Social dynamics in households that have been programme customers as relating to comfort control. Identification of issues relevant to customer targeting and pitching of Green Deal information
H9 Daily schedules The scheduling of daily life and heating routines affects opportunity and willingness to take comfort/maximise savings from energy efficiency measures.	Well documented from a sociological theory perspective where more empirical research is under-way (e.g. Guy and Shove 2000). Not yet widely applied to understanding of post-installation responses.	The strength of the relationship between programme impacts and household type & rhythms, identifying aspects of daily life where information/advice could be targeted to maximise benefits
H10 Human/technology interactions Human/technology interaction	Emerging evidence that this is an important influence on energy use (Combe et al. 2010, Woosey 2012, Huebner 2013a).	Whether the programme model recognises and seeks to improve the customer's skill at managing

Hypothesis	Evidence relevant to hypothesis (and strength)	Evidence gaps / research agenda
affects the effectiveness of GD/ECO measures – which is particularly relevant to unintentional comfort-taking and perverse effects. This includes the role of skills and agency.	DECC has researched heating controls in this context. Known to be an influence but varies according to measures/ technologies and programmes. The role of programme design (e.g. support for know-how) appears less well understood. Backgrounded energy feedback systems (Hargreaves et al, 2013) Programmable thermostats increase, not reduce, energy consumption because of their complexity (Shipworth et al, 2010)	comfort, at assessment and post-installation.
H11 Customer journey effects The customer journey prior to installation has an influence on the behaviour outcome and resulting energy saving. This includes the role of 'messengers' (assessors/installers) and influences on customers' skills, agency and commitment.	As above in H10, the interaction of programme design and delivery mechanisms (e.g. support for know-how) with energy-related behaviours appears less well understood.	The programme's recognition of and connections to behavioural determinants of outcomes Evidence on the role of the assessment and installation process in supporting effective in-use behaviour of the GD measures This is particularly relevant when consideration is given to any performance gap that may arise or be perceived to arise by the householder.
H12 Programme behavioural spill-over effects There is potential for both positive and negative behaviour spill-over from the GD/ECO – that is, taking up GD measures encourages or discourages one or several other energy related behaviours[17].	Behaviour spill-over remains a contested area for researchers. Is widely thought to exist but evidence is less convincing (Defra, 2010). Limited evidence related to the installation of renewable energy. See also Chitnis et al, 2013 for evaluation of rebound	Behavioural spill-overs in programme households (and control group)

[17] For example: installation of GD measures might inspire customers to acquire further energy saving measures or adopt other pro-environmental behaviours (positive spillover); alternatively, individuals feeling virtuous about energy saving from GD measures might be less inclined to consider other energy, water or waste saving actions or changes in individuals' physical experience of the building (e.g. it being hotter or more damp) encourage new behaviour patterns (e.g. using air conditioning) which lead extra energy use (negative spillover). For an in-depth review and exploration of behavioural spill-over see Austin et al (2011), Catalyst Behaviours, Defra.

4. Lessons on research design

This section considers the challenges posed by research in this area and the lessons of past projects

Previous studies provide lessons on research design and methods appropriate to investigation of post-installation energy responses

4.1. A summary of observations about research approaches and methods is provided below. It draws on both the evidence scan and discussion with experts (mainly academic researchers). It provides insights relevant to the design of possible research projects in this study.

The value of multi-disciplinary research

4.2. A key focus of past research has been rebound effects, comfort, and comfort-taking, although reviews of such studies (e.g. Sorrell 2009) have pointed to limitations and a need to further disentangle behaviour responses and their role in rebound (or post-installation impacts). There is general acknowledgement that research on domestic energy consumption needs to take into account both the building and its occupants, taking an interdisciplinary and socio-technical approach (e.g. Oreszczyn and Lowe 2010; Schweber and Leiringer 2012; Stevenson and Leaman 2010 in Gupta et al 2014b).

4.3. Several past and current studies have combined physical monitoring with occupant surveys or interviews, though the latter have been included for differing purposes (e.g. to test whether a self-completion carbon footprint tool could predict actual changes in energy consumption, Craig et al 2014; to investigate the meaning of comfort and comfort actions, Huebner et al 2013b; to test occupant experience and satisfaction, Gupta et al 2014a).

4.4. Qualitative research is desirable to identify *why* and *how* behaviour responses have occurred. It cannot be used to reach generalizable conclusions but can generate depth of insight and reveal explanatory mechanisms about household behaviour. Such insights can complement physical monitoring or lay the foundation for large scale consumer surveys capable of generating generalizable results, including potentially the foundation for predictive models. Some use of occupant questionnaires and in-depth interviews was identified in the literature scan (Gill et al, 2010; Gupta et al 2014a and b, Huebener et al, 2013, DECC's Solid Wall Insulation Research Project[18]) but only a few with extensive in-depth qualitative research (DECC 2012; Love 2014).

[18] As mentioned in consultations between DECC staff and ICF/Brook Lyndhurst conducted in February/March 2014

Factors to take into account in designing quantitative monitoring projects

4.5. Various limitations, constraints and recommendations are commonly mentioned with respect to physical monitoring and quantifying behaviour responses, including:

- Assessing different dimensions of impact: the desirability of combining building performance monitoring of energy use and environmental conditions (e.g. air quality, outside temperatures), social surveys of households and physical surveys of dwellings (Gupta et al. 2014b, Oreszczyn 2014).
- Difficulty accessing participant households: in terms of numbers, types and timeliness before installation of measures (especially if baseline energy use is to be measured over a heating season before installation). It is generally acknowledged that social housing tenants have proven easier to access than private owners.
- Sample sizes: these are often small for reasons of participant accessibility and the high costs of full-scale physical monitoring, including multi-room temperature monitoring. Some studies – including current ones investigating behaviours – have used more limited monitoring focused specifically on consumption (e.g. wi-fi 'real time' energy consumption or energy bills). Selection bias is a risk where there is inconsistent promotion (Woosey 2012) or take-up of a programme.
- Use of control samples: it is desirable to recruit control groups that will not receive measures but it can prove difficult to recruit "pure" control groups as many households have previously had some form of technical interventions such as double glazing and energy efficient appliances (Gupta et al 2013). Allowing for 'typical' measures (as opposed to 'intensive' measures like solid wall insulation) is therefore important (ibid).
- Attribution: it is difficult to disentangle technology performance from behavioural change (Oreszczyn 2014). Many studies report higher temperatures in homes after retrofitting and attribute this to comfort-taking (Huebner 2014) but higher temperatures may be due to other, physical, factors and may not impact on energy use. Temperature on its own may not be a good indicator of behaviour response. Similarly, if it is not identified or reported by households, under-performance of installed measures may mask apparent behaviour effects (Woosey 2012). "Externalities" (weather, energy tariffs, etc.) can also affect the comparison of pre- and post-installation energy measurements.
- Having a good measure of energy consumption pre- and post-installation: experts tend to recommend monitoring over two heating seasons, pre and post installation, though this is not always achieved (Sorrell et al 2009) because of practical and cost constraints. Accessing energy bills or meter readings has proved problematic (Woosey 2012; Sustainable Homes 2014; DECC 2012).

Factors to take into account in designing qualitative insight projects

4.6. The evidence scan points to limitations and recommendations that need to be considered where qualitative research is included in proposed research options:

- Social desirability response bias (which refers to wanting to give the 'right' answer), for example, reporting lower thermostat settings than the actual set temperature (Love 2014).
- Reliability of respondent recall. Energy use is a habitual behaviour which households might not be aware of (Shipworth, 2014) so that individuals may have limited capacity/inclination to recall behaviour accurately. This feature is explicitly recognised in [H4]. Accuracy of recall applies similarly to individuals' subjective experience of the performance of measures versus the actual technical performance (Love, 2014). It is therefore desirable to balance qualitative evidence on energy consumption with objective information, even if the latter is limited in scope.
- Use of in-depth methods: walkthroughs and in-home visits, and quasi-ethnographic interviews, can help overcome problems arising from simple depth interviews or self-completion diaries. In-home visits can expose challenges faced by occupants in using the technology (Gupta et al 2014a; Love 2014; Woosey, 2012). The project team also suggests it confirms the importance of understanding the wider home/lifestyle context of energy use, not only direct consumption actions.

4.7. In summary, the evidence scan points to a need for creative research methods that are capable of considering the complex interactions between daily life, personal identity, technological change and context. In particular, attention needs to be paid to the following specific features:

- Time periods – with a preference for two heating seasons (before/after);
- Sampling – including issues of access, size, study population and selection bias;
- Range of measures installed – recognising variation in response to different measures;
- Monitoring techniques – including trade-offs of the limitations between simple (e.g. energy bills) and extensive (e.g. whole house physical monitoring);
- The benefits of mixed methods – combining physical monitoring and customer insight research and/or household surveys.

5. Response to the research gaps

This section provides a response to the identified headline research hypotheses

5.1. This study has identified gaps in the understanding of:

- the impact of comfort-taking on observed energy savings; and
- why comfort-taking occurs and the behavioural factors that influence consumer responses to installation of energy efficiency measures.

5.2. On the issue of impact, there is a deficit of evidence on how comfort-taking might vary across consumer types/situations and in relation to aspects of the energy efficiency programme (i.e. the mix or sequencing of measures).

5.3. On the issue of causal factors, the study has identified a wide range of relevant research hypotheses pertinent to understanding the behavioural determinants of comfort-taking in the context of Green Deal and ECO that are not adequately addressed in the literature.

5.4. Behavioural responses to energy efficiency measures are commonly cited as a key influence on energy impacts but are recognised as an overarching gap in knowledge. Energy-relevant behaviours and household practices are not yet understood at a level that can be reliably predicted, and therefore quantified robustly.

5.5. Some studies underway are seeking to infer behaviours from energy use (e.g. IDEAL) or undertake long-term energy behaviour tracking (e.g. UCL Energy Lab[19]) but these are long-term projects and are not centrally focused on post-installation behaviour. The sub-sample of Green Deal households within those samples is likely to be small.

5.6. The scan of past and present research has demonstrated why the research topics of interest have resisted comprehensive analysis thus far: the theoretical, practical and economic barriers to the design and delivery of truly robust projects in this space are significant. The difficulties of household recruitment, of collecting reliable data on household conditions, of securing *ex ante* and *ex post* monitoring over several heating seasons are just some of the hurdles to be overcome.

5.7. It is therefore clear that quantifying the impacts of the Green Deal/ECO programme is not straightforward. Establishing the scale and determinants of rebound effects in households participating in the programme will require long term research.

5.8. Pre-installation research over at least one heating season is needed to establish a baseline against which to reference post-installation behaviours. However, *ex ante*

[19] Descriptions of the IDEAL and UCL Energy Lab projects are included in Annexes 6 and 7

monitoring is not easily reconciled with the current delivery model for either Green Deal or ECO.

5.9. The challenge therefore, is to identify options that can yield useful short term results within the available research window, but also lay the foundations of a more comprehensive solution.

5.10. These options are:

- A project, that could be completed within the shorter term, involving in-depth **qualitative research to gather insights on customers' post-installation behaviours and practices** (addressing the objective on 'behavioural underpinnings of comfort-taking'), with a potential follow-on quantitative project;
- For DECC to **engage with the lead researchers in selected university-led research projects** to explore the potential for those projects to contribute to the agenda outlined in this paper by incorporating a Green Deal/ECO component into their designs (aiming to contribute towards enhanced understanding of both the scale of comfort-taking and its behaviour underpinnings in a GD/ECO programme context).
- A small project which could focus on identifying adjustments to the Green Deal and ECO programme model that could (i) **lower the practical and cost barriers** (ii) **increase the opportunities** to monitor the programme's impact, evaluate feasibility, and re-evaluate the research options available on the basis of the adjustments agreed.

5.11. These would be complementary projects and could be best regarded as a package. Together these projects could lay the foundations for the future development of a much larger, long term research solution through:

- Providing **evidence** on the spectrum of post-installation behaviours;
- Establishing the **partnerships** that would enable an approach to the research questions that joined up relevant research initiatives in progress across the country;
- Identifying opportunities to improve the economics and practicalities of the **research environment** provided by the programme through adjustments to the programme model.

1: Conduct user-centred research on post-installation behaviours and practices

5.12. The purpose of this project would be to develop an in-depth understanding of behavioural practices relevant to energy use in the home, with a specific focus on how households have responded to the installation of Green Deal type measures. The project would explore underlying influences on behavioural practices, interactions with technology and programme design.

5.13. The first phase of the project would consist of in-depth qualitative research. The project would begin to build an explanatory account of how and why energy savings

are achieved (or under-achieved) in the Green Deal, to inform outputs from its impact modelling and, potentially, to provide foundations for improved modelling/prediction in future. It would build on the DECC High/Low study (DECC, 2012a) and the Green demonstration solid wall insulation project[20]. Links could be made to one or more university-based research projects for collaboration on quantitative follow-up depending on how those projects develop (see Annex 6 and 7).

5.14. Findings could be of immediate use to flag ways to help customers maximise savings from Green Deal or other energy efficiency measures. Interviews could be built into further rounds of the Green Deal evaluation.

5.15. The proposed approach would be a programme of quasi-ethnographic, in-home interviews of two hours duration, with interview guides framed around aspects defined in the selected hypotheses. The approach would be based on a purposive sample. The research hypotheses would be used to inform design of interview guides. A pragmatic approach would be taken to sample structure recognising the pattern of take-up of Green Deal plans, Green Deal assessment and ECO. Findings could not be used for statistical generalisation or predictive modelling.

5.16. The project, which would take around six months, is described in detail at Annex 5. Three sample size options are proposed: 24, 40 and 60. The larger sample size option would provide some scope for statistical analysis between groups (e.g. QCA, non-parametric tests of association), and would also offer some economies of scale. The principal project risk would be expected to be sample access. A scoping phase could be used to finalise the approach and costs.

5.17. Follow-on quantitative research could be considered as a second stage. Using outcomes from the qualitative insight research, this would seek to develop a behaviour scale/index for use in quantitative modelling. It would explain variance in comfort-taking with reference to aspects of customer behaviour responses, in addition to other known factors such as technology, building type and socio-demographics. The follow-on project would require large-scale quantitative consumer survey of households exposed to GD/ECO, with an indicative minimum sample size of 2,000 to enable either/both factor analysis or segmentation. Questionnaire design would build from the project and other projects identified in the evidence scan that have used survey approaches.

2: Establish research partnerships

5.18. Challenges to be addressed in tackling the research questions on behavioural responses to the Green Deal and ECO include:

- Neither the Green Deal nor ECO programme models are compatible with conducting the long term pre-installation monitoring required to determine change in energy usage at household level;

[20] Described in Annex 7.

- The limited understanding of the variation in observed energy use at a household level (having controlled for building type and efficiency) makes it difficult to generalise findings from small samples to the whole population;
- Large scale monitoring at household level using the methods traditionally deployed in home energy use research projects (e.g. consumers self-reporting energy use, temperature) is expensive and does not necessarily yield reliable results;
- While the National Energy Efficiency Data-Framework (NEED)[21] offers a potential long term solution to the problem of pre-installation energy consumption monitoring (by providing household-level consumption data over a number of years), the relevant types of data are not expected to be available to Green Deal/ECO analysts for the foreseeable future.

5.19. The research conducted for this feasibility study has concluded that there are advantages to partnering with current and planned home energy use research projects being undertaken by a number of UK universities, rather than attempting to tackle the research challenge independently. Partnership with, and expansion of the scope of, existing research projects could help DECC to address a broad range of questions on comfort-taking in the home before and after installation of energy efficiency measures. An integrated strategy could give access to technologies, analytical methods, and households relevant to the research questions. The research activity would encompass physical monitoring and collection of social/contextual data to find evidence of and the reason behind energy consumption and behaviour in the home. Recruiting samples for long term studies of the kind required to address the identified research questions is often difficult and expensive – securing additional public value added from existing and planned research projects could improve the overall value-for-money of investment in such research activity.

5.20. Annexes 6 and 7 provide a mapping of the research projects that have been reviewed for this study against the research hypotheses that have been identified. They show where and how each project could potentially contribute to the overall research programme. Two of the current projects – IDEAL and ORIGIN - have designed state of the art monitoring devices to collect data on indoor temperature, indoor air quality, electricity and gas demand, which are combined with metadata about the weather, building characteristics and household composition. These projects potentially offer the opportunity to combine highly advanced physical monitoring with qualitative methods to gather evidence on causes behind outcomes and variations in energy use, comfort and other household behaviour. Integrating a GD/ECO component into other projects would give DECC outputs from a nationally representative study, albeit with some delay. Within the Energy Lab sample, for example, a sample could be selected, monitored for one year and then incentivised to embark on the Green Deal customer journey. This would allow for pre- and post-installation comparison.

[21] See https://www.gov.uk/government/collections/national-energy-efficiency-data-need-framework

5.21. Working with these projects would be a long term endeavour. The projects are not currently configured to address GD/ECO programme specific issues. Setting up any collaboration would take time, as would design and recruitment of the sample and then installation of monitoring arrangements. The highlighted projects have not as yet gathered data. Information on pre-installation consumption would therefore either require a period of monitoring (ideally summer and winter months with one full heating season) before installation of measures or access to via historical bills or (if possible) NEED. Multi-annual funding arrangements would be required.

5.22. Engagement with the leadership of the projects was beyond the scope of this feasibility study. If collaboration were agreed, a more detailed definition of the form of collaboration and associated research plan could be prepared. An initial step would be for DECC to make contact with researchers currently designing the IDEAL, ORIGIN and Energy Lab projects to explore the possibility for the addition of Green Deal/ECO elements to their current research design, and under what terms. The approach would therefore be conditional on outcomes of those consultations.

5.23. These three potential research partners are described in detail at Annex 6 and 7. Annex 7 includes a list of other ongoing research projects with relevance to post-installation consumer behaviour. It identifies a range of possibilities of what might be gained from these projects either by collaborating with them in their current form or by modifying the research design to answer the post-installation behaviour questions. While this list is not to be seen as exhaustive, it provides an overview of the current research landscape, how DECC could possibly learn from them and what the short-term engagement strategy to link up with these projects could look like. It provides the possibility to explore other options in follow-up work if DECC sees value in doing so.

5.24. If initial consultations are positive the next step would be to work up project specifications based on the target hypotheses and associated funding arrangements.

3: Build a better platform for research on the programme

5.25. The aim of this project would be to identify where specific aspects of the Green Deal and ECO programme design creates barriers and/or increases the cost of conducting monitoring and research on the programme's impacts, and assess options for removing those barriers. The project could then revisit, working with research partners, the approaches that the programmes could support if/when those barriers are removed.

5.26. The GD/ECO evaluation has already identified a number of issues that make establishment of a cohesive impact monitoring system more difficult and expensive. Examples include:

- Customers on the Green Deal or ECO customer journey are not invited to provide consent to participate in programme research that is in the public interest;
- The telephone numbers of households that have a Green Deal assessment are not held on the Landmark database, such that researchers appointed by DECC need to write and/or door-knock to engage those programme

customers in research, significantly increasing the cost and complexity of engagement;

- DECC does not, under the terms of its contract, have access to all the Energy Performance Certificate (EPC) data lodged by assessors that are potentially of interest for DECC researchers.

5.27. A structured review of customer recruitment and data access issues involving DECC statisticians, research and policy staff, and research contractors could help to identify any further problems. This could be done through one or more workshops.

5.28. The next task would be to identify and explore potential remedies. This work would require engagement with a wider set of actors (e.g. Ofgem, Energy Savings Trust, DECC service providers). Addressing some barriers might require amendments to terms of contracts to be applied when services are retendered. Some might require modifications to databases and information management systems. The costs and benefits of potential remedies should be researched, described and presented together with a statement of the benefits of removing the barrier.

5.29. The final task would be to consider, based on the programme adjustments that have been agreed in the preceding task and the outline agreements reached with research partners under the preceding project, developing an integrated approach that (i) addresses the research questions identified in this study (ii) provides an improved programme of impact monitoring system. This could be done initially through workshops involving DECC staff and with the research partners, and then worked up further through consultations with programme delivery partners.

5.30. An example of the opportunity that might be opened up by a combination of collaboration with research partners and adjustments to the programme model would be the recruitment of customers who are at an early stage of the Green Deal customer journey into an in-home monitoring programme using the kind of smart technologies deployed in some of the research projects reviewed for this study. Together with use of smart meters, ECO could in this way provide a rich stream of data on in-home energy use and temperature that, in combination with targeted social research, could shed light on post-installation experience in a programme context whilst also contributing to the wider understanding of in-home energy use. Consultations would be needed with Ofgem, obligated energy companies, etc. to determine the feasibility of integrating such approaches into the Green Deal / ECO programme model, and over what time scales. Proposals could then be developed for the monitoring activity, including size and structure of sample.

5.31. The table below summarises the challenges and potential responses as suggested by the feasibility study research. The outcome of this project would have a significant impact on the future research options available and their cost.

Table 5.1 Research challenges and potential responses

Stage/activity	Issues	Potential response
Identification & recruitment		
	ECO database and EPC and Occupancy Assessment (OA) databases facilitate identification of programme participants but the costs of conducting research with these participants is higher and the logistics more complex than they would be if customers had provided consent and telephone or email contact details were available	Look at whether GD data capture/use barriers could be addressed in the future to reduce costs of engaging with households that have had GD assessments & so improve capacity for monitoring of the programme. Assessors obliged to invite customers to provide consent to participate in public purpose research on the programme as part of GD assessment protocol, with response lodged to the database. Customer phone number and/or email address captured and available to researchers.
	Project experience is that recruitment of homes is expensive, time-consuming and difficult	Engage with Ofgem and obligated parties to examine scope for ECO delivery model to support recruitment of customers into authorised research programmes (or introduce obligation to support recruitment and monitoring on obligated parties), e.g. by customers being invited to give consent to being contacted by a research organisation. Look at scope to incentivise GD providers to recruit households, or question in GD assessment on willingness to participate in monitoring. Partner up with social landlords or housing agencies to gain "trusted messenger" buy-in or simplified means to reach households.
Data capture		
General		
	Site visits to collect data (meter-readings) is expensive while self-reporting is unreliable and burdensome for householders.	Use 'smart' approaches in place of site visits, for instance: - Looking to remote monitoring, potentially using the kind of technical devices applied in other research projects (e.g. IDEAL). - Installing smart meters in recruited households and (subject to householder consent) linking them to a monitoring network; - Exploring the potential for use of macro / 'big data' solutions that [in a protected space] cross reference aggregated programme participant data against aggregated energy consumption data gathered in the energy supply network. Available options and their costs would depend on: (i) conclusions of the research partnership discussions; (ii) agreements on access to technologies and customers; (iii) conclusions of the 'programme research optimisation' work on changing requests for consent and access to customer data.
	Variation in practice within the GD programme model – e.g. variation in depth (time	Gather data on the customer journey so that allowance can be made for variation in programme delivery

Stage/activity	Issues	Potential response
	taken) and coverage (topics covered) of Green Deal assessment	
Control data		
	Capturing pre-installation data is hard – ECO incentives drive rapid delivery; ethics (and cost) of deferring delivery to monitor energy use.	Explore potential for use of macro / 'big data' solutions that [in a protected space] cross reference aggregated programme participant data against aggregated energy consumption data gathered in the energy supply network, comparing consumption before participation in the programme with later consumption. Explore potential in GD and ECO for inviting households to defer installations
	Capturing data from a control group outside the programme adds costs	Look in more depth at use of potential for other projects to provide non-GD & ECO control data
	The process of monitoring the control group could influence their behaviour (i.e. if they are required to collect bi-weekly meter readings) and therefore reliability of the collected data	Remote monitoring and smart meters are a less disruptive way to ensure objectivity of data
	Recruiting "pure" control groups is difficult as many households have had some form of technical intervention	Discern between 'typical' technical improvements e.g. double glazing, energy rated appliances and 'intensive' technical improvements e.g. solid wall insulation and hard to treat cavity wall insulation
Analysis	Behavioural influences on energy consumption appear to be important but are poorly understood	Aggregation of evidence from projects such as the proposed qualitative research project and third party research
Finance	Monitoring of home energy use is costly	Use smart technologies / approaches to reduce unit costs Look to integrate with / link to other projects to reduce costs (e.g. access to control data) Explore potential for future ECO monitoring to be financed via the obligation in future phases

5.32. The options identification task could give specific consideration to opportunities to complement the 'micro' strategy (i.e. data from in-home monitoring) with a 'macro', or 'big data' approach that seeks to combine data on programme participation with data on property-level energy consumption held in the energy supply network. Analysis of long term energy consumption data from the hundreds of thousands of households that have had ECO installations would provide some indication of the typical scale of reduction in energy consumption resulting from installation of the given measures. Similar analysis for households that have had Green Deal Assessments would provide opportunities to, for instance, compare baseline energy consumption of households that have received a Green Deal assessments with the consumption of those that have not and then track the change in energy use over time for both the programme participants and the control group.

5.33. The starting point for elaboration and appraisal of this option would be the NEED data framework established by DECC. A review of NEED documentation suggests that it contains the relevant energy consumption information for a sample of

households of interest. This information is linked into other key databases that facilitate analysis of household energy consumption against geographic, socio-economic and other parameters. Privacy protocols are established, analytical capacity is in place. The timescale for delivery of relevant data and analytical outputs would need to be confirmed.

Portfolio summary

5.34. The table below provides a summary of the possible actions.

Table 5.2 Option overviews

	Conduct research on customers' post-installation behaviours and practices	Establish research partnerships	Build a better platform for research on the programme
Purpose	To develop an in-depth qualitative understanding of behavioural practices relevant to energy use in the home, with a specific focus on how households have responded to the installation of Green Deal type measures.	Establish partnerships to answer a broad range of questions on comfort-taking in the home before and after installation of energy efficiency measures.	Identify adjustments to the programme model that would reduce the cost and increase the potential for research, and identify the research approaches that become feasible under this new set of constraints.
Hypotheses	Broad coverage of research hypotheses to deliver in-depth insight. Hypotheses focus on: underlying influences on behavioural practices; interactions with technology and programme design. Hypotheses would be used to inform design of interview guides.	Research partnerships could provide a broad coverage of hypotheses related to comfort-taking and change of comfort-taking. Insights would be used to provide evidence for H1, H3, H4, H8, H9, H10, H12.	Estimation of impacts and comfort-taking through analysis of energy use of programme customers and potentially through use of control groups of households outside the programme (via collaboration with research partners).
Benefits	DECC would begin to build an explanatory account of how and why energy savings are achieved (or under-achieved) in the Green Deal, to inform outputs from its impact modelling and, potentially, to provide foundations for improved modelling/prediction in future. Findings would be of immediate use to flag ways to help customers maximise savings from GD or other energy efficiency measures. Interviews could be built into further rounds of GD evaluation.	Outputs of the research partnerships could support better modelling of behaviour factors and the ability to develop a robust understanding of how those behaviour factors come about. Social/contextual data can be assessed alongside monitored data, revealing the causes behind outcomes and variations in energy use and behaviour, and the impact of installations on indoor air quality and temperature, comfort and occupant behaviour and how they are associated with observable household characteristics. The selected projects would also offer a simplified way of accessing control groups and representative samples	Would establish more favourable conditions for research on behavioural effects and on programme impacts by addressing cost and practical barriers to recruitment and engagement. Would create a stronger platform for commissioned and collaborative research.
Limitations	Qualitative approach based on a purposive sample: findings could not be used for statistical generalisation or predictive modelling.	Ongoing research projects rarely collect pre-installation data for a large sample. Most samples are not nationally representative. Some of the current projects are still in the sign-off phase and might not go ahead as planned/ have long lead times.	Pre-installation monitoring problems not easily resolvable given fundamentals of programme design, though energy consumption data potentially available via matching to NEED.
Approach	Quasi-ethnographic in-home interviews of two hours duration, with interview guides framed	After review and consultations, IDEAL's or ORIGIN's recruitment strategy and monitoring	Consultative process to facilitate the identification of barriers and appraisal of

	Conduct research on customers' post-installation behaviours and practices	Establish research partnerships	Build a better platform for research on the programme
	around aspects defined in the selected hypotheses. Pragmatic approach to sample structure recognising the pattern of take-up of the GD package, GD assessment and ECO. Four sub-groups targeted. Three sample size options proposed: 24, 40 or 60. Larger sample size option provides some scope for statistical analysis between groups (e.g. QCA, non-parametric tests of association). Risks identified with respect to sample access, suggesting a scoping phase to finalise the approach and costs.	procedures could be applied to i) a GD/ECO sample and ii) a control group. State of the art monitoring devices collect data indicative of energy consumption behaviour A GD/ECO focussed component could be included in the UCL Energy Lab's survey questionnaire. Monitored households under the survey could be recruited to undergo GD/ECO (whole customer journey) or to install GD/ECO measures.[22]	remedies. Engagement with research and programme delivery partners on approach identification and appraisal (e.g. exploring where there is scope to modify programme design to include incentives to participate in research (including temperature monitoring)).
Links to other projects	Builds on learning from DECC High/Low study (DECC, 2012a) and current Green Deal demonstration solid wall insulation project. Possible future links to one or more UK ERC centres for collaboration on quantitative follow-up depending on how those projects develop.	UCL Energy Lab could provide a platform for the quantitative follow-on to the proposed research project on customer-centred insights on post-installation behaviours and practices. The initial qualitative project would provide insights potentially helpful for the Energy Lab household surveys. Could potentially be conducted in cooperation with the monitoring plan. ORIGIN and IDEAL methodologies could be applied to a GD/ECO sample to provide insights to the second part of the proposed research project. Monitoring devices could be installed in households recruited for the first part of the project. The project could potentially be recruited from the IDEAL or ORIGIN sample if a GD focus is included.	Programme adjustments improve its capacity to support cost-effective research into programme impacts and rebound effects. Opportunities to link with other research projects and research interests on control groups, monitoring technologies, etc.

[22] The precise approach cannot be worked up because it would depend on the projects DECC wished to co-opt or collaborate with and the practicalities and possibilities to do so.

6. Conclusions

6.1. This feasibility study has examined the focus and feasibility of conducting research on household energy consumption and related behaviours in households that have had measures installed after a Green Deal assessment or by ECO. Its primary focus was on identifying options feasible within the current evaluation but it also looks to longer term strategies.

6.2. It has shown how quantifying the scale of energy savings and avoided carbon emissions delivered by the programme, taking into account household behaviour, means tackling issues that researchers have struggled with for many years. There are fundamental design challenges for which there are no easy solutions. Existing home energy use research projects have not involved significant numbers of Green Deal and ECO programme customers, and the programme design makes both recruitment and *ex ante* monitoring more difficult than it might be. Obtaining firm answers to the priority research questions is not feasible within the window provided by the current evaluation contract which ends in April 2015.

6.3. The study concludes that DECC's emphasis in the short term could instead be put on building the foundations of a long term research effort to properly address the research questions that have been identified. This could be achieved through:

- Conducting in-depth qualitative research with a cross section of Green Deal and ECO customers to begin to build an explanatory account of how and why energy savings are achieved (or under-achieved) in the Green Deal and, potentially, to provide foundations for improved modelling/prediction in future;
- Engaging with the leaders of selected research projects with a view to building collaborative research partnerships that could help address questions relating to the impact of Green Deal and ECO programme;
- Looking at how adjustments to the detailed configuration of the programme could: (i) reduce the costs and complexity of research with programme customers; and (ii) open up new research options.

6.4. In-depth qualitative research with programme customers could provide a better understanding of behavioural practices relevant to energy use in the home, with a specific focus on how households have responded to the installation of Green Deal type measures.

6.5. While there are several research projects on energy use in the home in progress and in preparation in the UK, none addresses the particular requirements of the Green Deal / ECO programme. Some are, however, developing and deploying innovative technologies and analytical techniques. Some could potentially be used as platforms for research relevant to the programme, or to provide control groups. Consultations

with the leaders of those projects could identify fundable augmentations and adaptations that would enable the projects to examine energy consumption and rebound specifically in the context of the Green Deal and ECO. At the time of writing some of the project concepts were still in their development phase; the decisions taken on the future of those projects will shape their potential to contribute to the issues addressed by this feasibility study.

6.6. There is also an opportunity to take stock and consider how the programme model and the capture and management of programme data could be adjusted to: (i) reduce costs (ii) increase options for monitoring various aspects of its impact (taking into account energy-relevant behaviours).

6.7. With these actions completed it would then be possible for DECC to work with research partners to put in place a long term strategy that addresses the research questions identified in this feasibility study, making best use of:

- The recruitment efforts, technologies and infrastructure of the research projects with which partnership have been forged;
- The enhanced customer recruitment, data access and other arrangements put in place to support research and evaluation of the programme;
- The preliminary insights on customer behaviours provided by the in-depth qualitative research.

6.8. The value of this strategy would not be limited to better estimation of the impacts of the Green Deal and ECO programme. An improved understanding of consumer behaviours relating to energy use following installation of energy efficiency measures would benefit the wider efforts to tackle fuel poverty and improve home energy efficiency.

Annex 1: Method

This annex describes the method adopted for the study. There were four stages, as follows:

- Definition of purpose and potential research hypotheses;
- A strategic appraisal of research;
- Definition and development of research options;
- Presentation of findings to inform ongoing and future research programmes.

Task 1: Definition of hypotheses

The purpose of task 1 was to confirm the purpose of the study and define potential research hypotheses that would meet the evaluation priorities and support the wider programme based on a:

- Review of the GD and ECO logic model, GD assessment methodology and tool, and other DECC programme documentation;
- Review of assumptions in the Green Deal impact assessment model;
- Consideration of consumer behaviours (and skills) assumptions relevant to the Green Deal/ECO;
- Consultations with DECC officials and the research community.

A short list of hypotheses was proposed via an interim note to DECC and comments received.

Task 2: Strategic appraisal of research

Information on research work in progress or completed relevant to the agreed research hypotheses was identified through conversations with DECC officials, contacts with the research community and a scan of the literature. The purpose of this was to assist in:

- confirming the validity of the hypotheses identified above;
- the identification of gaps in the relevant evidence base;
- the identification of the most valid research methods for testing these hypotheses;
- the review of existing or planned research projects with which DECC could coordinate for Project 6[23].

[23] This is a reference to a component of the Green Deal / ECO programme evaluation that was intended to focus on research into the impacts of the programme on consumer behaviours and energy consumption.

Evidence reviewed included:

- Information on the GD and ECO customer journey/experience to identify and highlight feasible opportunities for gathering relevant data;
- Installation data (GD/ECO/other) and consider how issues may vary according to the measure installed;
- Wider DECC data sets (NEED, etc);
- Each organisation's (DECC, ICF, Brook Lyndhurst, Heriot Watt University) own research and internal library of documents/research reports;
- DECC published (and un-published) research back catalogue (including work commissioned by the Energy Efficiency Deployment Office on heating behaviours and heating controls);
- Consultation with key staff from Brook Lyndhurst, ICF, GfK, Herriot Watt University and DECC, for their input on potential sources of evidence;
- Evidence recommended by key interviewees and academics;
- Evidence submitted under the call for evidence launched under the Sustainable Development Research Network (SDRN)
- A review of key online sources, including academic journals and abstracts.

The research review was not to be a formal Rapid Evidence Assessment according to GSI guidelines (due to time and budget constraints), though some of the techniques used in REA were applied. The study team's judgement was used in determining relevance and the scan was not to be as systematic as a formal REA.

On-going research and future research projects supported by DECC and in the external academic and research community that DECC can cooperate with were identified.

Scan of the peer-reviewed literature

The Google Scholar search engine was used to search for peer-reviewed journal articles relevant to post-installation behaviour. Search terms (Box 1) were defined by the research team and refined through conversations with DECC.

Box 1: Search terms

post-installation energy efficiency; household consumer energy behaviour; energy behaviour agent based model; energy behaviour direct rebound effects; energy efficiency saving behaviour; energy behaviour comfort

The following broad criteria were used to identify relevant evidence:

- Peer-reviewed journal articles, to ensure a minimum threshold of quality;
- Recent (last 10 years – though not strictly applied if slightly older, relevant evidence was found);
- UK-based (again, not strictly applied);
- About household behaviours (excluded research about e.g. offices);

- Abstract containing the keywords/search terms;
- Conceptually or methodologically relevant to the research question: understanding the post-installation behaviours of households who have installed energy efficiency measures, and how/which behaviours affect energy savings.

As well as noting the findings relevant to understanding post-installation behaviours, the team looked for commentary on methods that had worked well, problems experienced in application of chosen methods, and commentary on methodological limitations as background for working up options for Project 6.

The literature search proceeded in three steps: (1) long-listing; (2) short-listing; and (3) reading. First, a database of 90 references based on the search terms above was built. Second, the papers in this long list of 90 were assessed for relevance based on abstract and content scans in order to produce a short list of key readings. Third, the papers on the key texts short list were read in more detail and key information extracted and recorded. The list of all references (long-list) can be found in Annex 3. Details of the literature reviewed in the evidence scan (short-list) can be found in Annex 8.

Scan of the grey literature

Grey literature was selected from evidence provided by DECC, contractor resources, and from material found through snowballing[24]. DECC staff reviewed a list, prepared by the project team, of experts and suggested priorities. The schedule in 0 lists the experts consulted.

In addition, a call for evidence was made via the Sustainable Development Research Network (SDRN) newsletter. The replies were logged and (depending on availability of the respective researcher and relevance) were included in the expert consultations. Papers submitted as part of the response to the call for evidence or sent through as follow-ups to the expert consultations were assessed for relevance based on abstract and content scans.

How findings from the evidence scan were used

The quick evidence scan had a specific and narrow focus: to provide background intelligence for a series of workshops involving the project team members and DECC, where research propositions for investigating post-installation customer behaviour were developed (set out in chapter 4).

The scan was designed to complement the team's existing knowledge of the energy behaviours evidence base, to provide a sense-check on the validity of the initial hypotheses, to highlight research gaps in relation to the specific focus of post-installation behaviours, and learn from methods used in completed or on-going studies. The core focus was energy use and energy-related behaviours; technical studies of energy impacts and comfort from energy efficiency measures were identified only where the 'human' or behaviour dimension was mentioned.

Given this purpose (and time constraints) insights from the literature were recorded in relation to the initial hypotheses, for presentation at the workshops, rather than in

[24] Snowballing is an approach in which the researcher starts with a small number of relevant texts and increases this number with the assistance of the first set, e.g. following the references in the initial papers

conventional evidence review style involving systematic summary of each paper, analysis and synthesis. Details of the literature reviewed in the evidence scan (short-list) can be found in Annex 8.

Task 3: Definition and development of research options

The research project options needed to be feasible and affordable within resource, timing and other constraints. This task involved:

- Refining and developing hypotheses and associated research questions based on the preceding tasks;
- Organising and conducting a series of semi-structured brainstorming sessions among the research team and DECC to review findings from the content review and develop options for research projects;
- Undertaking an iterative process of developing, assessing and refining recommended options, including in each case:
  - The hypotheses tested (and those not tested);
  - Sampling approaches;
  - The methodological challenges posed (and associated solutions);
  - Costs and other practical issues;
  - Gaps in DECC's understanding and knowledge in this area;
  - Timing (taking into account seasonal effects and programme information needs); and
  - Feasibility of linking research to other relevant research.

Task 4: Presentation of findings to inform ongoing and future research programmes

This report is the output of task 4. It is required to review all relevant hypotheses, feasible research options (both those to be DECC funded and those linked to other external research) and recommended options of which research projects may wish to proceed with. In presenting the recommended options, it is required to consider:

- the hypotheses
- the robustness of the research approach
- practical concerns, e.g. costs, timing, capacity, inputs, outputs
- the value added to DECC, and to the Green Deal / ECO evaluation in particular, of each option;
- any additional communication/network support activities that might be warranted to meet the objectives of Project 6, over and above those provided for within the specific research options.

Annex 2: List of experts consulted

Name	Affiliation	Rationale/Role	Consultation
Dr David Shipworth	UCL Centre for Energy Epidemiology	Lead researcher UK Energy Lab Feasibility Project	Personal communication 28th March, 2014 Referenced as Shipworth 2014
Prof Tadj Oreszczyn	UCL Energy Institute	• Part of Complex Built Environment Systems group • Part of the People, Energy and Buildings: Distribution, Diversity and Dynamics project at UCL Energy Institute • Inputted into Lit Review of Overheating	Personal communication 27th March, 2014 Referenced as Oreszczyn 2014
Dr Gesche Huebner	UCL Energy Institute	Part of the People, Energy and Buildings: Distribution, Diversity and Dynamics project at UCL Energy Institute	Personal communication, written response to topic guide 27th March, 2014 Referenced as Huebner 2014
Dr Steve Sorrell	Sussex Energy Group University of Sussex	• Director of the Centre on Innovation and Energy Demand • Internationally recognised expert on the 'rebound effects'	Personal communication 25th March, 2014 Referenced as Sorrell 2014
Dr Sally Caird	Open University	Conducted research on user experiences and influence on heat pump performance.	Personal communication via email only
William Wright	Sustainable Homes	Conducts study which monitors energy usage in 600 housing association properties	Personal communication 11th March, 2014 Referenced as Sustainable Homes 2014
Prof. Rajat Gupta	Oxford Brookes	• Heads Low Carbon Building Group and the Oxford Institute for Sustainable Development • Ran project under EVALOC	Personal communication via email only
Helen Mulligan	Cambridge Architectural Research Ltd	Researched experience during two Retrofit for the Future projects	Personal communication via email only
Prof Erik Bichard	Salford University	Led research at the Energy House and attitudes to energy use	Personal communication 28th March, 2014
Jennifer Love, PhD	UCL Energy Institute	Researched, *inter alia*, the effect of retrofit on space use of occupants of UK dwelling	Personal communication 2nd April, 2014 Referenced as Love 2014

Annex 3: References

Abrahamse, W., Steg, L., (2009). How do socio-demographic and psychological factors relate to households' direct and indirect energy use and savings? Journal of Economic Psychology 30 : 711–720.

Abrahamse, Wokje, et al, (2005). A review of intervention studies aimed at household energy conservation." Journal of environmental psychology 25.3: 273-291.

Adua, Lazarus, (2010). To cool a sweltering earth: Does energy efficiency improvement offset the climate impacts of lifestyle? Energy Policy 38.10 : 5719-5732.

Allcott, H., & Mullainathan, S., (2010). Behavioral science and energy policy. Science, 327(5970), 1204-1205.

Austin, A., Cox, J., Barnett, J. and Thomas, C., (2011). Exploring catalyst behaviours: Summary Report. A report to the Department for Environment, Food and Rural Affairs. Brook Lyndhurst for Defra, London.

Azar, Elie, and Carol C. Menassa, (2011). Agent-based modeling of occupants and their impact on energy use in commercial buildings. Journal of Computing in Civil Engineering 26.4: 506-518.

Behar, C., (2013) Utilising resident feedback to inform energy-saving interventions at the Barbican. Local Environment: The International Journal of Justice and Sustainability.

Black, J. Stanley, Paul C. Stern, and Julie T. Elworth, (1985). Personal and contextual influences on household energy adaptations. Journal of applied psychology 70.1 (1985): 3.

Bleda, M., & Valente, M., (2009). Graded eco-labels: a demand-oriented approach to reduce pollution. Technological forecasting and social change, 76(4), 512-524.

Boulanger P.-M. J. Couder, Y. Marenne, S. Nemoz, J. Vanhaverbeke, A. Verbruggen, G. Wallenborn, (2013). Household energy consumption and rebound effect. Belgian Science Policy 2013.

Brännlund, Runar, Tarek Ghalwash, and Jonas Nordström, (2007). Increased energy efficiency and the rebound effect: Effects on consumption and emissions. Energy economics 29.1 (2007): 1-17.

Caird, Sally, Robin Roy, and Horace Herring, (2008). Improving the energy performance of UK households: Results from surveys of consumer adoption and use of low-and zero-carbon technologies. Energy Efficiency 1.2: 149-166.

Caird, Sally, Robin Roy, and Stephen Potter, (2012). Domestic heat pumps in the UK: user behaviour, satisfaction and performance. Energy Efficiency 5.3: 283-301.

Cantono, S., & Silverberg, G. , (2009). A percolation model of eco-innovation diffusion: the relationship between diffusion, learning economies and subsidies. Technological forecasting and social change, 76(4), 487-496.

Carlsson-Kanyama, A., & Lindén, A. L., (2007). Energy efficiency in residences—Challenges for women and men in the North. Energy Policy, 35(4), 2163-2172.

Carlsson-Kanyama, Annika, Anna-Lisa Lindén, and Björn Eriksson, (2005). "Residential energy behaviour: does generation matter?" International Journal of Consumer Studies 29.3: 239-253.

Chatterton, T., (2011) An introduction to thinking about 'Energy Behaviour': a Multi Model Approach. DECC.

Chitnis, M, Sorrell, S, Druckman, A, Firth, SK, Jackson, T., (2014). Who rebounds most? Estimating direct and indirect rebound effects for different UK socioeconomic groups. SLRG Working Paper. Available at http://www.sustainablelifestyles.ac.uk/sites/default/files/publicationsdocs/slrg-wp-01-14.pdf

Chitnis, M., Sorrell, S, Druckman, A, Firth, SK, Jackson, T., (2013). Turning lights in to flights: Estimating direct and indirect rebound effects for UK households, Energy Policy 55, 234-250.

Craig, T., Polhill, J. G., Dent, I., Galan-Diaz, C., & Heslop, S., (2014). The North East Scotland Energy Monitoring Project: Exploring relationships between household occupants and energy usage. Energy and Buildings, 75(0), 493-503. doi: http://dx.doi.org/10.1016/j.enbuild.2014.02.038

Darby, S., (2001) Making it obvious: designing feedback into energy consumption in S Darby - Energy efficiency in household appliances and lighting.

Darnton, A, Verplanken, B, White, P and Whitmarsh, L., (2011). Habits, Routines and Sustainable Lifestyles: A summary report to the Department for Environment, Food and Rural Affairs.

Dimitropoulos, J., (2007). Energy productivity improvements and the rebound effect: An overview of the state of knowledge. Energy Policy 35.12: 6354-6363.

Dolan, P and Metcalfe, R., (2013). Neighbors, knowledge, and nuggets: Two natural field experiments on the role of incentives on energy conservation.

Dounis, Anastasios I., and Christos Caraiscos, (2009). Advanced control systems engineering for energy and comfort management in a building environment—A review. Renewable and Sustainable Energy Reviews 13.6 (2009): 1246-1261.

Druckman, Angela, et al, (2011). Missing carbon reductions? Exploring rebound and backfire effects in UK households. Energy Policy 39.: 3572-3581.

Ehrhardt-Martinez, Karen, and John A. Laitner, (2010). "Rebound, technology and people: Mitigating the rebound effect with energy-resource management and people-centered initiatives." ACEEE Summer Study on Energy Efficiency in Buildings. 2010.

Ekins, P., and C. Spataru, (2012). "To work, the Green Deal needs to take seriously the diversity of human behavior." HHIC Journal (2012).

Eppel, S., V. Sharp, L. Davies, (2013). A review of Defra's approach to building an evidence base for influencing sustainable behaviour, Resources, Conservation and Recycling, Volume 79, Elsevier.

Fell D., King G., (2012). “Domestic energy use study: to understand why comparable households use different amounts of energy”. A report to the Department for Energy and Climate Change. Brook Lyndhurst. DECC, London.

Fischer, Corinna, (2008). "Feedback on household electricity consumption: a tool for saving energy?" Energy Efficiency 1.1: 79-104.

Freire González, Jaume, (2010). "Empirical evidence of direct rebound effect in Catalonia." Energy Policy 38.5: 2309-2314.

Frenken, K and Faber, A., (2009). Introduction: Evolutionary methodologies for analyzing environmental innovations and the implications for environmental policy. 449-452 In Koen Frenken, Albert Faber (Eds) Sepcial Issue Technological forecasting and social change (2009)"

Frondel, Manuel, Jörg Peters, and Colin Vance, (2008). "Identifying the rebound: evidence from a German household panel." The Energy Journal (2008): 145-163.

Galvin, R., (2014). “Making the rebound effect more useful for performance evaluation of thermal retrofits of existing homes”, Energy and Buildings 69: 515-524

Gauthier, S; Shipworth, D., (2012). Predictive thermal comfort model: Are current field studies measuring the most influential variables? In: Proceedings of the 7th Windsor Conference: The Changing Context of Comfort in an Unpredictable World, Cumberland Lodge, Windsor, UK, 12-15 April 2012. NCEUB (Network for Comfort and Energy Use in Buildings)

Gauthier, S; Shipworth, D., (2013) Review of methods to map people's daily activity – application for smart homes. In: Sustainability in Energy and Buildings: Proceedings of the 4th International Conference on Sustainability in Energy and Buildings (SEB’12). Springer-Verlag: Berlin. (In press).

Gill, Z.M. M.J. Tierney, I.M. Pegg, A., (2010). Low-energy dwellings: the contribution of behaviours to actual performance. Building Research and Information, 38 (5), pp. 491–508.

Gram-Hanssen, Kirsten, (2010). Residential heat comfort practices: understanding users. Building Research & Information 38.2: 175-186.

Greening, Lorna, David L. Greene, and Carmen Difiglio, (2000). Energy efficiency and consumption—the rebound effect—a survey. Energy Policy 28.6: 389-401.

Gupta, R. and Kapsali, M., (2014a). Evaluating the effect of occupant behaviour and expecations on actual energy use and environmental conditions in “sustainable” social housing in South East England. Proceedings of 8th Windsor Conference: Counting the Cost of Comfort in a changing world. Cumberland Lodge, Windsor, UK, 10-13 April 2014.

Gupta, R., Barnfield, L. and Hipwood, T., (2014b). Impacts of community-led energy retrofitting of owner-occupied dwellings, Building Research & Information, DOI: 10.1080/09613218.2014.894742

Gupta, R.and Barnfield, L., (2013). Unravelling the unintended consequences of home energy improvements. Sustainable Building Conference. http://architecture.brookes.ac.uk/research/lowcarbonbuilding/index.html

Guy, Simon and Shove, Elizabeth (2000). “The Sociology of Energy, Buildings and the Environment: Constructing Knowledge, Designing Practice.” 2000. London: Routledge.

Gyberg, Per, and Jenny Palm, (2009). Influencing households’ energy behaviour—how is this done and on what premises? Energy Policy 37.7: 2807-2813.

Hamilton, I.G.; Summerfield, A.J.; Lowe, R.; Ruyssevelt, P.; Elwell, C.A.; Oreszczyn, T. (2013). Energy epidemiology: a new approach to end-use energy demand research. Building Research & Information, 41 (4) 482 - 497

Hargreaves, T., Nye, M. and Burgess, J., (2013). Keeping energy visible? Exploring how householders interact with feedback from smart energy monitors in the longer term. Energy Policy 52: 126-134.

Henly, John, Henry Ruderman, and Mark D. Levine, (1988). Energy saving resulting from the adoption of more efficient appliances: a follow-up. The Energy Journal: 163-170.

Hens, Hugo, Wout Parijs, and Mieke Deurinck, (2010). Energy consumption for heating and rebound effects. Energy and Buildings 42.1: 105-110.

Herring, Horace, and Robin Roy, (2007). Technological innovation, energy efficient design and the rebound effect. Technovation 27.4: 194-203.

Hong, Sung H., et al., (2009). A field study of thermal comfort in low-income dwellings in England before and after energy efficient refurbishment. Building and Environment 44.6: 1228-1236.

Hong, Sung H., Tadj Oreszczyn, and Ian Ridley, (2006). The impact of energy efficient refurbishment on the space heating fuel consumption in English dwellings. Energy and Buildings 38.10 (2006): 1171-1181.

Huebner, G. M., Cooper, J., and Jones K., (2014) Barriers towards reducing domestic Energy Consumption–Findings of a Study among Social Housing Tenants. International Journal of Environment and Sustainable Development, 13 (4) 425 - 448

Huebner, Gesche M., et al, (2013a). The reality of English living rooms–A comparison of internal temperatures against common model assumptions. Energy and Buildings 66: 688-696.

Huebner, Gesche Margarethe, Justine Cooper, and Keith Jones, (2013b). Domestic energy consumption—What role do comfort, habit, and knowledge about the heating system play? Energy and Buildings 66: 626-636.

Huebner, Gesche M., et al., (2013c). Heating patterns in English homes: Comparing results from a national survey against common model assumptions. Building and Environment 70 (2013c): 298-305.

Huebner, Gesche M., Justine Cooper, and Keith Jones, (2011). Energy saving practices, barriers against and reasons for change among social housing tenants. In: Proceedings of the research students conference on "Buildings don't use energy, people do?" - domestic energy use and CO2 emissions in existing dwellings, 28 June 2011 Bath. Bath: EDEn, University of Bath. Department of Architecture and Civil Engineering, University of Bath, Bath, UK.

Hughes, M; Palmer, J; Cheng, V; Shipworth, D; (2013). Sensitivity and Uncertainty Analysis of the UK's Housing Energy Model. Building Research and Information: the international journal of research, development and demonstration, 41 (2) 156 - 167.

Hutchinson, Emma J., et al, (2006). Can we improve the identification of cold homes for targeted home energy-efficiency improvements? Applied energy 83.11: 1198-1209.

Jaccard, Mark, and Bataille, Chris (2000). Estimating future elasticities of substitution for the rebound debate. Energy Policy 28.6: 451-455.

Jackson, J. (2012). Lessons learnt from prospective and actual occupants of energy efficient homes in a major Sustainable Urban Extension (SUE), Northampton, UK. Draft paper

Keirstead, James, (2007). Behavioural responses to photovoltaic systems in the UK domestic sector. Energy Policy 35.8: 4128-4141.

Kelly, S., Shipworth, M., Shipworth, D., Gentry M., Wright, A., Pollitt, M., Crawford-Brown, D., and Lomas, K, (2012). A panel model for predicting the diversity of internal temperatures from English dwellings. (Tyndall Working Papers 154). Tyndall Centre for Climate Change Research: Norwich, UK.

Lindén, Anna-Lisa, Annika Carlsson-Kanyama, and Björn Eriksson, (2006). Efficient and inefficient aspects of residential energy behaviour: What are the policy instruments for change? Energy Policy 34.14: 1918-1927.

Lopes, M. A. R., C. H. Antunes, and N. Martins, (2012). Energy behaviours as promoters of energy efficiency: A 21st century review. Renewable and Sustainable Energy Reviews 16.6: 4095-4104.

Madlener, Reinhard, and Blake Alcott, (2009). Energy rebound and economic growth: A review of the main issues and research needs. Energy 34.3: 370-376.

Masoso, O. T., and Grobler, L. J., (2010). The dark side of occupants' behaviour on building energy use. Energy and Buildings 42.2: 173-177.

McMichael, M; Shipworth, D, (2013). The value of social networks in the diffusion of energy efficiency innovations in UK households. Energy Policy , 53 159 - 168

Milne, G. and B. Boardman, (2000). Making cold homes warmer: the effect of energy efficiency improvements in low income homes. Energy Policy 28: 411-424.

Mizobuchi, Kenichi, (2008). An empirical study on the rebound effect considering capital costs." Energy Economics 30.5: 2486-2516.

Moran Jay, B; Howard, D; Hughes, N; Whitaker, J; Anandarajah, G; (2013). Modelling socio-environmental sensitivities: How public responses to low carbon energy technologies could shape the UK energy system. The Scientific World Journal

Nässén, Jonas, and John Holmberg, (2009). Quantifying the rebound effects of energy efficiency improvements and energy conserving behaviour in Sweden. Energy Efficiency 2.3: 221-231.

Ockwell, David G, (2008). Energy and economic growth: Grounding our understanding in physical reality. Energy Policy 36.12: 4600-4604.

Oikonomou, Vlasis, et al, (200(). Energy saving and energy efficiency concepts for policy making. Energy Policy 37.11: 4787-4796.

The Open University, Department of Engineering and Innovation. Research programme on consumer adoption, use and performance of low carbon energy efficiency and renewable technologies in residential buildings.

Oreszczyn, Tadj, et al, (2006). Determinants of winter indoor temperatures in low income households in England. Energy and Buildings 38.3: 245-252.

Oreszczyn, Tadj, et al, (2006). Mould and winter indoor relative humidity in low income households in England. Indoor and Built Environment 15.2: 125-135.

Ouyang, Jinlong, Enshen Long, and Kazunori Hokao, (2010). Rebound effect in Chinese household energy efficiency and solution for mitigating it. Energy 35.12: 5269-5276.

Pfafferott, J., and Herkel S., (2007). Statistical simulation of user behaviour in low-energy office buildings." Solar energy 81.5: 676-682.

Poortinga, Wouter, Linda Steg, and Charles Vlek, (2004). Values, Environmental Concern, and Environmental Behavior A Study into Household Energy Use. Environment and behavior 36.1: 70-93.

Raw, GJ; (2012). How does the behaviour of building occupants affect overheating risk? Department for Communities and Local Government: London, UK.

Schipper, Lee, and Michael Grubb, (2000). On the rebound? Feedback between energy intensities and energy uses in IEA countries. Energy Policy 28.6: 367-388.

Schwarz, Nina, and Andreas Ernst, (2009). Agent-based modeling of the diffusion of environmental innovations—an empirical approach." Technological forecasting and social change 76.4: 497-511.

Scottish Government, (2013). Influencing behaviours; moving beyond the individual. A practical user guide to the ISM tool. Andrew Darnton and Jackie Horne.

Sorrell, Steve, and John Dimitropoulos, (2008). The rebound effect: Microeconomic definitions, limitations and extensions. Ecological Economics 65.3: 636-649.

Sorrell, Steve, John Dimitropoulos, and Matt Sommerville, (2009a). Empirical estimates of the direct rebound effect: A review." Energy policy 37.4: 1356-1371.

Sorrell, Steve, (2009b). Jevons' Paradox revisited: The evidence for backfire from improved energy efficiency. Energy Policy 37.4: 1456-1469.

Sorrell, Steve, (2007). The Rebound Effect: an assessment of the evidence for economy-wide energy savings from improved energy efficiency. London: UK Energy Research Centre.

Spataru, C., & Gauthier, S. (2013). How to monitor people 'smartly' to help reducing energy consumption in buildings?. Architectural Engineering and Design Management, 10, 60-78

Spataru, C., & Gillott, M., (2011). The Use of Intelligent Systems for Monitoring Energy Use and Occupancy in Existing Homes. Smart Innovation, Systems and Technologies, 7, 247-256.

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

Stern, Paul C., (1992). What psychology knows about energy conservation." American Psychologist 47.10: 1224.

Straughan, Robert D., and James A. Roberts, (1999). Environmental segmentation alternatives: a look at green consumer behavior in the new millennium. Journal of consumer Marketing 16.6: 558-575.

Swords, B., Eugene Coyle, and Brian Norton, (2008). An enterprise energy-information system." Applied Energy 85.1: 61-69.

ThØgersen, John, (1995). Understanding of consumer behaviour as a prerequisite for environmental protection." Journal of consumer policy 18.4: 345-385.

UCL Institute for Sustainability. Retrofit insights: perspectives for an emerging industry: Key Findings: Analysis of a selection of Retrofit for the Future projects"

Van den Bergh, Jeroen CJM, (2011. "Energy conservation more effective with rebound policy." Environmental and resource economics 48.1): 43-58.

Verspagen, B. (2009). The use of modeling tools for policy in evolutionary environments. Technological forecasting and social change, 76(4), 453-461.

Weidlich, Anke, and Daniel Veit, (2008). "A critical survey of agent-based wholesale electricity market models." Energy Economics 30.4: 1728-1759.

Wilhite, Harold, et al, (2000). "The legacy of twenty years of energy demand management: we know more about individual behaviour but next to nothing about demand." Society, behaviour, and climate change mitigation. Springer Netherlands, 109-126.

Wilhite Harold, (2008). New thinking on the agentive relationship between end-use technologies and energy-using practices, Energy Efficiency, 1:121-130

Willis, Rachelle M., et al, (2010). Alarming visual display monitors affecting shower end use water and energy conservation in Australian residential households. Resources, Conservation and Recycling 54.12: 1117-1127.

Wilson, Charlie, and Hadi Dowlatabadi, (2007). Models of decision making and residential energy use." Annu. Rev. Environ. Resour. 32: 169-203.

Windrum, P., Ciarli, T., & Birchenhall, C., (2009). Consumer heterogeneity and the development of environmentally friendly technologies. Technological Forecasting and Social Change, 76(4), 533-551.

Yohanis, Yigzaw G., et al, (2008). Real-life energy use in the UK: How occupancy and dwelling characteristics affect domestic electricity use." Energy and Buildings 40.6: 1053-1059.

Grey literature

AECOM, 2012. Investigation into Overheating in Homes: Literature Review. Department of Communities and Local Government. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/7604/2185850.pdf

Chatterton T., (2011). An introduction to thinking about 'Energy Behaviour': a Multi Model Approach. DECC.

Chiu, LF et al, (2012) Post Occupancy Interview Analysis Report. Institute for Sustainability. http://www.instituteforsustainability.co.uk/latestpublications.html

Chiu, LF et al, (2013) Post-occupancy interview report: Key findings from a selection of Retrofit for the Future projects. Institute for Sustainability. Http://www.instituteforsustainability.co.uk/uploads/File/2236_IFS_POI_Report_Final_05.06.13.pdf

DECC, (2011) Evaluation of the delivery and uptake of the Carbon Emissions Reduction Target. Research Report Undertaken by Ipsos MORI, CAG consultants and BRE. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48208/3339-evaluation-of-the-delivery-and-uptake-of-the-carbo.pdf

DECC, (2012a) Domestic energy use study: to understand why comparable households use different amounts of energy. Brook Lyndhurst for DECC. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/65599/6919-domestic-energy-use-study.pdf

DECC (2012b). What works in changing energy using behaviours, a rapid evidence assessment, RAND Europe.

Green, G. and J. Gilbertson, (2008). Health Impact Evaluation of the Warm Front Scheme. Centre for Regional, Economic and Social Research, Sheffield Hallam University.

Munton, A.G., Wright, A.J., Mallaburn, P.S, & Boait, P.J. (2014). How heating controls affect domestic energy demand: A Rapid Evidence Assessment. A report to the Department of Energy and Climate Change. DECC, London.

Palmer, J and Cooper, I (2011). Great Britain's Housing Energy Fact File (Department of Energy and Climate Change). https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48195/3224-great-britains-housing-energy-fact-file-2011.pdf

Palmer, J. Terry, N.and Peter Pope (2012). How much energy could be saved by making small changes to everyday household behaviours? Cambridge Architectural Research. DECC https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/128720/6923-how-much-energy-could-be-saved-by-making-small-cha.pdf

Raslan, R, Lowe, RJ, Chiu, LF and Altamirano, H. (2011). Key Findings report: retrofit project team perspectives. Institute for Sustainability.

http://www.instituteforsustainability.co.uk/uploads/File/KeyFindingReports_Retrofit.pdf/

Wilson,C., H. Pettifor and G. Chryssochoids, (2013). Understanding Homeowners' Renovation Decisions: Findings of the Verd Project. Unviersity of East Anglia: Norwich, UK.

Woosey, Steve, (2012). Evaluation of arbed Phase One: A report into the impacts of the first phase of the Welsh Government's arbed programme between 2011 and 2012. Eco Centre Wales.

Annex 4: Hypothesis long list

The rebound effect has been examined in depth (i.e. Sorrell 2007). In beginning the construction of a framework for thinking about behaviour response and comfort-taking, we have combined categories described by Sorrell et al. (2008, 2009a, 2009b) with our knowledge of the environmental behaviours literature (including Chatterton 2011, Dolan et al. 2010, Austin et al. 2011). This framework provides a context for the long list of hypotheses in this Annex, showing how different aspects relate to one another.

In the diagram below, rows shaded in blue are interpreted from descriptions in Sorrell et al (2009a and b), to illustrate the relationship of behaviour factors to overall shortfall between expected and actual energy saving. The rest of the diagram lists features we believe are central to an exploration of behaviours and comfort-taking – both directly behavioural factors and their interaction with physical features of homes, energy efficiency measures and the route by which measures were accessed. In thinking about the comfort-taking behaviour response we have made a distinction between unconscious and conscious comfort-taking. The factors listed in between the two in the diagram introduce the wide range of behaviour influences from the literature which are central to some of the hypotheses in the long list below.

Shortfall Expected energy savings for home heating (based on engineering estimates) minus actual savings		
Temperature take-back *change in internal temperature following the EE improvement*		Other
Behavioural	Physical & other factors	Poor engineering estimates Equipment performance Quality of installation
Who lives there (demographics): e.g. • objective: size, age, health, income etc • subjective: 'feeling the cold', preferences that affect comfort (e.g. clothing, washing etc)		
How they use the home: e.g. • existing preferences & practices • daily patterns of use • start level of comfort & energy consumption	**Interaction with the design of housing and modifications** How that influences use patterns, the experience of comfort and decisions about how to organise heating	
Comfort taking response Unconscious/accidental values, attitudes, beliefs, costs, awareness, salience, benefits, incentives, emotions, agency, skills, habits, defaults, networks, meanings, messengers, tastes, identity, norms, institutions, opinion leaders, schedules, technologies, objects, rules, commitments, priming, framing Conscious/wilful	**Interaction with technologies and measures** Design of heating controls and how that influences active management of comfort Understanding of heating controls Unintended consequences (e.g. damp, over-heating)	**Influence of the route to getting to installation and experience of it** Hypothesis: 'Journey' up to installation interacts with behaviour response • advice may influence post-installation behaviour • equipment performance and quality of installation may interact with behaviour

[H1] Perceptions of comfort, and hence comfort-taking, will be influenced by who lives in the house and their starting level of comfort pre-installation (and how that interacts with bundles of behaviour factors identified below)

Potential hypotheses are:

- Comfort-taking is higher, and intentional, in lower income households because they are starting from a lower base (and there is some evidence of this in the rebound literature – see Sorrel, 2007)
- Comfort-taking is higher, and intentional, in households with older people or those in poor health (e.g. the DECC DEUS study flagged this as an influence on differences between high and low gas users). Understanding health benefits from comfort-taking is important to policy on fuel poverty.
- Other things being equal, smaller household sizes have less scope to decrease consumption compared to bigger households.
- Owner occupiers are more likely to change behaviour to save energy than tenants because they have greater vested interest in capturing the savings from GD investments

[H2] Comfort-taking may be influenced by the mix of measures taken up and (if relevant) the order in which they are adopted, and how people interact with them

- Households picking and choosing measures, rather than installing a full package of GD recommended measures, negatively impact the savings. If an energy saving measure is installed in a home without temperature sensitive heating - i.e. insulation is installed without smart valves/ temperature sensors in the home - the space might be warmer, but occupants might still leave the thermostat set at the original temperature or have the heating on for the same amount of time as before. Occupants might then adapt to the warmer temperature in their home by wearing fewer clothes etc., but without reducing their energy consumption
- Are (energy and behaviour) outcomes sensitive to:
  - How many measures are installed?
  - In what bundles?
  - In what order?
  - Is impact additive or not?
- Does the driver for getting the measure (e.g. a new boiler) affect propensity for comfort-taking e.g. planned versus emergency measures?
- Comfort-taking may be influenced by whether the measures installed are passive (e.g. insulation) or active (e.g. heating systems and controls); high or lower cost; how much noticeable difference they make to internal temperature without any change in behaviour.
- Positive or negative reinforcement – e.g. if measures under-perform or aren't good quality are people de-motivated to make an effort to make them work effectively and save energy?

- Alternatively, we could speculate:

- Due to technology performance, whether or not people change behaviour does not affect the level of energy savings significantly. *Ergo* correctly installed measures are the main parameters and behaviour is only marginal.

[H3] Emotion and mental short-cuts are implicated in decision-making about energy and can result in non- (economically) rational choices and strategies which can result in unintentional comfort-taking

- For example we can suggest that mental accounting (e.g. 'earmarking')[25] affects households' responses to potential energy savings – e.g. the mental construct of the 'budget' for energy may not be malleable. People have earmarked a certain amount of their spending and, as long as the bill is more or less within that range, they aren't that interested in maximising savings. We could speculate responses:
  - Switch to other energy using behaviours (e.g. more cleanliness/hot water)
  - As long as the bill goes down a bit the precise amount may not matter thus motivation to make a personal effort (i.e. incur a loss of time/increased hassle) to make sure measures work as well as predicted may be undermined. The latter will also relate to values, attitudes, norms and identity.
  - If it exists, this effect is likely to vary between households of different income.
- It is possible that households don't make rational calculations or pay enough attention to usage data or bills to motivate them to maximise their savings. Instead, they may feel that higher comfort is a 'right' and have low feelings of guilt about using it or wasting it.
- 'Feeling the cold' was identified as a key influence on gas use in the DECC DEUS study. This is more a personal/emotional influence than a rational one.
  - Is comfort-taking more pronounced where people 'feel the cold'?
  - How does that relate objectively to temperature?
  - Is there something specific that could be done to help those who 'feel the cold' get the most from GD measures?

[H4] Habits and behaviour lock-in can lead to unconscious or unintentional comfort-taking

- Patterns of use of the home and heating systems are strongly habitual (Fell and King 2012; Guy and Shove 2000) and we could suggest the GD experience (as presently offered) is an insufficient 'disruptor' to break habits (see for example Darnton et al. 2011), which results in unplanned comfort-taking. Post-installation conditions require adaptation to how the home and heating are used. Carry-through of past knowledge and behaviours (which DEUS suggests is common) may undermine how effectively new measures perform (passive measures) or are managed (active measures). Some specific hypothetical examples:
  - Households with small children have higher energy consumption and are less flexible to change demand

[25] See Boulanger et al, 2013.

- Households are less willing to change behaviour for certain consumption patterns compared to others – i.e. always take a 20min hot shower after coming home from a run and need to wash laundry at 60 degrees, but willing to turn down heating at night

[H5] Salience and defaults – exposure to the GD through assessment and/or finance raises salience and the likelihood of people making an effort to maximise savings, but households may return to default behaviours over time

- Evidence indicates that many (perhaps most) households have low awareness of how much energy they consume, or even the precise amount of their bills. Two possible hypotheses are:
- GD Assessments/GD Finance makes energy use much more salient which focuses people's attention on what they need to do (and understand) to make sure they achieve the predicted financial savings. For example:
  - People that have taken up GD measures decidedly/voluntarily may be more likely to reduce their energy consumption (i.e. actively avoid comfort-taking) than ECO households because salience is greater
- The salience of energy efficiency diminishes over time: once measures are installed and energy behaviour settles to a new norm, households pay little attention to how much they are saving, given current low awareness of bills (with potential variation by level of cost incurred/to be repaid, and ECO versus GD)
  - Householders might change their behaviour directly after a measure has been installed, but fall back into their original default energy using behaviour shortly after (3 weeks to 6 months post-installation)
- We also need to be aware of likely bias in the population of early adopters of GD – they may have been more aware of energy use and manage energy more actively than the population as a whole. And we could also hypothesise potential differences between GD and ECO households in terms of how their different experiences influence the salience of energy efficiency.

[H6] Norms play an important role in determining perceptions of 'acceptable' levels of comfort, and therefore propensity for comfort-taking

- Social conventions affect perceptions of what is acceptable and desirable with respect to comfort and cleanliness (e.g. bathing). These could be wider social norms and/or social conventions within the household. Where people perceive themselves to be located with respect to these conventions will influence how they respond to opportunities to take extra comfort (e.g. indoor clothing, washing). This may also include feelings of 'rights' to extra comfort, depending on personal identity with respect to energy saving (e.g. I am the kind of person who doesn't feel guilty if I waste a bit of energy).
  - People's perceptions of what is acceptable from a thermal comfort point of view vary significantly
  - Households value comfort over costs (possibly distinguish by income groups)

[H7] Values, attitudes and identity will influence active management of energy and paying attention to maximising benefits from installed measures

- To what extent does being 'energy consciousness' and having 'willingness to contribute' influence comfort-taking?
- It can be suggested:
- Values and attitudes towards energy saving make a difference to the extent of comfort-taking post-installation – those whose self-identity involves being 'committed' to energy reduction/carbon saving make more effort to maximise savings.
- (NB This hypothesis needs challenging: the Defra evidence base for pro-environmental behaviours and other work often shows a gap between what people say and what they do; there is probably specific evidence for energy behaviours - e.g. the DEUS study was inconclusive on the influence of values; the DECC 2012 evidence review (2012b) suggests motivations are much more complex)

[H8] The social dynamics of households influence who controls comfort and how they do it which will affect the pattern of comfort-taking

- Energy behaviour may depend on the person handling the energy bills and their attitude/ whether they promote energy saving behaviour in the household or not.
- Comfort-taking may depend on who has control of, and the degree to which they understand, heating controls (e.g. DEUS suggested men more often tend to control boiler settings; women tend to have control over thermostats).

[H9] The scheduling of daily life and heating routines affects opportunity and willingness to take comfort/maximise savings from energy efficiency measures

- The amount of time people spend in their homes may be correlated with their willingness to change behaviour (to save energy)
- Comfort-taking may reflect who is at home, how much and when. This may not relate easily to socio-demographic groups (but it might).
- Comfort-taking may reflect the overall use pattern of the house (e.g. keeping certain rooms/areas warm on a 'just-in-case' basis even though that will undermine potential savings) which will in turn be related to the physical configuration of the house, household composition, routines, preferences etc.
- Households with central heating may reduce consumption to a lesser extent than households with decentralised heating.

[H10] Human/technology interaction affects the effectiveness of GD/ECO measures – which is particularly relevant to unintentional comfort-taking and perverse effects

- Skill and confidence (agency and the influence of status quo bias) affect individuals'/households' ability and willingness to use heating controls to get the most out of energy efficiency measures.
- Lack of basic numeracy and literacy may reduce the effectiveness of GD leaflet guidance/ engaging with new installations.

- Lack of understanding about how to get the most out of installed measures could lead to people using them ineffectively, even if their intention and desire is to save energy and cut bills. The same could be true with respect to poor understanding of how to organise heating across their home as a whole to get the maximum energy saving benefit from energy efficiency measures.
- There may be limits to the amount of time people will persist with trying to get the best out of their heating controls, if they are having problems making them work properly.
- There is a risk that people sustain old habits (practices and patterns of behaviour) in the 'new' post-installation heating environment they find themselves in which undermines the performance of energy efficiency measures. Is the GD experience a big enough 'disruptor' to change habits?
- There is a risk that people stick with equipment defaults – how they were set when installed, automation etc – rather than tailoring them to their own situations (including property characteristics), which may lead to sub-optimal use of measures.
- The design of equipment sends unconscious cues on how to behave (e.g. the range of temperatures on a thermostat, default settings for programmes) which could be positive or negative.
- Some age groups/types of people (e.g. educational background) may be less willing to actively engage with heating systems or understand how to maximise benefits from installed measures.
- Some of the newer technologies (e.g. remote programming) may have perverse consumption effects: for example, because individuals cannot physically feel the level of comfort and respond if it's too hot or being heated at the wrong time.

[H11] The customer journey prior to installation has an influence on the behaviour outcome and resulting energy saving

- The Green Deal assessment process, and contact with installers, affects post-installation behaviours and optimising benefits from installed measures (e.g.):
  - Who the messenger is
  - Trust in messenger/credibility
  - Knowledge of messenger (variable quality) and how that supports personal skill/sense of agency
  - What aspects the messenger places emphasis on with respect to energy savings (e.g. you can leave it alone or have to learn how to use it; what to do if it gets too hot in your home)
  - Whether you think it's being 'done to' you (e.g. ECO) or you have actively chosen it
  - How does the quality of the experience in ECO and GD compare; and does it make any difference to the influence of this aspect on subsequent energy behaviours?
  - Whether, and how, the GD assessment and/or financial package acts as a 'commitment device' to actively save energy post-installation (and how it compares, say, to other routes to getting assessments and measures – e.g. community-led energy efficiency initiatives, energy suppliers etc)

[H12a] There is potential for positive spill-over from the GD/ECO

Individual

- Positive spill-over: people that take up a GD package, might "get hooked" and install similar/ more energy saving or renewable energy technologies – the conveyor belt, or ratchet effect.

Social

- Post-installation savings may trigger take up through social spill-over, i.e. neighbours telling each other about GD measures and their savings on bills. Rural areas with closely-knit communities might be more prone to do above than households in urban areas
- Local social networks may be important in supporting knowledge transfer about how to get the best out of GD measures and therefore reduce the contribution of behaviour factors to shortfall.
- The competition-factor: if people compare savings, there will be "a race to the bottom" and people try to top each other in savings they make on their bills.

[H12b] There is potential for negative spill-over or unintended consequences from GD improvements

- Better insulated houses lead to more need for air-conditioning in the summer (or, alternatively, better insulated houses lead to less need for air-conditioning in the summer.
- Certain types of measure (e.g. solid wall insulation) cause moisture or damp problems which households remedy through extra heating.

Applying MINDSPACE to the Green Deal: initial thoughts on hypotheses related to MINDSPACE dimensions

Development of the initial list of hypotheses was informed by the MINDSPACE framework, among other sources. Links between MINDSPACE and the hypotheses are shown below, with MINDSPACE categories in the left column and our hypotheses in the right column, with flags to the complete list in the main body of Annex 4.

Messenger We are heavily influenced by who communicates information Includes: • Role of experts • Peer effects • Importance of consistency	[H10] The Green Deal assessment process, and contact with installers, affects post-installation behaviours & optimising benefits from installed measures (e.g.): • Who the messenger is • Trust in messenger/credibility • Knowledge of messenger (variable quality) • What aspects messenger places emphasis on with regard to energy savings (e.g. you can leave it alone or have to learn how to use it; what to do if it gets too hot in your home) • Whether you think it's being 'done to' you (e.g. ECO) or you have actively chosen it
Incentives Our responses to incentives are shaped by predictable mental shortcuts, such as strongly avoiding losses, discounting of future rewards	[H3] Mental accounting (e.g. 'earmarking') affects households' responses to potential energy savings – e.g. the construct of the 'budget' for energy may not be very malleable (Boulanger 2013). We could speculate responses: • Switch to other energy using behaviours (e.g. more cleanliness/hot water) • As long as the bill goes down a bit the precise amount may not matter thus motivation to make a personal effort (i.e. a loss) to make sure

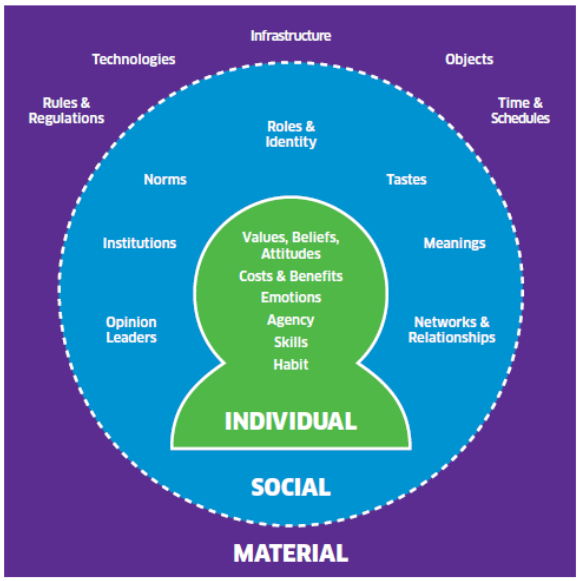
	measures work as well as predicted may be undermined
Norms We are strongly influenced by what others do And need consistent reminders of this over time	[H6, H8] The social dynamics in households (Fell and King 2012) affect their approach to comfort saving (e.g. gender, who 'feels the cold') Interaction with neighbours and others who have undergone GD assessment or installed measures helps to optimise energy saved. [H5] Comparative feedback can help to maximise savings from energy saving interventions (DECC 2012b) [H2] Social conventions affect perceptions of what is acceptable and desirable with respect to comfort and cleanliness. Where people perceive themselves to be located with respect to these conventions may influence how they respond to opportunities to take extra comfort (e.g. indoor clothing, washing etc) – see also Ego and 'rights' to comfort
Defaults We 'go with the flow' of pre-set options	[H4] Patterns of use of the home and heating systems are strongly habitual (Fell and King 2012, Guy and Shove 2000) and the GD experience is an insufficient 'disruptor' to break habits (see, i.e., Darnton et al. 2011). Post-installation conditions require adaptation to how the home and heating are used. Carry-through of past knowledge and behaviours (which Fell and King (2012) suggest is common) may undermine how effectively new measures perform (passive measures) or are managed (active measures)
Salience Our attention is drawn to what is novel and seems relevant to us	[H5] Evidence indicates that many (perhaps most) households have very low awareness of how much energy they consume, or even the precise amount of their bills. Two possible hypotheses here: • GD Assessments/GD Finance makes energy use much more salient which focuses people's attention on what they need to do (and understand) to make sure they achieve the predicted financial savings • The salience of energy efficiency diminishes over time: once installed, households pay little attention to how much they are saving, given current low awareness of bills (with potential variation by level of cost incurred/to be repaid, and ECO versus GD) We also need to be aware of bias in the population of early adopters of GD – they may have been more aware of energy use and committed to saving than the population as a whole. And also potential differences between GD and ECO households in terms of how their different experiences influence the salience of energy efficiency.
Priming Our acts are often influenced by sub-conscious cues	[H10] Human interaction with the design of equipment and devices (especially heating controls) influences how effectively they are used and over what time period. For example: • Framing – do thermostat designs send passive cues about what is the 'right' temperature • Scripting - do programmers encourage particular patterns of behaviour that might be at odds with what's most effective, given the 'patterning' of heat use by different kinds of household? (e.g. have it on when 'comfort' is not being needed, revert to defaults set by the programmer) • Lack of skill – if people experience difficulty understanding/using their heating controls (or even how to keep their 'new' home at the temperature they want when they want) do they give up in frustration and revert to pre-settings that may not be right for their situation?
Affect Our emotional associations can powerfully shape our actions	[H2, H3] It is possible that households don't make rational calculations or pay enough attention to usage data or bills to motivate them to maximise their savings. Instead, they may feel that higher comfort is a 'right' and have low feelings of guilt about using it or wasting it. 'Feeling the cold' was identified as a key influence on gas use in Fell and King (2012). This is more a personal/emotional influence than a rational one. • Is comfort-taking more pronounced where people 'feel the cold'? • How does that relate objectively to temperature?

	• Is there something specific that could be done to help those who 'feel the cold' get the most from GD measures?
Commitments We seek to be consistent with our public promises, and reciprocate acts	[H11] The GD assessment report and recommendations might act as a 'public commitment' which people try to stick to after they have measures installed. GD finance packages are a commitment device that encourage a focus on maximising energy savings. There may be aspects of the advice people are given that could reinforce and sustain commitments.
Ego We act in ways that make us feel better about ourselves and like to think of ourselves as consistent	[H7] Values and attitudes towards energy saving make a difference to the extent of comfort-taking post-installation – those whose self-identity involves being 'committed' to energy reduction/carbon saving make more effort to maximise savings. (This hypothesis needs challenging: the Defra evidence base for pro-environmental behaviours and other work often shows a gap between what people say and what they do; there is probably specific evidence for energy behaviours (e.g. Fell and King (2012) gave a preliminary indication that attitudes had little influence; the DECC (2012b) evidence review suggests motivations are much more complex)

Overview of Scottish Government ISM framework for behaviours

From the practical guide to the ISM
http://www.scotland.gov.uk/Resource/0042/00423436.pdf

FIGURE 1
FACTORS THAT INFLUENCE BEHAVIOUR IN THE INDIVIDUAL, SOCIAL AND MATERIAL CONTEXTS ('THE ISM MODEL')



THE INDIVIDUAL CONTEXT
This includes the factors held by the individual that affect the choices and the behaviours he or she undertakes. These include an individual's values, attitudes and skills, as well as the calculations he/she makes before acting, including personal evaluations of costs and benefits.

THE SOCIAL CONTEXT
This includes the factors that exist beyond the individual in the social realm, yet shape his or her behaviours. These influences include understandings that are shared amongst groups, such as social norms and the meanings attached to particular activities, as well as people's networks and relationships, and the institutions that influence how groups of individuals behave.

THE MATERIAL CONTEXT
This includes the factors that are 'out there' in the environment and wider world, which both constrain and shape behaviour. These influences include existing 'hard' infrastructures, technologies and regulations, as well as other 'softer' influences such as time and the schedules of everyday life.

Annex 5: User-centred insight on post-installation behaviours and practices

Project: User-centred research on post-installation behaviours and practices

Part 1 - Qualitative behaviours study

The aim of this project would be to develop an in-depth understanding of behavioural practices relevant to energy use in the home, with a specific focus on how households have responded to the installation of Green Deal type measures.

Such an understanding would be necessary as a platform for building quantitative models that better capture and explain the behaviour dimension of post-installation energy use. This understanding is likely to go beyond direct energy behaviours (e.g. use of thermostats) to encompass also the values, objectives and practices of households that determine how they define and achieve comfort (and, with respect to water heating, cleanliness too).

The project would build on the existing evidence base regarding energy-relevant behaviours and behaviour change in general, and examine how this translates into the specific Green Deal and ECO context.

Framing of energy consumption, rebound and comfort/comfort-taking would be based on the understandings set out in chapter 3 which puts human-technological-material interaction at the centre of an understanding of how people use their homes and consume energy. Energy use is not treated as a discrete 'behaviour' in this framing but rather as an outcome of energy-relevant behaviours and practices.

The research would:

- Generate rich consumer insight about post-installation experience and behaviour responses, including the role (if any) of prior steps in the customer journey in influencing behaviour outcomes (e.g. via know-how, skills);
- Provide a stronger platform for identifying which dimensions of behaviour responses are most implicated in post-installation impacts and provide candidate variables for including in further quantitative behaviour studies (e.g. large-scale quantitative survey and factor analysis to derive behaviour variables that could be considered in impact modelling);
- Inform further Green Deal monitoring and evaluation activities in both the immediate and longer terms.
- As a result DECC will begin to build an explanatory account of how and why energy savings are achieved (or under-achieved) in the Green Deal, to inform outputs from its impact modelling and, potentially, to provide foundations for improved modelling/prediction in future.

Hypotheses

Qualitative research is not designed for testing hypotheses in the quantitative sense of attributing statistically robust values to behaviour factors (e.g. that x% of observed changes in energy use can be attributed to norms and y% to habits). Qualitative research nonetheless explores hypotheses to generate rich explanatory accounts of *how and why* people behave (rather than the extent). The rich insights from qualitative research are often used as a preliminary stage in developing quantitative household surveys to ensure that the right lines of enquiry and specific question approaches are adopted.

The project would therefore be focused on developing a broad understanding of behaviour responses, and how they interact, with the following hypotheses in mind (numbers in brackets relate to the headline list in chapter 2 and longer definitions in the Annexes):

1. *Behavioural responses, including comfort-taking, to energy efficiency installations will be influenced by:*
    a. *household composition and socio-economic status (who lives in the house and their starting level of comfort pre-installation), plus other household and individual characteristics such as attitudes and norms, and skills and knowledge [H1, H6, H7, H9, H10];*
    b. *the type and mix of measures taken up and the order in which they are adopted [H2].*

2. *Exposure to the GD through assessment and/or finance raises salience and influences behavioural responses [H4, H5, H11]:*

    a. *Going through the GD process may increase the likelihood of people changing their behaviour to make savings – GD may be a moment of change in terms of habit disruption*

    b. *However, households may return to default behaviours over time*

    c. *There may be both positive and negative spillover from energy efficiency installations and from the GD process itself [H12]*

    d. *GD vs ECO: the nature of the process (passive/active/volitional/other-led) will affect the levels of savings achieved.*

3. *Emotion and mental short-cuts are implicated in decision-making about energy and can result in non- (economically) rational choices and strategies which will affect the savings achieved [H2, H3, H4, H6, H7]*

4. *Human/technology interaction affects the effectiveness of GD/ECO measures – which is particularly relevant to unintentional comfort-taking and perverse effects [H10, H9, H2, H3, H4, H5, H11]*

a. *Skill and confidence (agency and the influence of status quo bias) affect individuals'/households' ability and willingness to use heating controls to get the most out of energy efficiency measures.*

b. *There may be limits to the amount of time people will persist with trying to get the best out of their heating controls, if they are having problems making them work properly.*

c. *There is a risk that people stick with equipment defaults – how they were set when installed, automation etc – rather than tailoring them to their own situations (including property characteristics), which may lead to sub-optimal use of measures.*

5. *The customer journey prior to installation has an influence on the behaviour outcome and resulting energy saving [H11, H5]*

    a. *Whether, and how, the GD assessment and/or financial package acts as a 'commitment device' to actively save energy post-installation (and how it compares, say, to other routes to getting assessments and measures – e.g. community-led energy efficiency initiatives, energy suppliers)*

    b. *The Green Deal assessment process, and contact with installers, affects post-installation behaviours and optimising benefits from installed measures (e.g.):*

        i. *Trust in messenger/credibility/Knowledge of messenger (variable quality) and how that supports personal skill/sense of agency*

        ii. *What aspects the messenger places emphasis on with regards to energy savings (e.g. you can leave it alone or have to learn how to use it; what to do if it gets too hot in your home)*

    c. *Whether you think it's being 'done to' you (e.g. ECO) or you have actively chosen it*

The research would provide evidence that would contribute to understanding of post-installation behavioural practices in a 'normal' home environment[26]. It would build on previous work (including that supported by DECC, e.g. in the 'High/Low' project[27]), and explore the interaction of energy-relevant behaviours with installation of energy efficiency measures.

Method

Approach

Reflecting outcomes of the evidence scan (in chapter 3), this research could incorporate use of creative, people-centred research methods that can take account of the

[26] As distinct from the responses examined in projects that have applied comprehensive retrofits.

[27] Domestic energy use study: to understand why comparable households use different amounts of energy, 2012. Brook Lyndhurst for DECC. (DECC, 2012a).

interactions between the dynamics of daily life, technological change, and the social and material context.

It is proposed that the project would comprise:

- A set of in-home, extended depth/quasi-ethnographic qualitative interviews;
- Collection and analysis of energy bill data.

The 'quasi-ethnographic' element refers to the need to visit the participants' homes, to meet different members of the family and to understand the human context into which the GD/ECO measure was installed. In-home, face-to-face interviews, in which the researcher and participants can move around the home, for example, to look at a new boiler or inspect heating controls, would be a crucial aspect of the research design; since much energy-relevant behaviour is habitual and relies on defaults and heuristics, it is important to interact with participants in the context in which they interact with the energy efficient installations, so that participants can more easily describe and explain their behavioural responses. Interview schedules (topic guides) would be guided by the hypotheses listed above; interviews would last a minimum of two hours each, and would include various interactive activities to elicit information from participants about their pre- and post-installation daily lives.

Sample

Following standard qualitative research practice, sampling would be purposive, designed to recruit a balance of respondents across key characteristics that are of interest in the Green Deal population (as set out below). It would not be a statistically representative sample.

The programme of interviews would be based on specific groups, examples of which are given below. Clearly, the choice of groups will have a substantial influence on certain aspects of demographics and household formation. The aim will be to select households from a diversity of groups such that the linkage between behavioural change and various household characteristics, demographics and technology choices can be explored.

The sample approach would need to be a pragmatic response to the emerging evidence on how many households, and of which types, have experienced the Green Deal/ECO in one way or another. If they can be found, it would be desirable to include a 'non-Green Deal' set of households so that the research can compare between the different ways of arriving at an energy efficiency installation and how that may, or may not, influence behaviour outcomes. The four main groups would be:

- households that have had a Green Deal assessment and have taken out Green Deal finance;
- households that have had a Green Deal assessment and have paid for measures with an alternative form of finance;
- ECO households;
- households that have installed energy efficiency measures but not participated in Green Deal or ECO.

Ways of accessing potential sample were considered in outline at the third workshop for this feasibility study. The following are initial suggestions on avenues for accessing

sample (but these would need to be tested further before finalising a project and resource plan).

Group	Access/recruitment strategy
GD assessed, GD financed [A]	DECC data
GD assessed, non-GD financed [B]	DECC data for GD cashback households (no access to self-financed households)
ECO [C]	Ofgem ECO data
HHs with non GD/ECO installations [D]	Standard recruitment process (via professional recruitment service)

Letters in brackets are sub-sample identifiers which relate to cost options later in this section.

Three scenarios, with different sample sizes for each of the above groups have been considered: 24, 40 or 60. The smallest sample would produce a robust but basic thematic analysis and limited ability to compare between the different sub-groups; the largest sample would enable some comparison between broad groups, including some statistical testing.

Drawing on the evidence findings, it is suggested that further quotas could be set so that the following characteristics are balanced across the sample:

- Income group (e.g. above median income/low-income-fuel-poor);
- Household composition (e.g. different ages/life stages and number of residents);
- Tenure (Social, private rented[28], owner-occupied);
- Geographical region - three case study locations would be selected in different parts of England.

A detailed recruitment specification that sets out how the sample would match the various quotas would be devised as part of a detailed project plan.

Analysis

The qualitative dataset would be analysed using appropriate techniques such as thematic content analysis, and QCA (Qualitative Comparative Analysis). For the scenarios with larger samples, non-parametric statistical techniques could be used to generate generalizable findings (e.g. tests of association such as the Mann-Whitney test provide p-values for small-medium n samples).

[28] Evidence from other studies in the evaluation suggests that private tenants are under-represented in the population of households having Green Deal assessments.

Research challenges and risks

This initial proposition has assumed that sample participants would be accessible through existing data sources. This is a risk which could result in unforeseen resource requirements: it needs testing/exploring further. For example, additional screening of a sample identified initially on the basis of GD/other exposure may be needed to ascertain other household characteristics. There is therefore some merit in a preliminary sample scoping phase at the start of the project before costs are finalised.

All qualitative research runs the risk of selection bias in the sample. Sampling would be purposive with quotas set for specific characteristics of interest (agreed with DECC) to minimise the effect of participant bias. Where appropriate, recruitment could be undertaken by an accredited recruitment agency working to the MRS code of conduct.

Gathering data on energy use would be desirable but this will realistically be limited to the current situation and a comparison with pre-installation usage is unlikely to be feasible. However, where households have had a GD assessment it may be possible to compare actual to expected savings. No additional monitoring (e.g. in-home temperature monitoring) is proposed.

The research responds to the limitations of respondent recall identified in the evidence scan by proposing quasi-ethnographic in-home visits. Framing research guides around the selected hypotheses also brings issues such as habitual lock-in or emotion to the fore of the enquiry which should also help to avoid the risk of 'first answer' responses.

Qualitative research normally involves incentives for participants. This would need to be acknowledged and cleared in the context of the sample being Green Deal/ECO households.

Robustness and limitations

Suggested sample sizes outlined above are based on standard social research practice[29]. To ensure robustness, development of the interview guides would build on the hypotheses identified above (which in turn are grounded in the literature on behaviours) and, where possible, draw on tools used successfully in other energy research projects. They would also be sense-checked by DECC social scientists.

It would need to be acknowledged, however, that the use of this approach would limit the size of sample that would be feasible. The primary purpose of the project would not be to produce generalizable and scalable results. Some statistical analysis would be feasible for the larger scale sample scenarios, using non-parametric tests that are designed for small and non-random samples (e.g. to compare between household types). The study would also provide a sounder basis (than now) for developing questionnaires that could be used in future quantitative studies of post-installation energy behaviours.

Project benefits

The project would provide short run benefits:

[29] For example: Emmel (2013) Sampling and choosing cases in qualitative research, Sage. Ritchie J, Lewis J. (2003 & 2009) Qualitative research practice, a guide for social science students and researchers. London: Sage.

- A rich, in-depth, people-centred understanding of the impacts of GD/ECO interventions on people's lives (and therefore energy use and savings) covering:
  - How the policy is working in practice;
  - An explanatory account of impacts – how and why (and if) GD/ECO installations work out 'on the ground';
  - Implications for how to maximise positive impacts of ongoing Green Deal/ECO programme, including insights into:
    - Motivations, barriers, and the kind of information, communication, knowledge and skills support that could help householders maximise post-installation benefits;
    - Customer satisfaction with the GD/ECO journey;
    - Specific information about fuel-poor households, and the impact of installations on their lives;
    - The role of social networks in the diffusion of information/advice about the programme and installations;
    - Consumer knowledge and use of related technologies such as Smart Meters.

Part 2 - Longer term quantitative behaviours study

Outcomes from Part 1, described above, would provide a platform for further development of quantitative explanatory models of behaviour influences on post-installation energy use, either in a specific Green Deal context or for energy efficiency measures more widely.

The complexity of the human-social-technological-material interaction, plus the potentially large number of energy-relevant behavioural practices involved, creates the need for data reduction techniques to be used with future behavioural quantitative datasets. In essence, composite explanatory behaviour variables need to be developed based on a sound understanding of the underlying complexity (from the qualitative research).

Potential methods that could be used to create manageable variables for use in future quantitative work include factor analysis or cluster analysis, which could be employed to build a behavioural index/scale/segments that could be used as independent, mediating or moderating variables in explanatory/predictive statistical models.

The precise scope and approach of this project idea has not been worked up in detail because its shape would depend on decisions made about other potential projects, collaborations and, potentially, outcomes from earlier projects (including the proposed qualitative research project). For example, it might be considered as a bespoke, stand-alone project or might be suited to collaboration with other projects where some energy monitoring is already in place or has happened. Each potential avenue for executing this option comes with particular challenges and potential compromises which would be

worked out in detail depending on the route chosen. The following is an indicative skeleton of a follow-on quantitative study to meet the objectives set out above which could be pursued via various routes.

Part 2 - Overview

Purpose	Using outcomes from the qualitative insight research, to develop a behaviour scale/index for use in quantitative modelling; to explain variance in comfort-taking with reference to aspects of customer behaviour responses, in addition to other known factors such as technology, building type and socio-demographics.
Hypotheses	Primary focus would be [H1, H2] but also building on key behavioural factors related to other hypotheses identified through the qualitative research project.
Benefits	Quantification of specific behaviour factors or bundles that influence post-installation energy outcomes. This could assist DECC to develop or improve predictive models of outcomes from energy efficiency measures; and identify the relative importance of targeting specific behaviour barriers for maximising energy saving.
Limitations	The complexity of behaviour responses, and anticipated differences for specific technologies, may require the research scope to be limited (a criticism made of existing research on rebound effects). This would undermine the extent to which results could be generalised. There are potential limitations on the ability/cost to combine physical monitoring on this scale with consumer surveys; and to run repeat waves. If the study were focused narrowly on Green Deal households (given the demographics of the GD population) its application to wider energy efficiency contexts might be limited.
Approach	Large-scale quantitative consumer survey of households exposed to GD/ECO (similar to the proposed research project), indicative minimum sample size of 2,000 to enable either/both factor analysis or segmentation. Questionnaire design would build from the project and other projects identified in the evidence scan that have used survey approaches. Ideally, pre and post installation energy measurement over two heating seasons, accompanied by interview surveys. • Decisions about sampling, mode and how the survey would be administered would be taken in light of further exploration of potential collaborative options – for example adding Green Deal booster samples to existing research projects (e.g. the UCL Energy Lab study) or as part of a large-scale monitoring project for the Green Deal.

Links to other projects	Further consideration of links to the UCL Energy Lab or Oxford/UCL Energy Use in Buildings programmes; or a new bespoke long-term Green Deal monitoring programme. Would need to learn from other current projects modelling energy behaviours (e.g. IDEAL, ORIGIN).

Annex 6: Cooperating with existing research projects

Overview

	IDEAL study	Energy Lab	ORIGIN
Purpose	Understand household energy-relevant practices.	Gather data about buildings, technology use and people's energy use behaviour over thousands of homes.	Orchestration of demand response in communities
Hypotheses	✓ H1 ✓ H10 ✓ H12	✓ H1 ✓ H3 ✓ H4 ✓ H8 ✓ H9 ✓ H10	✓ H1 ✓ H10 ✓ H12
Benefits	State of the art monitoring devices can collect data indicative of energy consumption behaviour.	Data generated from a longitudinal panel survey A large representative sample to draw from Advanced monitoring technology which could be replicated	Detailed social surveys have been conducted in each community Community have participated in the design of interfaces State of the art monitoring devices are collecting energy consumption behaviour
Limitations	IDEAL has not collected pre-installation data to date. While IDEAL technology aims to collect very frequent data (once per minute), the GD/ECO research interest is observation of longitudinal changes.	Long lead times Conditional on DECC's approval	Intentional communities are involved in the study so behavioural responses may not be mainstream Two of the three communities are from outside the UK
Approach[30]	Include i) a GD/ECO sample and ii) a control group without feedback and compare to the control sample in this study.	Include a GD/ECO focussed component into the survey Recruit households from the sample, monitor for one year and then incentivise them to undergo GD/ECO in order to ensure pre- and post-installation data generation	Apply the community engagement and monitoring procedure to i) a GD/ECO sample and ii) a control group without feedback
Timing	The monitoring technology was under development during the research for this paper	Household installation sub-sample monitoring would not be operational before 2018 as per the current design	Monitoring technology and approach has been developed and deployed Social survey approach has been carried out Community engagement strategy has been developed
Links to other projects	With a GD sample and the IDEAL control, this could be	This could provide a platform for doing the	The ORIGIN project methodology could be applied

[30] The precise scope and approach of these project ideas have not been worked up in detail because the potential would depend on decisions made by the respective research teams.

	used to run the second stage of the proposed research project. The limitation is the sample size – probably too small to meet the requirements of the aims of the project.	second stage of the proposed research project. The first stage would provide insight to support design of the Energy Lab household surveys. It could potentially also be conducted as or in cooperation with the monitoring plan	to a GD/ECO sample to provide insights to the second stage of the proposed research project – similar to IDEAL and would suffer from the same limitation associated with sample size

Background and aim

There are home energy use research projects in progress or in preparation that are potentially of interest for the design and delivery of a long-term monitoring plan. At the same time, they provide synergy effects with the proposed research project (part 1, part 2). The potential linkages include provision of control groups, as exemplars of best practice in household recruitment, as potential sources of cost-effective technology packages for monitoring, and as potential sources of analytical tools.

This integrated approach would also address a recommendation of the House of Commons Energy and Climate Change Committee, i.e. that DECC “should attempt to coordinate its own evaluation studies with research being carried out by other institutions in this area, in order to maximise the utility of any data being collected” (para. 24). By exploring the opportunity to connect the evaluation to ongoing research projects and getting in touch with some of their key researchers, the project will have provided the foundation for collaboration between DECC and the wider research community.

Approach

The review of relevant external research projects has identified a number of projects, listed in Annex 7, that are addressing / have recently addressed issues relevant to the research hypotheses developed in this feasibility study, albeit not in a Green Deal / ECO context.

It is, firstly, important to distinguish between projects that provide illustrative, or comparative, case-studies and those that might be used as genuine experimental controls. The majority of completed projects, due to their scope and sample size, would generally be described as the former. While these cannot be used as a normative baseline for a new set of measurements (on a different sample) they still provide valuable existing research demonstrating quantified energy savings (and, in some cases, monitored behavioural responses) of a range of pre- and post-retrofit projects. They may also provide useful guidance for any bespoke monitoring exercise suggested in this proposal.

Some currently active projects, such as ORIGIN and IDEAL, could provide a more appropriate pre- and post-retrofit comparison. Although these projects are not focussed on technology retrofits at present, they do have a number of homes that are already being monitored in detail over a long period of time. If the kinds of energy efficiency measures supported by GD and ECO were installed in these homes (potentially by households being invited to go through the ECO/GD customer journey), the pre-installed

monitoring equipment would provide a wealth of data - both before and after the retrofit - and valuable insights. Some of the algorithms being developed by these, and similar, projects (relating to feedback protocols to encourage optimal energy behaviour) could also be highlighted and applied to future work.

The information gathered in this feasibility study suggests that none of the existing projects – if 'co-opted', adapted or expanded – could directly respond to the need for a monitoring approach to focus on GD and ECO households, and capture pre as well as post installation data. The existing projects do, however, have various things to offer in terms of approach, technology packages, as sources of control group data etc. In Annex 7 external research projects of potential interest are identified and their potential utility assessed. Projects are ranked according to relevance. Options for cooperation are flagged. It also shows what hypotheses could be addressed. Short-term actions to explore the propositions given under each project are identified.

The feasibility of any cooperation, the focus and timing of the work, and the incremental resourcing required are all hypothetical at present as no direct contact has been made with the projects. If there is DECC interest in the principle of collaboration with external projects and some multi-year funding is available the suggested next step would be to contact the project coordinator to explore the feasibility and implications of a collaboration with Green Deal/ECO, the focus of the activity and mechanics of collaboration. If those discussions are positive then outline project specifications could be drawn up.

UK Energy Lab Feasibility Project

Description

Co-funded by DECC and the RCUK investment in the UCL Centre for Energy Epidemiology (UCL CEE), the UK Energy Lab feasibility study project reviewed the feasibility of setting up a repeat-wave nationally representative socio-technical survey for understanding energy use in homes and workplaces across the UK. The UCL CEE together with the UCL Department of Science, Technology, Engineering and Public Policy and the National Centre for Social Research carried out the project. . The work was divided into 8 strands:

- Available Data
- Design options
- Non-domestic settings
- Ethics and data security
- Governance
- Finance
- Pragmatics and piloting
- The Case for UK Energy Lab

The aims of the UK Energy Lab are to help evaluate and inform national energy policy, and to provide a platform for innovation and research. Such a data collection platform may include gathering data about buildings, technology use and people's energy use behaviour over thousands of homes and workplaces. The feasibility study considers including a sub-sample of households in which specific intervention (retrofit measures) would be trialled and then matched to a similar sample. This trial, coined 'Innovation Lab' would not be operational before 2018 (Shipworth 2014).

Hypotheses

Co-opting the Energy Lab project would provide insights on hypotheses:
✓ H1
✓ H3
✓ H8
✓ H9
✓ H10

Method/Approach

Include a GD/ECO focussed component into the survey. Recruit households from the sample, monitor for one year and then incentivise them to undergo GD/ECO in order to ensure pre- and post-installation data generation

Robustness and limitations

While this project does offer potentially useful tools and methodologies, the UK Energy Lab's primary goal is to generate baseline data on energy behaviour in the whole UK housing stock. It is not specifically focussed on installation of energy-efficiency measures. In addition, its launch date (2018) does not align with the requirement to have an effective programme monitoring system operational in the near future.

Benefits

The potential utility of the Energy Lab is shown in the table below:

Potential value for collaboration	**Potential value for purpose of monitoring plan**
Comprehensive mapping of ongoing data collections which can flag up other opportunities for collaboration or data sources to draw from	Data generated from a longitudinal panel survey
Sampling and survey design consideration and assessment of benefits of different options	A large representative sample to draw from
Consideration given to data privacy and the issues of commercial confidentiality and data access	The potential to include a GD/ECO focussed component into the survey
Indication of costings for in-house monitoring	Advanced monitoring technology which could be replicated

ORIGIN

Description

Heriot-Watt University's ORIGIN project[31], which is funded by the EU FP7 programme, is developing a sophisticated intelligent ICT system for the management of energy in a

[31] http://www.origin-energy.eu/

community. The ORIGIN control system will orchestrate energy demand within a community with the aim of better aligning it to local renewable generation. This will lead to imported energy savings and associated financial and on and off site emission benefits. User-friendly tools are being developed that provide demand and supply forecasting and these forecasts can then be used to suggest when to do certain tasks or in some cases to actuate tasks. A simple example of this would be to propose the scheduling of energy demanding tasks, such as operating a washing machine, in periods of expected high renewable energy supply.

The ORIGIN software will elicit behavioural scripts from consumption patterns that will permit bespoke guidance and tariffs to be created for individual households. These behavioural scripts will also be analysed to understand changes that have occurred as a consequence of system deployment. The expected renewable energy supply forecast is based on weather forecasting predictions used to calculate the potential wind and or solar energy. The project is also exploring possible business models for the commercialisation of this system. The project is a collaboration of eight organizations from five different European Union member states. The developed solutions will be validated in three eco-communities in three different climatic setting in northern Scotland, southern Portugal and the Italian alpine foothills.

The project will have access to a number of homes with highly developed monitoring systems recording a range of energy-related activities. The project would be open to amending some of these monitoring experiments to accommodate the GD and ECO requirements, explicitly measuring the effect of changes in the dwelling and corresponding reductions in energy consumption. In addition to this, the scripts developed within the project will be transferrable to more conventional pre- and post-retrofit studies, estimating expected behavioural patterns as a result of new technology deployment.

IDEAL

Description

The aim of this ‘socio-technical’ project, funded by the Engineering and Physical Sciences Research Council (EPSRC), is to examine the effects of household-specific and behaviour-specific feedback on household energy consumption. Given that information feedback is a well-established tool to reduce household energy demand, it is hypothesised that detailed, tailored feedback will be an even more effective tool, with different effects in different income groups.

The sample consists of 576 households in two locations – Edinburgh and Milton Keynes, and is split evenly between high income and low income/fuel poor groups. Three comparison groups are included:

- households receiving overall feedback on household energy consumption, similar to that provided by a smart meter;
- households receiving tailored, household-specific behaviour-specific feedback; and
- households receiving ‘social’ feedback, comparing their own consumption to that of other similar households.

The fieldwork is running from 2013 to 2016, and is using a combination of in-home monitoring and consumer research. For the in-home monitoring element, wireless sensors in participant homes are being used to transmit data once per minute on temperature, humidity, and electricity and gas demand, which is combined with metadata about the weather, building characteristics and household composition. These data are streamed to internet servers to be analysed using Bayesian machine-learning methods. Tailored behavioural feedback is generated and transmitted to the household via a special dedicated tablet computer. An example of the personalised feedback is: "*Your second bedroom is unoccupied at night but is being heated to 21°C. If you reset the heating controls to switch off that bedroom at night, you could reduce your gas bill by £5/week*."

The consumer research is designed to "examine why and how different forms of personalised behavioural feedback influence energy-related behaviour, and explore the impact of household composition and dynamics […and] provide insight into the complexity of interacting factors which modulate energy demand in households." This element consists of six-monthly online surveys which are sent to all participant households, plus semi-structured in-depth interviews in Year 2 with a subset of 50 households, selected on the basis of contrasting attitudes to feedback. The six-monthly surveys are also designed to capture changes to buildings, in particular, the installation of energy efficiency measures – a stated aim is to quantify the rebound effect.

Hypotheses

Working with IDEAL could provide insights on H1, H10, H12.

Approach

Include i) a GD/ECO sample and ii) a control group without feedback and compare to the control sample in this study.

Benefits

The key element of interest in IDEAL is its ground-breaking monitoring and analytical methods. Technical devices specifically designed to collect data indicative of energy consumption behaviour could be used for a wide range of projects relevant to testing hypotheses identified in this paper. In addition recruitment methods used for pre-installation data could potentially be replicated.

Although this project is not focussed on technology retrofits at present, they do have a number of homes that are already being monitored in detail over a long period of time. If the kinds of energy efficiency measures supported by GD and ECO were installed in these homes (potentially by households being invited to go through the GD/ECO customer journey), the pre-installed monitoring equipment would provide a wealth of data - both before and after the installation - and valuable insights.

Costs

The costs of the engagement on research partnerships would depend on the agreed scope of work, reporting requirements, other outputs (e.g. formal agreements), how many discussions proceeded to concept development and the extent to which DECC wished to outsource the engagement as opposed to handle it with staff technical and legal resources.

Recommendation

The IDEAL study still offers flexibility in its design, so a co-opted approach seems feasible at this point. At the same time, the DECC Salford University Core Cities Green Deal 'demonstrator' research projects, the Newcastle heating controls advice trial, the DECC Solid Wall Insulation Research Project as well as projects by Sustainable Homes, ETI/DECC and UKERC/ UCL and Oxford University Energy Use in Buildings should be observed for research outputs.

Annex 7: Overview of relevant research projects

Institution/ Topic	Timescale	Summary	Co-opt	Cooperate	Hypotheses answered	Recommended action
UCL, UK Energy Lab Feasibility Project	Ongoing	The UK Energy Lab - feasibility study project is reviewing the feasibility of setting up a repeat-wave nationally representative socio-technical survey for understanding energy use in homes and workplaces	• Include a GD/ECO focussed component into the survey • Recruit households from the sample, monitor for one year and then incentivise them to undergo GD/ECO in order to ensure pre- and post-installation data generation	• Data generated from a longitudinal panel survey • A large representative sample to draw from • Advanced monitoring technology which could be replicated • Comprehensive mapping of ongoing data collections which can flag up other opportunities for collaboration or data sources to draw from • Sampling and survey design consideration and assessment of benefits of different options • Consideration given to data privacy and the issues of commercial confidentiality and data access • Indication of costings for in-house monitoring	✓ H1 ✓ H3 ✓ H8 ✓ H9 ✓ H10	See text
University of Edinburgh, IDEAL	Ongoing	Testing the impact of detailed energy-use feedback on household energy demand with 576 households in Edinburgh and Milton Keynes	• Integrate a GD/ECO energy improvement measures group • Include a control group subject to no feedback	• Access to existing pre- and post-installation data for some non-GD/ECO retrofitted households over two heating seasons • Monitored data from a non-GD/ECO (and smart-meter type feedback)	✓ H1 ✓ H10 ✓ H12	See text

				• control group • A framework for pre- and post-installation monitoring and data analysis		
Heriot-Watt University, ORIGIN project	Ongoing	Developing an intelligent ICT system for the management of energy in a community, orchestrating energy demand within a community with the aim of better aligning it to local renewable generation. The ORIGIN software will elicit behavioural scripts from consumption patterns that will permit bespoke guidance and tariffs to be created for individual households.	Potential for using homes already being monitored, and applying the developed behavioural scripts to technology adoption in other identified homes.			See text
ETI/DECC, Smart Systems and Heat Programme	Ongoing	Workshops are organised where people report on their energy-use diaries. Some groups were monitored with follow-up surveys. 30 homes (range of different groups of occupants) are monitored in detail. A much larger survey will be conducted. In a major field trial home energy management systems will be installed in houses (in a year's time).	Incentivise the 30 homes which have been monitored in detail to either i) take up GD&E or ii) offer to install energy measures for free. This would allow for pre- and post-installation comparison	• Additional purposive sample • Access to qualitative data on household energy use • Potential access to pre-installation consumption data	✓ H1 ✓ H7 ✓ H9	→ Explore option to gain access to findings → Find out what kind of data is gathered in the monitored households
DECC, Salford University, Core Cities Green Deal 'demonstrator' research projects	Ongoing	Two separate research projects in Leeds and Manchester to monitor and evaluate the measures installed as part of the Green Deal "core cities demonstrator". Both physical and behavioural impacts of the measures installed are being evaluated with a focus on properties receiving Solid Wall Insulation (SWI). Both projects commenced in March 2013 and will run until Summer 2014.		• Access to existing pre- and post-installation data for some GD/ECO retrofitted households • Access to insights on non-GD&E customer journey	✓H10 ✓H12	→ Find out how many properties have been involved → Obtain interview guides to see to what extent the behavioural impact aspect covers P6 hypotheses

Newcastle heating controls advice trial Nudge Unit & NatCen, Impact of advice on heating behaviour	Ongoing	The project is investigating the role of information and advice with social tenants through trusted messenger (landlord). Three way target sample split, 1000 in each group (Interactive advice, Leaflet, Control group). Sample – target 3400, aim to reach 1,000 to 2,000	Include a target sample with broader heating systems supported under the Green Deal	• Access to insights on non-GD&E customer journey • Access to pre- and post-installation consumption • Control group of 1000 social tenants (types of data monitored and timeframe unclear at this point)	✓ H1 ✓ H11	→ Find out what kind of data is gathered in the monitored households
DECC, Solid Wall Insulation Research Project	Ongoing	The aim of the Solid Wall Insulation Research Project is to provide better estimates of energy savings from Solid Wall Insulation through improved understanding of heat losses. The project began in March 2013 and will run over 2 years. One work package includes monitoring and investigating unintended consequences.	• Potential to extend the project to include other measures supported under GD&E • Include a focus on behaviour in the research on the monitored homes	• Access to existing pre- and post-installation data for some non-GD/ECO retrofitted households • Learnings could be built upon in a larger Green Deal focused qualitative study	✓H2 ✓H3 ✓H4 ✓H7 ✓H9	→ Engage with the research team → Find out how many properties have been involved
Sustainable Homes	Ongoing	Conducts study which monitors energy usage in 600 housing association properties with the goal to test effect on feedback on energy consumption (valid data gathered from 360 homes)	• Include the monitored households as control group • Install ECO in households	Access to pre-installation consumption data (self-reported and meter readings only)	✓ H11	→ Observe project progress
Open University, Heat-Pump Field Trial	Concluded	In collaboration with the EST, the OU conducted a major study of user experiences, behaviours and satisfactions with ground and air source heat pump systems installed in nearly 90 dwellings.	Project concluded, so only follow-up possible	• Technical insights on system efficiencies and inefficiencies, carbon emissions of ASHP and GSHP. • A non-GD control group (83 homes including private and social housing dwellings) with one full year of technical	✓ H2 ✓ H10	→ Explore option of follow-up with the research team → Obtain questionnaire

				• monitoring of the types of measures supported under the GD and qualitative data • Questionnaire testing user satisfaction and comfort-taking		
Jennifer Love, PhD thesis at UCL, Post retro-fit heating behaviour	Handed in 27/04/2014	Jennifer investigated energy consumption of ten households in social housing estates before and after they had SWI installed in their homes.	Project concluded, so only follow-up possible	• Access to existing pre- and post-installation data for some non-GD/ECO retrofitted households (small sample • A framework for pre- and post-installation monitoring and data analysis • General willingness from landlords to cooperate again with UCL	✓ H1	→ No immediate action necessary; however, if research partnering goes ahead, potential to replicate data gathering approach and analytical framework
UKERC/ UCL and Oxford University, Energy Use in Buildings	Ongoing	The research is addressing the pace of technical change, variance in energy use between similar buildings and the scope for reduction, both behavioural and technical. Policy research, both on new policies (e.g. the Green Deal) and existing regulations (e.g. building standards) is also a part of this work.	Depends on primary data collection	Depends on primary data collection	Depends on primary data collection	→ Engage with the research team to find out more
Kirklees Council (and partners), Kirklees Warm Zone (KWZ)	2007-2010	134,000 energy assessments of households, resulting in 51,155 homes being retrofitted (primarily loft and cavity-wall insulation). A series of post-occupancy technical and behavioural information is available from a number of studies using the data collected.	Much data already in public domain, with some behavioural data in the process of being published.			Behaviour analysis could usefully inform further qualitative or quantitative research design, therefore

						overlap with the proposed research project (both elements)
Technology Strategy Board (TSB), Retrofit for the Future	2009-2013	Over 100 homes were retrofitted with a target of 80% CO2 reduction. Considerable collaboration between householders, contractors, practitioners and researchers to identify the success of these measures.	Technical and economic data readily available (see also EMBED) to provide a comparison with any new data collection exercise.	Not applicable	Not applicable	Not applicable
Energy Saving Trust, EMBED database	Ongoing	An interactive, online platform to collate a range of building energy performance data. Includes the TSB data listed above, as well other databases from EST field trials. With the platform being relatively wide-ranging, not all data relates to retrofit projects.	Will be both a source of data (to guide new data collection activities) but also a portal for disseminating any further data collected by the Project 6.	Not applicable	Not applicable	Not applicable
Gentoo Housing Association, Pay-as-you-save (PAYS) trials	2012	PAYS scheme run with social housing tenants to explore methods for repaying large capital cost investments for retrofits.	Useful as a comparison for Green Deal take up barriers	Not applicable	Not applicable	Not applicable
Affinity Sutton, FutureFit report	2013	150 homes retrofitted with a range of measures (costing between £6,500 and £25,000) for reducing energy bills. Modelled results compared with measured energy savings to highlight the difference. Pulse gas meters, electricity meters and temperature sensors all used in analysis, along with resident questionnaires.	Considerable amount of data already in public domain. Also highlights need for empirical information for retrofit studies	Not applicable	Not applicable	Not applicable
BRE/Scottish Government 2020 Built Environment Group, Retrofit Scotland	Ongoing	Open database of domestic retrofit projects across Scotland. A wide range of case-studies that focus on different metrics, so difficult to collate together to form a coherent whole, but useful collection of individual	As with EMBED, this will be a useful database to gain existing data but also for disseminating future data from.	Not applicable	Not applicable	Not applicable

	case-studies to contrast with elsewhere

Annex 8: Articles reviewed in the evidence scan

Reference

Abrahamse, W., Steg, L. (2009) How do socio-demographic and psychological factors relate to households' direct and indirect energy use and savings? Journal of Economic Psychology 30 (2009) 711–720.

Abrahamse, Wokje, et al. "A review of intervention studies aimed at household energy conservation." Journal of environmental psychology 25.3 (2005): 273-291.

Adua, Lazarus. 2010. "To cool a sweltering earth: Does energy efficiency improvement offset the climate impacts of lifestyle?." Energy Policy 38.10 (2010): 5719-5732.

Allcott, H., & Mullainathan, S. (2010). Behavioral science and energy policy. Science, 327(5970), 1204-1205.

Azar, Elie, and Carol C. Menassa. "Agent-based modeling of occupants and their impact on energy use in commercial buildings." Journal of Computing in Civil Engineering 26.4 (2011): 506-518.

Behar, C; (2013) Utilising resident feedback to inform energy-saving interventions at the Barbican. Local Environment: The International Journal of Justice and Sustainability

Black, J. Stanley, Paul C. Stern, and Julie T. Elworth. "Personal and contextual influences on household energy adaptations." Journal of applied psychology 70.1 (1985): 3.

Bleda, M., & Valente, M. (2009). Graded eco-labels: a demand-oriented approach to reduce pollution. Technological forecasting and social change, 76(4), 512-524.

Boulanger P.-M. J. Couder, Y. Marenne, S. Nemoz, J. Vanhaverbeke, A. Verbruggen, G. Wallenborn (2013). Household energy consumption and rebound effect. Belgian Science Policy 2013

Brännlund, Runar, Tarek Ghalwash, and Jonas Nordström. "Increased energy efficiency and the rebound effect: Effects on consumption and emissions." *Energy economics* 29.1 (2007): 1-17.

Caird, Sally, Robin Roy, and Horace Herring. "Improving the energy performance of UK households: Results from surveys of consumer adoption and use of low-and zero-carbon technologies." Energy Efficiency 1.2 (2008): 149-166.

Caird, Sally, Robin Roy, and Stephen Potter. (2012) "Domestic heat pumps in the UK: user behaviour, satisfaction and performance." Energy Efficiency 5.3 (2012): 283-301.

Cantono, S., & Silverberg, G. (2009). A percolation model of eco-innovation diffusion: the relationship between diffusion, learning economies and subsidies. Technological forecasting and social change, 76(4), 487-496.

Carlsson-Kanyama, A., & Lindén, A. L. (2007). Energy efficiency in residences—Challenges for women and men in the North. Energy Policy, 35(4), 2163-2172.

Carlsson-Kanyama, Annika, Anna-Lisa Lindén, and Björn Eriksson. "Residential energy behaviour: does generation matter?." International Journal of Consumer Studies 29.3 (2005): 239-253.

Craig, T., Polhill, J. G., Dent, I., Galan-Diaz, C., & Heslop, S. (2014). The North East Scotland Energy Monitoring Project: Exploring relationships between household occupants and energy usage. Energy and Buildings, 75(0), 493-503. doi: http://dx.doi.org/10.1016/j.enbuild.2014.02.038

Darby, S. (2001) Making it obvious: designing feedback into energy consumption
S Darby - Energy efficiency in household appliances and lighting, 2001

Dimitropoulos, John. "Energy productivity improvements and the rebound effect: An overview of the state of knowledge." *Energy Policy* 35.12 (2007): 6354-6363.

Dolan, Paul, and Robert Metcalfe. "Neighbors, knowledge, and nuggets: Two natural field experiments on the role of incentives on energy conservation." (2013).

Dounis, Anastasios I., and Christos Caraiscos. 2009. "Advanced control systems engineering for energy and comfort management in a building environment—A review." Renewable and Sustainable Energy Reviews 13.6 (2009): 1246-1261.

Druckman, Angela, et al. "Missing carbon reductions? Exploring rebound and backfire effects in UK households." *Energy Policy* 39.6 (2011): 3572-3581.

Ehrhardt-Martinez, Karen, and John A. Laitner. "Rebound, technology and people: Mitigating the rebound effect with energy-resource management and people-centered initiatives." *ACEEE Summer Study on Energy Efficiency in Buildings*. 2010.

Ekins, P., and C. Spataru. "To work, the Green Deal needs to take seriously the diversity of human behavior." *HHIC Journal* (2012).

Fischer, Corinna. "Feedback on household electricity consumption: a tool for saving energy?." Energy efficiency 1.1 (2008): 79-104.

Freire González, Jaume. "Empirical evidence of direct rebound effect in Catalonia." *Energy Policy* 38.5 (2010): 2309-2314.

Frenken, K and Faber, A. (2009) Introduction: Evolutionary methodologies for analyzing environmental innovations and the implications for environmental policy Pages 449-452 In Koen Frenken, Albert Faber (Eds) Special Issue Technological forecasting and social change (2009)

Frondel, Manuel, Jörg Peters, and Colin Vance. "Identifying the rebound: evidence from a German household panel." *The Energy Journal* (2008): 145-163.

Gauthier, S; Shipworth, D; (2012) Predictive thermal comfort model: Are current field studies measuring the most influential variables? In: Proceedings of the 7th Windsor Conference: The Changing Context of Comfort in an Unpredictable World, Cumberland Lodge, Windsor, UK, 12-15 April 2012. NCEUB (Network for Comfort and Energy Use in Buildings)

Gauthier, S; Shipworth, D; (2013) Review of methods to map people's daily activity – application for smart homes. In: Sustainability in Energy and Buildings: Proceedings of the 4th International Conference on Sustainability in Energy and Buildings (SEB'12). Springer-Verlag: Berlin. (In press).

Gill, Z.M. M.J. Tierney, I.M. Pegg, A. (2010). Low-energy dwellings: the contribution of behaviours to actual performance. Building Research and Information, 38 (5) (2010), pp. 491–508.

Gram-Hanssen, Kirsten. "Residential heat comfort practices: understanding users." Building Research & Information 38.2 (2010): 175-186.

Greening, Lorna, David L. Greene, and Carmen Difiglio. "Energy efficiency and consumption—the rebound effect—a survey." *Energy policy* 28.6 (2000): 389-401.

Gupta, R. and M. Kapsali (2014)a. Evaluating the effect of occupant behaviour and expecations on actual energy use and environmental conditions in "sustainable" social housing in South East England. Proceedings of 8th Windsor Conference: Counting the Cost of Comfort in a changing world. Cumberland Lodge, Windsor, UK, 10-13 April 2014.

Gupta, R., L. Barnfield and T. Hipwood (2014)b: Impacts of community-led energy retrofitting of owner-occupied dwellings, Building Research & Information, DOI: 10.1080/09613218.2014.894742

Gupta, R.and L. Barnfield (2013) Unravelling the unintended consequences of home energy improvements. Sustainable Building Conference. http://architecture.brookes.ac.uk/research/lowcarbonbuilding/index.html

Gyberg, Per, and Jenny Palm. "Influencing households' energy behaviour—how is this done and on what premises?." Energy Policy 37.7 (2009): 2807-2813.

Hamilton, IG; Summerfield, AJ; Lowe, R; Ruyssevelt, P; Elwell, CA; Oreszczyn, T; (2013) Energy epidemiology: a new approach to end-use energy demand research. Building Research & Information , 41 (4) 482 - 497

Henly, John, Henry Ruderman, and Mark D. Levine. "Energy saving resulting from the adoption of more efficient appliances: a follow-up." *The Energy Journal* (1988): 163-170.

Hens, Hugo, Wout Parijs, and Mieke Deurinck. "Energy consumption for heating and rebound effects." *Energy and buildings* 42.1 (2010): 105-110.

Herring, Horace, and Robin Roy. "Technological innovation, energy efficient design and the rebound effect." Technovation 27.4 (2007): 194-203.

Hong, Sung H., et al. "A field study of thermal comfort in low-income dwellings in England before and after energy efficient refurbishment." Building and Environment 44.6 (2009): 1228-1236.

Hong, Sung H., Tadj Oreszczyn, and Ian Ridley. "The impact of energy efficient refurbishment on the space heating fuel consumption in English dwellings." Energy and Buildings 38.10 (2006): 1171-1181.

Huebner, G. M., J. Cooper, and K. Jones. "Barriers towards reducing domestic Energy Consumption–Findings of a Study among Social Housing Tenants." *International Journal of Environment and sustainable Development*.

Huebner, Gesche M., et al. "Heating patterns in English homes: Comparing results from a national survey against common model assumptions." *Building and Environment* 70 (2013): 298-305.

Huebner, Gesche M., et al. "The reality of English living rooms–A comparison of internal temperatures against common model assumptions." *Energy and Buildings* 66 (2013): 688-696.

Huebner, Gesche M., Justine Cooper, and Keith Jones. "Energy saving practices, barriers against and reasons for change among social housing tenants." (2011).

Huebner, Gesche Margarethe, Justine Cooper, and Keith Jones. "Domestic energy consumption—What role do comfort, habit, and knowledge about the heating system play?." *Energy and Buildings* 66 (2013): 626-636.

Hughes, M; Palmer, J; Cheng, V; Shipworth, D; (2013) Sensitivity and Uncertainty Analysis of the UK's Housing Energy Model. Building Research and Information: the international journal of research, development and demonstration , 41 (2) 156 - 167.

Hutchinson, Emma J., et al. "Can we improve the identification of cold homes for targeted home energy-efficiency improvements?." Applied energy 83.11 (2006): 1198-1209.

Jaccard, Mark, and Chris Bataille. "Estimating future elasticities of substitution for the rebound debate." *Energy policy* 28.6 (2000): 451-455.

Jackson, J. (2012) Lessons learnt from prospective and actual occupants of energy efficient homes in a major Sustainable Urban Extension (SUE), Northampton, UK. Draft paper

Keirstead, James. "Behavioural responses to photovoltaic systems in the UK domestic sector." Energy Policy 35.8 (2007): 4128-4141.

Kelly, S; Shipworth, MD; Shipworth, DT; Gentry, MI; Wright, A; Pollitt, M; ... Lomas, K; + view all Kelly, S; Shipworth, MD; Shipworth, DT; Gentry, MI; Wright, A; Pollitt, M; Crawford-Brown, D; Lomas, K; - view fewer (2012) A panel model for predicting the diversity of internal temperatures from English dwellings. (Tyndall Working Papers 154). Tyndall Centre for Climate Change Research: Norwich, UK

Lindén, Anna-Lisa, Annika Carlsson-Kanyama, and Björn Eriksson. "Efficient and inefficient aspects of residential energy behaviour: What are the policy instruments for change?." Energy policy 34.14 (2006): 1918-1927.

Lopes, M. A. R., C. H. Antunes, and N. Martins. "Energy behaviours as promoters of energy efficiency: A 21st century review." Renewable and Sustainable Energy Reviews 16.6 (2012): 4095-4104.

Madlener, Reinhard, and Blake Alcott. "Energy rebound and economic growth: A review of the main issues and research needs." *Energy* 34.3 (2009): 370-376.

Masoso, O. T., and L. J. Grobler. "The dark side of occupants' behaviour on building energy use." Energy and Buildings 42.2 (2010): 173-177.

McMichael, M; Shipworth, D; (2013) The value of social networks in the diffusion of energy efficiency innovations in UK households. Energy Policy , 53 159 - 168

Mizobuchi, Kenichi. "An empirical study on the rebound effect considering capital costs." Energy Economics 30.5 (2008): 2486-2516.

Moran Jay, B; Howard, D; Hughes, N; Whitaker, J; Anandarajah, G; (2013) Modelling socio-environmental sensitivities: How public responses to low carbon energy technologies could shape the UK energy system. The Scientific World Journal

Nässén, Jonas, and John Holmberg. "Quantifying the rebound effects of energy efficiency improvements and energy conserving behaviour in Sweden." *Energy Efficiency* 2.3 (2009): 221-231.

Ockwell, David G. "Energy and economic growth: Grounding our understanding in physical reality." *Energy Policy* 36.12 (2008): 4600-4604.

Oikonomou, Vlasis, et al. "Energy saving and energy efficiency concepts for policy making." *Energy Policy* 37.11 (2009): 4787-4796.

Oreszczyn, Tadj, et al. "Determinants of winter indoor temperatures in low income households in England." Energy and Buildings 38.3 (2006): 245-252.

Oreszczyn, Tadj, et al. "Mould and winter indoor relative humidity in low income households in England." Indoor and Built Environment 15.2 (2006): 125-135.

Ouyang, Jinlong, Enshen Long, and Kazunori Hokao. "Rebound effect in Chinese household energy efficiency and solution for mitigating it." *Energy* 35.12 (2010): 5269-5276.

Pfafferott, J., and S. Herkel. (2007) "Statistical simulation of user behaviour in low-energy office buildings." Solar energy 81.5 (2007): 676-682.

Poortinga, Wouter, Linda Steg, and Charles Vlek. "Values, Environmental Concern, and Environmental Behavior A Study into Household Energy Use." Environment and behavior 36.1 (2004): 70-93.

Raw, GJ; (2012) How does the behaviour of building occupants affect overheating risk? In: AECOM (Ed) Investigation into Overheating in Homes - Literature Review. Department for Communities and Local Government: London, UK.

Research programme on consumer adoption, use and performance of low carbon energy efficiency and renewable technologies in residential buildings
The Open University, Department of Engineering and Innovation

Schipper, Lee, and Michael Grubb. "On the rebound? Feedback between energy intensities and energy uses in IEA countries." *Energy policy* 28.6 (2000): 367-388.

Schwarz, Nina, and Andreas Ernst. (2009) "Agent-based modeling of the diffusion of environmental innovations—an empirical approach." Technological forecasting and social change 76.4 (2009): 497-511.

Sorrell, Steve, and John Dimitropoulos. "The rebound effect: Microeconomic definitions, limitations and extensions." *Ecological Economics* 65.3 (2008): 636-649.

Sorrell, Steve, John Dimitropoulos, and Matt Sommerville. "Empirical estimates of the direct rebound effect: A review." *Energy policy* 37.4 (2009): 1356-1371.

Sorrell, Steve. "Jevons' Paradox revisited: The evidence for backfire from improved energy efficiency." *Energy Policy* 37.4 (2009): 1456-1469.

Sorrell, Steve. *The Rebound Effect: an assessment of the evidence for economy-wide energy savings from improved energy efficiency*. London: UK Energy Research Centre, 2007.

Spataru, C., & Gauthier, S. (2013). How to monitor people 'smartly' to help reducing energy consumption in buildings?. Architectural Engineering and Design Management, 10, 60-78

Spataru, C., & Gillott, M. (2011). The Use of Intelligent Systems for Monitoring Energy Use and Occupancy in Existing Homes. Smart Innovation, Systems and Technologies, 7, 247-256.

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

Stern, Paul C. "What psychology knows about energy conservation." American Psychologist 47.10 (1992): 1224.

Straughan, Robert D., and James A. Roberts. (1999) "Environmental segmentation alternatives: a look at green consumer behavior in the new millennium." Journal of consumer Marketing 16.6 (1999): 558-575.

Swords, B., Eugene Coyle, and Brian Norton. "An enterprise energy-information system." Applied Energy 85.1 (2008): 61-69.

ThØgersen, John. "Understanding of consumer behaviour as a prerequisite for environmental protection." Journal of consumer policy 18.4 (1995): 345-385.

UCL Institute for Sustainability. Retrofit insights: perspectives for an emerging industry. Key Findings: Analysis of a selection of Retrofit for the Future projects

Van den Bergh, Jeroen CJM. "Energy conservation more effective with rebound policy." *Environmental and resource economics* 48.1 (2011): 43-58.

Verspagen, B. (2009). The use of modeling tools for policy in evolutionary environments. Technological forecasting and social change, 76(4), 453-461.

Weidlich, Anke, and Daniel Veit. (2008) "A critical survey of agent-based wholesale electricity market models." Energy Economics 30.4 (2008): 1728-1759.

Wilhite, Harold, et al. "The legacy of twenty years of energy demand management: we know more about individual behaviour but next to nothing about demand." Society, behaviour, and climate change mitigation. Springer Netherlands, 2000. 109-126.

Willis, Rachelle M., et al. "Alarming visual display monitors affecting shower end use water and energy conservation in Australian residential households." Resources, Conservation and Recycling 54.12 (2010): 1117-1127.

Wilson, Charlie, and Hadi Dowlatabadi. (2007)"Models of decision making and residential energy use." Annu. Rev. Environ. Resour. 32 (2007): 169-203.

Windrum, P., Ciarli, T., & Birchenhall, C. (2009). Consumer heterogeneity and the development of environmentally friendly technologies. Technological Forecasting and

Social Change, 76(4), 533-551.

Yohanis, Yigzaw G., et al. "Real-life energy use in the UK: How occupancy and dwelling characteristics affect domestic electricity use." Energy and Buildings 40.6 (2008): 1053-1059.

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