Programme Area: Smart Systems and Heat

Project: Consumer Response and Behaviour

Title: Literature Review

Abstract:

This report was prepared for the ETI by the consortium that delivered the project in 2013 and whose contents may be out of date and may not represent current thinking. The delivery of consumer energy requirements is a key focus of the Smart Systems and Heat Programme. This project will identify consumer needs and behaviours relating to heat and provide insights into consumer response to Smart Energy System proposals, providing a consumer focus for the other Work Areas The literature review was carried out to aid in the understanding of existing research within this field.

Context:

The delivery of consumer energy requirements is a key focus of the Smart Systems and Heat Programme. The Consumer Response and Behavior Project will identify consumer requirements and predict consumer response to Smart Energy System proposals, providing a consumer focus for the other Work Areas. This project involved thousands of respondents providing insight into consumer requirements for heat and energy services, both now and in the future. Particular focus was given to identifying the behaviour that leads people to consume energy - in particular heat and hot water. This £3m project was led by PRP Architects, experts in the built environment. It involved a consortium of academia and industry - UCL Energy Institute, Frontier Economics, The Technology Partnership, The Peabody Trust, National Centre for Social Research and Hitachi Europe.

Smart Systems and Heat (SSH) Technology Programme

Work Area 5: Consumer Response and Behaviour

WP5.1a: Literature Review

A review of the literature on consumer response to smart energy systems

Version 4 – Final draft following ETI validation review

30 September 2013

Contents

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This review was conducted as part of the Consumer Response and Behaviour (CRaB) project, within the Smart Systems and Heat (SSH) Programme of the Energy Technologies Institute (ETI).

ETI is a public-private partnership between global industries and the UK Government. The ETI is focused on accelerating the deployment of affordable, secure low-carbon energy systems for 2020 to 2050 by demonstrating technologies, developing knowledge, skills and supply-chains and informing the development of regulation, standards and policy. Further information can be found at www.energytechnologies.co.uk.

The principal authors of this report are Gary Raw and Clare Littleford of UCL but the review is founded on the intensive effort of the following members of the CRaB project team in identifying and reviewing documents and adding their notes to the review database.

Will Anderson (consultant to UCL)
Tessa Barraclough (Peabody)
Kirsten Burrows (PRP)
Sara Celentano (PRP)
Jake Elstow-Jones (consultant to UCL)
Mike Fell (UCL)
Sioned Holland (PRP)
Kieran Keohane (Frontier Economics)
Akira Kobayashi (Hitachi Europe)
Paula Morgenstern (UCL)
Isabella Neuweg (Hitachi)
Eleni Oikonomou (UCL)
Rokia Raslan (UCL)
Vicky Sedgwick (Frontier Economics)
Claire Thornhill (Frontier Economics)
Anna Wieckowska (Hitachi Europe)

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Executive Summary

Introduction

An understanding of the needs that consumers meet (or seek to meet) through energy use, and the behaviours and technologies through which they do this, is fundamental to the design of a smart energy solution (SES) aimed at meeting unmet needs or meeting needs in a different way. If needs and behaviour are not well understood, the design risks failing to meet needs or conflicting with how consumers wish to behave, ultimately resulting in failure of the design. This review seeks to provide that understanding on the basis of the current literature. It deals principally with the use of heat energy by occupants in residential buildings but incorporates evidence on other energy applications and from non-domestic buildings where this provides relevant insights. Use of heat energy includes heating spaces and water, cooling, ventilation, and alternative methods of temperature control such as heating or cooling the person or insulating the building.

Consumer needs

Using energy is not an aim in itself – it is part of how householders meet a wide range of needs. Needs are here conceived principally from the perspective of individual persons, while recognising that individuals act within a complex social context. Needs may be directly those of the person taking the action that results in energy use, or the action may be decided by negotiation (e.g. to manage differences in thermal comfort) or done on behalf of someone else. A need exists whether or not it is currently met, and whether or not a person is conscious of the need itself or how it relates to energy use.

Needs have been categorised as follows, each area of need having potential for both positive and negative effects on energy-related behaviour.

- The wider implications of energy use: a need to act in a way that protects or promotes interests beyond the household, at scales of the planet, country or neighbourhood (e.g. climate change, pollution, depletion of natural resources, environmental damage and energy security).
- Resource-related needs: saving (or making) money; being in control of finances; adding value to property; getting a bargain or free offer; avoiding waste; or achieving self-sufficiency.
- Quality of life: well-being (comfort, relaxation, rest, health, safety, security, privacy, freedom from worries or fears); productivity; aesthetics; ease; simplicity; confidence (in the technology); control (over technology, energy use and indoor environment); entertainment and happiness.
- Social needs: self-image; identity; recognition; self-esteem; aspirations; conforming with social norms; teaching the next generation; developing a sense of competence, choice or control; pride in a neighbourhood, city or country; association with role models; social interaction and caring for others.
- Regulatory needs: complying with laws and standards.

Most people have some awareness of a connection between energy use and global environmental impact, and this becomes more salient if emphasis is placed on local implications, but this is not the principal need underlying energy-related behaviour. Resources (particularly financial), quality of life and social needs tend to dominate. Global impacts can, nevertheless, have a validating role in people explaining their actions to others, in reinforcing a person's belief that his/her action was worthwhile or in accepting Government action on energy. Regulatory needs having a constraining role. Priorities of needs vary widely between individuals, contexts and the specific behaviours or choices in question. A need that is currently being met might not even be thought of as a need and if the highest priority need is met, others will likely be revealed.

There is generally a lack of evidence on relationships among needs, how these vary over time (hours or years), or with the characteristics of persons or dwellings, or how needs relate to current behaviour, practices or purposes of home, or response to SES. For example, an apparently simple behaviour such as taking a shower, meeting an obvious need (to get clean), actually addresses a wide range of needs. The implication is that "priorities of need" is a risky way of thinking in relation to SES design; the more effective approach appears to be to identify common patterns of need.

What do people do and why do they do it?

Potential ways of explaining behaviour include the needs being met, along with awareness, knowledge, beliefs, experience of different thermal climates, habits and constraints. There is always some combination of behaviour and technology, even if the technology is a blanket, hence the two need to be considered together. The possible behaviours will depend on the technology that is available, the householders' ability to use that technology or install new technology, and the time and space required to fit the technology.

While attitudes are a good predictor of intentions, the characteristics of the dwelling and household are a better predictor of actual behaviour. So stated motives are a useful starting point but not definitive (although they can be useful in presenting proposed changes or new technology). General barriers to adoption include the social risk of neighbours or other local residents reacting adversely, perceptions of the technology being difficult to operate, and market prices being higher than homeowners are willing to pay.

Frequency of behaviour influences the interaction a consumer would need to have with an SES and how it should be presented in order to gain acceptance. Behaviour can be frequent (more-or-less daily), occasional (perhaps only once during a person's occupation of a home) or infrequent (between these two). These affect the amount of time and thought that a consumer is likely to give to the behaviour, which in turn affects whether an SES could easily change the behaviour or whether it would need to work within the confines of existing behaviour. Frequency also affects who is in control (e.g. an individual or a household), the required resources for the behaviour and the required technology. As frequency decreases, the likelihood of a behaviour entailing acquisition of technology (and therefore the cost) increases.

Space heating is driven not simply by the desired temperature but principally by comfort and other well-being needs (e.g. aesthetics and making life easier), with social needs also playing a role, but constrained by resources, regulations and (for some) wider implications of energy use. Behaviour also depends on the heating system and controls (e.g. requiring either frequent interaction or largely operating in the background). But this is complicated by the extent to which the users understand and are physically able to operate the heating system and by negotiation within households.

There is widespread misunderstanding of controls (e.g. complex controls are often used as simple switches) so the mere presence of controls does not signal how they will be used or the indoor environment that will be achieved. However, using a thermostat tends to result in lower room temperatures but timing controls may result in heating systems being on for longer, depending on what the household did prior to the installation. Householders also appear to strike some balance between limiting energy use and keeping the heating on when the home is unoccupied because of a desire not to return to a cold home. The extent of actual energy wastage is unknown, for example as a result of rooms being heated when they do not need to be (e.g. when empty) or heated more than is necessary for comfort. It is also unknown how much spaces are used without being heated to the extent the occupants wish.

Maintenance (e.g. boiler servicing) is a key infrequent behaviour but if it is never done it is replaced by occasional repair or replacement. The main occasional behaviours are major installations such as a new heat source (e.g. a boiler or heat pump), controls or complete heating system. Retrofit tends to happen in response to failure of the existing system or action by a landlord. Action by an owner-occupier is most likely to be, as near as possible, a like-for-like replacement.

The strategy (for both space and water heating) is not necessarily fixed within a household but can vary daily or with season, who is at home and how they make decisions. Major occasional water heating behaviours include installing a new boiler or solar thermal hot water system, and insulating the hot water tank.

Taking a bath (of varying depth), shower (average just under 7 minutes, range of 1-30 minutes) or both is now an almost daily occurrence. Showers have progressively taken over from baths as the usual means of washing, accompanied by new technologies delivering higher flow rates and better control of water temperature. Water use for showers has been projected to double over 20 years. Almost a quarter of householders sometimes shower outside the home.

A washing machine is the dominant means of doing laundry and only about half of households always wash a full load. Frequency of washing depends on: how often (and over what period) items are worn between washes; the number owned and whether they require different washing machine settings; machine capacity; acceptability of washing less than a full load; space to store laundry; the number of people in the household and whether they do laundry independently. There is substantial diversity in how often people use items before washing them, but typically only once for some items. Commonly cited reasons for washing clothes are that they look dirty, smell or need freshening, but often simply because they have been worn, suggesting influence of norms about washing rather than actual cleanliness. It is common to use laundry services outside the home. Households vary widely in when they do their washing but options for drying laundry have relatively little influence, so the means of drying is constrained by when the washing is done.

Among households with a dishwasher, a third use it for most of their washing up and slightly fewer report a fairly equal mix between dishwasher and sink use, but almost a quarter rarely or never use it. The timing and frequency of washing up varies substantially with dishwasher ownership and other factors. Outsourcing, in the form of eating out, is common – around 25% do not prepare all, or nearly all, their meals in the home.

As an area for action in relation to behavioural impacts on energy use, water heating may be (or become) more important than space heating because: it could be more open to interventions targeting peak power demand, shifting load to different times of day (or to outside the home); as insulation and the efficiency of space heating improve, the proportional role of occupant space-heating behaviour in determining energy consumption is diminishing; major water-using appliances are replaced more often than heating systems; and water use is more individually decided rather than requiring negotiation in a household. There are clearly opportunities to design SES for hot water but the effects are difficult to predict. For example, common advice is to save water and energy by using a shower rather than a bath but, as a result of showering trends, water consumption has moved above the level previously due to having baths.

Examples of frequent behaviours to stop heat escaping are closing windows or curtains, and placing a draught excluder at the base of doors (with related infrequent behaviours of purchasing curtains or draught excluders). However, the bulk of the evidence concerns occasional behaviours such as: insulating walls, lofts or roofs, and floors; installing new windows or doors; draughtproofing the building; and insulating hot water storage vessels or pipes. This is driven largely by comfort, health and cost savings, although advertising increasingly refers to CO_2 and climate change.

Renovation for aesthetic, lifestyle, status or functional reasons is generally prioritised over retrofit to save energy although the latter may be seen as an added benefit. A lack of interest in retrofit may go with a lack of personal connection with the home or an (often mistaken) perception that adequate energy efficiency improvements have already been made. Retrofit often falls short of the standards for new build and some simple retrofit has not yet been carried out at all. Barriers include inconvenience (e.g. reducing loft space or clearing the loft) and adverse effects on the appearance of a building, especially if it is an older building or there is uncertainty about the performance of the insulation. Consumers would prefer loft insulation to be thinner and less irritant. The potential of insulation to either reduce or increase the risk of overheating in summer is important but not widely mentioned by consumers.

Insulating or heating individual persons is a highly energy-efficient strategy, allowing room temperatures to be reduced, e.g. by putting on extra layers of clothing or extra blankets/duvets (at night or during the day); using local heat from a radiant heater, hot water bottle, electric blanket or even a pet's body heat; using hot drinks, showers and baths; and putting clothes, towels or bedding over a radiator to warm them before use. Support for the further development of technologies and social practices encouraging these solutions is important to emphasise, when much focus is placed on building fabric and systems.

Frequent behaviours to keep cool include: ventilation (generally using windows rather than other devices); air conditioning; using shading at windows (in response to overheating or in anticipation); using thermal mass (e.g. when leaving windows open at night to cool the building); using a dehumidifier or fan; reducing physical activity and/or clothing or bedding; having a cool shower or using cool sprays or cloths; turning off heat-producing appliances or using appliances that produce less heat; and leaving the home during the hottest part of the day or using cooler parts of the home. All this may require infrequent and occasional behaviours such as hiring or buying items; improvement or resetting of heating/cooling controls; maintenance (e.g. repairing or adjusting windows to make them more easily or securely openable); or action to eliminate external noise or air pollution, so that windows can be opened.

Windows may be opened to reduce temperature or humidity or increase air movement, but also to avoid condensation and mould, improve indoor air quality (IAQ), talk to someone or hear what is happening outside, and habit. Equally important is when people want to open windows or doors but opt not to, for reasons such as: external noise or air pollution/odours; the weather; concerns over security, privacy or the safety of young children or vulnerable adults; keeping pets in or keeping animals/insects/pests out; and practical/ergonomic difficulties in opening the window. The balance of influencing factors depends on the purpose of the room – whether it is "lived in" (i.e. living rooms), characterised by low constant window-opening at all times of day; "functional" (e.g. kitchens and bathrooms), characterised by frequent short-term ventilation on an "as needed" basis); or "for sleeping", where windows are opened three or four times more than in other rooms, especially at night. There is a current trend to use chemical air fresheners to improve IAQ; the implications for energy consumption and health are uncertain.

Some studies have found reduced window-opening where mechanical ventilation (MV) is in use, but there also appears to be a preference to continue opening windows when they are not strictly necessary for ventilation. There is also evidence that householders do not understand MV and use it for less time than design intentions or do not efficiently use "boost" or heat exchanger bypass modes, or do not clean the systems.

There is relatively little policy action to reduce cooling demand and some thermal retrofit (e.g. internal wall insulation) can increase the risk of overheating. A trend for smaller homes, closer together, with more people experiencing air conditioning in other contexts, and continued climate warming, creates concern that there will be widespread demand for air conditioning in homes. It is critical, therefore, that any SES should address passive cooling on an equal footing with heating. Where air conditioning is installed in homes, the limited UK evidence is that there is general user satisfaction but the usual temperature settings and pattern of use would demand more energy than strictly necessary for comfort.

Heat energy use is affected by behaviours that people do not necessarily count as heating, such as: drying laundry (e.g. outdoors, in a tumble dryer or around the home); storing and cooking food; general use of lights and appliances (and turning them off when not in use); using daylight where possible; and using light to create a mood of cosiness, instead of (or in addition to) heating. Related infrequent and occasional behaviours include purchase of energy-saving items; switching between indoor and outdoor drying with the season; switching cooking to a microwave oven; and maintenance. Increases in the number (and sometimes power) of appliances owned mean that overall electricity consumption per household for lighting and appliances has increased in recent years. Such changes have implications for heating: incidental gains are increased and explicit heating accounts for a decreasing proportion of total energy use. The same kind of negative consequences could also arise in relation to new heat energy technology.

Individual behaviours are important, but should not be viewed in isolation. Rather, they should be seen as something that shapes and is shaped by a complex web of needs, purposes of home, and the physical and technological context. It is generally unclear, for example, whether a behaviour would easily be adapted to an SES or whether the SES should be designed around the behaviour. The answer may be found in the extent to which the behaviour is an integral part of a lifestyle, meeting multiple needs (e.g. taking a shower to feel clean and fresh, sooth aches, wake up in the morning and feel confident to face the day) or more specific and functional (e.g. running a dishwasher).

Differences across the population

Needs, behaviours and the motives and rationale that link them can all vary across the population, with implications for the requirements of SES. The reasons for this variation can be viewed at three levels: individual (education, age, gender and environmental values); household – either direct (tenure, income, cultural differences, social class, household size and composition and energy payment model) or indirect (e.g. MOSAIC groups); and community (e.g. urban/rural location). The overall impact is large, with energy use in homes varying by 300% or more across similar properties, as a result of how the occupants use the building.

The influence of some characteristics is structural, constraining the behaviours that can be performed (e.g. being in a rented property or being off the gas grid). Other characteristics influence an individual or household's ability to perform a behaviour (e.g. through a lack of knowledge, time or money), or the patterns of use established by individuals or households.

The trend is for greater action to save energy among people who are more highly educated, older, owner-occupiers, with higher incomes and pro-environmental values. Even in these cases, the evidence is not entirely straightforward or consistent and, because the reasons for the effects are unclear, predicting what will happen in future is uncertain. In other cases, the evidence is either even less clear or absent. Therefore, defining any simple and worthwhile predictive demographic segmentation, and tailoring and targeting interventions on the basis of prior assignment to a particular group, may prove unworkable.

Instead, groups should be defined on the basis of clusters of needs. This grouping could guide the development of SES to make available some combination of: individual offers that are likely to be suited to many groups of individuals or households; sets of offers, at least one of which should suit any given group of individuals or households; and tailoring through interaction at the level of individual households (starting with the dwelling characteristics, but with a knowledge of what the range of consumer groups will be, along with their likely dominant needs).

Consumer response to smart energy systems and the design implications

How people respond to an SES will depend on the solution characteristics and this therefore informs what characteristics solutions should have. This may be seen as the culmination of the CRaB project – providing guidance on key requirements for the design and deployment of SES from a consumer perspective. It is therefore a key link to the wider SSH Programme.

Response to an SES is not just about changes in energy use (although this is important in itself and also an indicator of other aspects of response) – it includes accepting the SES (with or without paying for it), retaining and using it, using it to good effect (in terms of either the design aims or the user's personal aims) and supporting the spread of the SES to other households.

In characterising response, account also needs to be taken of whether the behaviours involved are purely one-off decisions about acquisition or there are ongoing implications for intentional or habitual behaviours. Frequent behaviours tend to be most easily changed but typically achieve only a few percentage points reduction in energy demand or around 10% shift in peak consumption (although better design of SES should improve on this). Occasional behaviour that has big effects on energy demand may require bigger investment but also has greater benefit.

Options for elements of a complete SES include:

- information, advice, and real-time and historic feedback (with or without benchmarking against other households' energy consumption);
- smart controls for heating and hot water, ideally linked to feedback;
- incentives to shift load away from peak times, e.g. using time of use (ToU) tariffs, critical peak pricing or microgeneration (such as solar photovoltaic power) that has its peak outside the grid peak period;
- incentives to reduce overall consumption or adopt new technology, e.g. target-setting or competitions (at individual or community level) and direct financial incentives such as rewards, loans or subsidies;
- technology that directly provides the means to reduce energy consumption and/or carbon emissions, through improved insulation, heat or hot water production, or microgeneration;[1]
- "lateral" solutions such as water conservation initiatives, fashionable clothes that are warmer, cooler, dirt-repellent or deodorising, and soaps and shampoos that are easier to rinse off;
- social elements such as general and personalised consumer engagement strategies; communications and education; effective logistics, implementation strategies and delivery processes; and support for energy-oriented personal and household social networks and community-level action.

No single SES element is likely to be sufficient. For example, energy advice is essential in helping people to know what to do and how to do it (e.g. so that they decrease rather than increase consumption in response to consumption feedback) but insufficient on its own. Combinations therefore need to be designed that will complement each other in meeting needs and in delivering the means, motive and opportunity to manage energy better.[2] Much of the evidence on response to SES relates to individual elements, with limited combinations or sequences studied in detail, so there is uncertainty in predicting responses to whole systems but response to the elements is a fair starting point.

A particular consumer response is not guaranteed simply by implementing a particular SES element: response depends on how it is designed, delivered and combined with other elements. The whole customer journey also needs to be considered, from first engaging with an SES, to initial impact and sustaining actions over a longer period. Consumer response could also change over years or decades, depending on a range of external factors: the policy and official communication (at local, UK and EU level; regulation of energy markets; the services offered by energy suppliers; trust between consumers and Government in relation to energy; energy prices and the availability, ease of access, cost and quality of technology, along with cost structures (e.g. capital costs, running costs, grants, subsidies and taxes).

[1] Where these involve change in use of electricity, the means by which power is generated (e.g. fossil fuel vs nuclear vs renewable) could also affect response.

[2] The *means* is the technology and behaviour that will lead to some outcome in response to an SES. This includes the consumer having the necessary knowledge and skills. The *motive* is the reason why households will want to act. The *opportunity* is the resource (e.g. time, space or money) to act.

Each element will have its own ideal characteristics but the following general recommendations apply across elements.

An SES should focus on meeting all the relevant consumer needs (not just the most obvious ones), fitting with existing behaviour where possible (e.g. recognising non-negotiable activities) but effectively changing behaviour where necessary (e.g. operating the heating continuously if using a heat pump), with challenges or incentives to change behaviour where appropriate. It should be credible and recognisable for its purpose but novel, associating with existing technology that is positively perceived and avoiding association with any that is negatively perceived. It should be tailored to the individual home, household or individual and aim to put users in control while automating what they want to automate to improve efficiency. It should also be aesthetically and functionally suitable for a diverse range of householders, taking into account visual disability, manual dexterity, mobility and intellectual ability.

The features of the SES should include, as appropriate:

- clear, simple, unambiguous, jargon-free language, graphics, signals and symbols – delivered in a way that gets consumers' attention (e.g. combining comprehensive guidance, individual "tips" and location-specific signs such as stickers or magnets);
- the right level of detail – easy access to basic information and control options but more complex information and controls also available;
- information that people want and understand, e.g. room temperature and cost of energy used (not CO_2 emissions or m^3 of gas) broken down by appliance or application, with contrast between weekdays, Saturday and Sunday (rather than between weekdays);
- good timing, e.g. occasional updates and reminders, seasonally relevant advice, data by tariff period and feedback at intervals that are relevant to the decisions being made (e.g. turning down a thermostat for a week or turning off a light for an evening);
- effective placement, e.g. controls in locations than are easily accessible and relevant to what is being controlled, and in-home displays (IHDs) that are portable;
- eliminating (or explaining) risks (e.g. noise from heat pumps) and misunderstandings (e.g. what a thermostat is), and ensuring effectiveness and reliability with low maintenance.

While the design should be intuitive and logical, there is also a need for explanation and assistance in the form of installation, instruction and demonstration, specific to the SES being offered and with a choice of channels (e.g. verbal, written, graphic or online interactive). This should be based on how to achieve the consumer's aims with the SES, not just how to operate or live with it – consumers should believe that they can carry out the necessary actions, and that those actions will not be isolated or ineffective.

Promotion of the SES should include clear presentation of benefits and value, delivered at the right time for the household, e.g. when moving to a new home or having a family, or undertaking a home extension or refurbishment (e.g. insulation and double glazing are considered the norm when extending a home). The sources and messengers should be trusted (to be reliable as to the facts, competent to deliver, honest in expression and transparent in motive), with consistency among parties (e.g. peer advice backed up by professional and official information and performance labels). This could involve use of intermediaries such as schools, estate agents, surveyors, lenders and those in construction and retail businesses. Community-level action can be effective but may require a higher initial investment and will not necessarily work in all localities; the key characteristics of this approach to make it cost-effective have not been determined.

Commissioning, delivery and installation should be straightforward for the consumer (including any arrangements for income or connection to the grid), minimising hassle and disruption. Ideally there will be a clear impact that the user can see, as quickly as possible (e.g. improved aesthetics, warmer rooms, shorter warm-up time), without wastage (e.g. rooms heated when not necessary) and in a form that the user can easily communicate to others. The SES should then be scheduled to sustain positive behaviour change (e.g. if financial incentives are used, maintain them for no longer than necessary to achieve impact, while also using them to achieve consumer investment in technology, development of new habits, peer support or transition to another intervention).

As much as possible, all of this should be achieved with: low cost (capital and operating), beneficial loans and subsidies, high energy savings, short payback period, direct income for the consumer, enhanced property value and clear, believable advance information on these benefits.

1. Extended Summary

1.1. Introduction

This review was conducted as part of the Consumer Response and Behaviour (CRaB) project, within the Smart Systems and Heat (SSH) Programme of the Energy Technologies Institute. The review deals principally with the use of heat energy by occupants in residential buildings but incorporates evidence on other energy applications and from non-domestic buildings where this provides relevant insights. Use of heat energy includes heating spaces and water, cooling, ventilation, and alternative methods of temperature control such as heating or cooling the person or insulating the building.

An understanding of the needs that consumers meet (or seek to meet) through energy use, and the behaviours and technologies through which they do this, is fundamental to the design of a smart energy solution (SES). If needs and behaviour are not well understood, the design risks failing to meet needs or conflicting with how consumers wish to behave, ultimately resulting in failure of the design. Meeting needs (or the attempt to do so) does not necessarily lead to adoption of efficient or smart energy technology or behaviour but SES that meet consumer needs are more likely to be adopted and used.

An SES is defined here as a system of both technologies and social interaction. The technologies might include elements that could themselves be called "smart" together with simple elements such as insulation or written advice. The whole solution would then be "smart", with the way the elements are integrated forming a key feature. Elements aimed primarily at energy use may also be combined with other applications (e.g. communication or security). The social elements could include payment models and how the solutions might be presented and facilitated: general and personalised consumer engagement strategies; communications and education; logistics, implementation strategies and delivery processes; and support for energy-oriented personal and household social networks and community-level action.

A range of external factors (factors outside the direct influence of programmes to implement SES) may change over time. This review has identified the most relevant external factors as: political (EU, UK or local policies); economic (income, the cost of energy technologies and energy, and housing tenure); social (age, education and household size); technological (electrification of domestic energy, decarbonisation and diversity of energy generation, and advances in the technology of energy use); legal (energy sector regulation, Building Regulations and energy labels); and environmental (rising temperatures, heatwaves and other extreme weather events). The influence of changes in these factors on energy use and SES is noted at the appropriate points in the review. This responds to two Research Questions, *RQ5: What external factors, that could affect consumer needs, behaviour, motivation or rationale are likely to change over time?* and *RQ6: How would these factors be expected to impact consumer needs, behaviour, motivation or rationale?*

1.2. Consumer needs

1.2.1. Introduction

This section addresses Research Question *RQ1: What needs do consumers want to meet, that involve energy use?*

Using energy is not an aim in itself – it is part of how householders meet a wide range of needs, all of which should be taken into account in the design of SES. A need exists whether or not it is currently being met, and whether or not a person is conscious of either the need itself or how it relates to energy use. Needs have been defined very broadly, from those that are objectively "essential for life" to preferences based on the perception of individual needs or values. Needs may be addressed as high level "purposes" of home (e.g. having a comfortable life, maintaining cleanliness, or caring for a family) or as specific targets, such as how much of the home is heated and to what temperature. CRaB has adopted an intermediate level as detailed in the following sections, under five broad categories: the wider implications of energy use; resource-related needs; quality of life; social needs; and regulatory needs.

Needs are conceived principally from the perspective of individual persons, while recognising that individuals act within a complex social context. Needs may be directly those of the person taking the action that results in energy use, or the action may be decided by negotiation or done on behalf of someone else. However, we found little evidence on the "social dynamics" of how energy-related decisions are made in households.

This report uses a simple framework rather than any particular theoretical approach. The framework is based on the *means*, *motive* and *opportunity* for behaviour (such as response to SES). The *means* is the technology and behaviour that will lead to some outcome in response to an SES. This includes the consumer having the necessary knowledge and skills. The *motive* is the reason why households will want to act. The *opportunity* is the resource (e.g. time, space or money) to act. Motives can be seen as "needs in action": when a need leads to a behaviour, that need has become a motive for the behaviour. This framework is intended to allow easy comparison of the roles of different elements of SES – it does not imply any particular conscious or unconscious, rational or irrational thought processes on the part of energy users.

1.2.2. Needs related to the wider implications of energy use

Save the planet

Climate change, CO_2, global pollution and depletion of natural resources are major issues for some people while others have less understanding or concern. Most people have some awareness of a connection between these issues and energy use but this is not the principal need underlying energy-related behaviour. There can also be conflicts over personal preferences for some uses of fossil fuel (e.g. gas cooking, gas central heating and coal fires) that outweigh otherwise negative views of fossil fuels. Global impacts can, nevertheless, have a validating role in people explaining their actions to others, in reinforcing a person's belief that his/her action was worthwhile or in accepting Government action on energy.

Save the country

Logically, "saving the planet" includes "saving the country" but there is an additional national element. Again this is not generally front-of-mind in energy decisions but, if questioned, a substantial majority are concerned about energy security in particular (dependence on other countries, having alternatives in place when fossil fuels are no longer available, and the prospect of frequent power cuts) and its impact on energy costs. Environmental degradation in other countries may lead to wars and mass movement of people, some of them to the UK, but this does not yet appear to arise in consumers' thinking.

Save my neighbourhood

This refers to more local issues, underlying a desire to avoid loss of land, severe weather, rising sea levels, floods and property becoming uninsurable and losing value, and/or maintain local security of energy supply. Concern about climate change appears to increase when the emphasis is placed on local implications. It might therefore be expected that, if effects of climate change are felt at a local level, this would lead to action on climate change but this is not certain. Energy security can be seen in terms of personal energy security through having diverse forms of energy or power generation in the home or locally.

1.2.3. Resource-related needs

Save (or make) money

This refers to needs such as saving money on energy bills; making money by generating energy; raising property value (e.g. by installing new technology); getting a bargain or free offer; and spending money on something other than energy. Financial motives tend to dominate in householders' stated reasons for reducing energy use. Some money-saving actions (e.g. boiler maintenance or heating/ventilating to avoid damp and mould) may be driven more by health and safety concerns. This need also overlaps with the need for control (of energy costs and the predictability of bills) and concern over energy security.

Avoid waste

This refers to a desire to avoid wastage of energy or other resources. Avoiding waste is an element of other needs but there is also – for some people – an inherent dislike of waste, regardless of whether money is saved or the prospects for long-term availability of a commodity. Waste avoidance could also be a barrier if inefficient technology is retained when there would be a net energy or CO_2 benefit from replacing it.

Self-sufficiency

This need may be expressed directly in terms of fulfilling a desire for self-sufficiency and/or in terms such as independency of fossil fuels or energy supply companies, becoming more in tune with nature. This need is likely to relate most strongly to generating energy or using free energy. Extreme weather events, causing loss of power, could prompt householders to want to become more self-sufficient or could have the opposite effect, focusing householders' on the resilience of their home to storms and floods rather than energy.

1.2.4. Needs related to quality of life

Well-being

This refers to needs such as: being comfortable, relaxed, rested and healthy; being free from worries or fears; being productive (in employment or domestic work); having safe appliances, building fabric or lifestyle; and having actual or perceived security and privacy. Some such needs are directly met through heat energy (e.g. cooking and eating; keeping oneself clean; washing clothes or dishes; and relieving aches and pains). Meeting other needs – principally thermal comfort – depends on the achieved indoor environment and this can also affect noise, security, indoor air quality, lighting and the occurrence of damp, mould and mites.

People differ in the exact thermal conditions under which they express thermal comfort, and the optimum conditions vary as people change activities, clothing or other personal insulation. Predicting comfort is not the issue: the home should allow people to achieve comfort as they define it, which entails a range of temperatures being achievable. People with different requirements, occupying the same space, need to negotiate over heating and clothing but SES could make it easier to achieve different temperatures in different rooms, or offer finer spatial control over radiant temperature and air movement. Improving comfort or health does not correlate perfectly with saving energy; indeed there can be a negative relationship.

Being healthy and comfortable should increase productivity but the relationship is not simple. Health, comfort and productivity are also linked to people's ability to control the indoor environment. There may be circumstances in which safety is a decisive issue, e.g. in replacing an old boiler or turning off appliances when not in use. Safety concerns may also be a barrier (e.g. not running kitchen appliances overnight for fear of electrical fires or loss of water). Privacy can also have a negative effect, particularly in relation to any technology that involves yielding control of energy systems or release of data. Perception of the impact of energy-saving more generally on quality of life is a potential barrier where consumers perceive that the required changes in energy consumption will lead to greater discomfort or the sacrifice of standard of living.

Aesthetic appeal

This refers to the look (or feel, or smell) of the home or something within it (from the occupants' perspective). While some other motives can relate to slow or small benefits, an aesthetic improvement can be immediate and (to the householder) very important. Adverse aesthetic perception can exclude an energy intervention without further consideration. The historic nature of many buildings adds a further dimension to questions of aesthetic appeal, with some tension between conservation and measures to improve energy efficiency.

Make my life easier

This refers to reducing the burden of an activity, or increasing convenience. This may be expressed as a need for the right technology to facilitate desired behaviours, saving time or reducing "hassle". This need may be particularly relevant to changing habits, through offering an alternative, easier habitual behaviour.

Confidence in the technology

This refers to people's need to trust building technology or appliances, their ability to achieve effective control through the technology and confidence that they can make a difference through how they use technology. This would depend, for example, on understanding and experience of technologies, personal recommendation and convincing information about technology, not just its actual effectiveness.

Entertainment

This refers to enjoyable pursuits such as watching TV, listening to music or playing musical instruments. The consequences for heating energy demand arise from, for example, the associated level of physical activity.

1.2.5. Social needs

Self-image or recognition

Self-image or recognition refers to a person's identity (individually or as a household) and aspirations in a social context (e.g. in relation to the cost or aesthetics of technology). This can be seen as self-esteem, 'kudos' and conforming with social norms, through gaining social acceptance (or avoiding rejection); teaching the next generation; developing a sense of competence, choice or control; and association with role models. This does not necessarily imply selfishness: it can be altruistic and derive from doing something for the wider good or taking pride in a neighbourhood, city or country. It can also relate to national, ethnic or religious identity. The impact on energy-related behaviour may be positive (e.g. showing off new solar panels) or negative (e.g. turning up the heat instead of putting on a jumper, to avoid appearing poor, quirky or mean).

Social interaction

This relates closely to self-image but is more specifically about direct interaction with people inside and outside the home. An important aspect of this is taking care of other people's needs, especially children, elderly people or those who are unwell. It also includes: living harmoniously within the home; socialising with friends and family in the home (including by telephone, etc.); being involved with, or feeling connected to, local or more dispersed groups; being supported by other people or groups; and a wider social concern for inequality in the benefits of new energy technology and/or the impact on local or national employment. In the case of community-based energy initiatives, the social motive can be the dominant one.

1.2.6. Regulatory needs

This refers to a need to comply with mandatory requirements – either legal or industry-based. Impact will depend on the extent to which regulations are disseminated, explained, understood and enforced.

1.2.7. Linkages and priorities

The needs that tend to dominate are those related to resources, quality of life and social factors, with needs related to wider implications having a supporting but background role, and regulatory needs having a constraining role. But the details of priority vary widely between individuals, contexts and the specific behaviours or choices in question. In particular, a need that is currently met might not even be thought of as a need, especially if met through habitual behaviour. Critically, the need that is foremost in consumers' minds does not necessarily stand alone: take away that layer of need and others would likely be revealed. Where an SES has implications for the whole energy system, additional values apply: social justice, fairness, honesty, transparency and expectations that Government will have a coherent long-term plan.

While some relationships among needs are obvious, logical or well evidenced, there is not a complete picture of the relationships as they exist in consumers' minds. It is difficult for any theoretical framework to capture entirely the "real life" complexity of needs and how they are reflected in purposes of home. It is also unclear how relationships among needs vary with the characteristics of persons or dwellings, or how needs (individually or in clusters) determine current behaviour or responses to SES. In making linkages among needs and behaviours, each linkage requires detailed analysis, going beyond the obvious or straightforward. For example, an apparently simple behaviour such as taking a shower, meeting an obvious need (to get clean), actually addresses a wide range of needs.

Hence, the definition of needs is complex, depending on who is dominant in the decision-making, the needs of a range of persons, and care responsibilities. Needs can vary over time (hours or years) and may be observable only where there is a limit on the resources available. Priorities also depend on relationships between needs – one behaviour can address several needs and one need may be met in several different ways. The implication is that "priorities of need" is a risky way of thinking in relation to SES design. The more effective approach appears to be to identify common patterns of need.

1.3. What do people do and why do they do it

1.3.1. Introduction

This section addresses two Research Questions – *RQ2: What do people currently do that uses energy?* and *RQ3: Why do consumers exhibit particular energy-using behaviours?*

Energy-using behaviours and the reasons for them are diverse and the question of why consumers exhibit particular behaviours applies whether or not the behaviour is a conscious choice or the person is aware of the energy impact. There is incomplete understanding of the reasons for behaviours or the interchangeability of behaviours that appear to address the same need or purpose of home, and behaviours that are apparently related do not necessarily have the same implications for SES design. As a result, simple predictable responses to SES should not be assumed. Also, behaviours are not all equally amenable to change. So, however they are grouped or categorised, individual behaviours need to be understood.

Frequency of behaviour influences the interaction a consumer would need to have with an SES and how it should be presented in order to gain acceptance. Behaviour can be frequent (more-or-less daily), occasional (perhaps only once during a person's occupation of a home) or infrequent (between these two). These affect the amount of time and thought that a consumer is likely to give to the behaviour (e.g. whether it is a habit, routine or an extensively researched investment), which in turn affects whether an SES could easily change the behaviour or whether it would need to work within the confines of existing behaviour. Frequency also affects who is in control (e.g. an individual or a household), the required resources for the behaviour (money, time and space) and the required technology. There is always some combination of behaviour and technology, even if the technology is a blanket, hence the two need to be considered together:

- the possible behaviours will depend on the technology that is available, the householders' ability to use that technology or install new technology, and the time and space required to fit the technology;
- as frequency decreases, the likelihood of a behaviour entailing acquisition of technology (and therefore the cost) increases – interventions therefore tend to have greatest impact on frequent behaviours;
- one technology may meet several needs and one need may be met by a combination of technologies;
- the motivation for a behaviour can come from acquisition of the technology rather than vice versa.

Potential ways of explaining behaviour include various aspects of the needs being met, along with people's awareness, knowledge, beliefs about how much energy they use, experience of different thermal climates (e.g. in cars, other countries or in different buildings), habits and constraints. While attitudes are a good predictor of intentions for energy-related behaviours, the characteristics of the dwelling, services and household are a better predictor of actual behaviour. Stated motives are, therefore, a useful starting point but not definitive (although they can be useful in presenting an SES).

The key issues obviously depend on the domain of behaviour: space or water heating, insulation, keeping the person warm, and cooling/ventilation. These are all interrelated, e.g. heating the space or the person are alternatives, people use water to get warm or cool, and use windows for reasons other than cooling. Even so, a simple separation of domains is helpful in summarising the evidence, as in the following sections.

1.3.2. Space heating

Space heating is driven not simply by the desired temperature but principally by comfort and other aspects of well-being, with social needs also playing a role, but constrained by resources, regulations and (for some) wider implications of energy use. Behaviour will also depend on the heating system and controls (e.g. whether they require frequent interaction or operate largely in the background). Controls, in addition to a sense of control, can help users meet needs related to saving money, avoiding waste, wellbeing, aesthetics, self-image and making life easier. But this is complicated by the extent to which the users understand and are physically able to operate the heating system, as well as negotiation within households.

At one extreme, in the absence of timing or thermostatic controls, choices may be made daily or more frequently to adjust individual radiators or heaters. Where there are controls, adjustments should be less frequent but many householders also use controls in ways that reflect confusion over their purpose (e.g. heating more-or-less constantly or making frequent manual adjustment, using timers or thermostats as on-off switches or using thermostats as though they are power controls). Mixed strategies are also common, such as using a timer to set heating hours but frequently overriding it. A strategy is not necessarily fixed within a household but can vary with season, who is at home and how they make decisions. The net effect is that the mere presence of controls does not signal how they will be used or the indoor environment that will be achieved. However, using a thermostat tends to result in lower room temperatures but timing controls may result in heating systems being on for longer, depending on what the household did prior to the installation.

Householders also appear to strike some balance between limiting energy use and keeping the heating on when the home is unoccupied because of a desire not to return to a cold home. But the extent of actual energy wastage is unknown, for example as a result of rooms being heated when they do not need to be (e.g. when empty) or heated more than is necessary for comfort. The extent to which spaces are used but not heated to the level the occupants wish is also unknown.

Maintenance (e.g. boiler servicing) is a key infrequent behaviour and the main occasional behaviours are installations such as a new heat source (e.g. a boiler or heat pump) or complete heating system. Retrofit tends to happen in response to failure of the existing system or action by a landlord. Action by an owner-occupier is most likely to be, as near as possible, a like-for-like replacement. One common choice (to install a combi boiler) could reflect a balance of preferences (constant availability but with a limit on flow rate, or stored water with good flow rate and compatibility with solar thermal water heating).

1.3.3. Water heating

The majority of domestic water use involves water heated centrally (supplied through outlets such as taps and showers) or in appliances. Frequent behaviours that produce or use hot water involve: managing hot water availability (e.g. manually timing hot water or overriding timing settings); personal hygiene; doing laundry; food and drink (preparation, cooking and washing up). There can also be infrequent changes in routines, plus fitting new controls; setting the timer on a boiler or the thermostat on a boiler or hot water vessel; servicing a boiler; using a dishwasher on special occasions only; or fixing a dripping tap. Occasional behaviours would principally be installing a new boiler or solar thermal hot water system, or insulating the hot water tank. As with space heating, managing water heating will depend on the level of user control provided and the extent to which the users understand and are physically able to operate the controls.

Taking a bath, shower or both is now an almost daily occurrence. Showers have progressively taken over from baths as the usual means of washing, accompanied by new technologies delivering higher flow rates and better control of water temperature. Water use for showers has been projected to double over 20 years. The average time spent under the shower is just under 7 minutes but with a range of 1-30 minutes. Almost a quarter of householders sometimes shower outside the home.

A washing machine is the dominant means of doing laundry and only about half of households always wash a full load. Frequency of washing depends on: how often (and over what period) items are worn between washes; the number of items owned and whether they require different washing machine settings; space to store laundry; machine capacity; acceptability of washing less than a full load; the number of people in the household and whether they do laundry independently. There is substantial diversity in how often people use items before washing them, but typically only once for underwear, socks and sports clothes. Commonly cited reasons for washing clothes are that they look dirty, smell or need freshening, but often simply because they have been worn, suggesting influence of norms about washing rather than actual cleanliness. It is common to use laundry services outside the home. Households vary widely in when they do their washing and what determines this, but options for drying (e.g. in dry weather or when electricity is cheapest) have relatively little influence, so the means of drying is constrained by being at the end of the process.

Of households with a dishwasher, a third use it for most of their washing up and slightly fewer report a fairly equal mix between dishwasher and sink use, but almost a quarter rarely or never use it. The timing and frequency of washing up varies substantially with dishwasher ownership and other factors. Outsourcing, in the form of eating out, is common – around 25% do not prepare all, or nearly all, their meals in the home.

As an area for action in relation to behavioural impacts on energy use, water heating may be (or become) more important than space heating because: it could be more open to interventions targeting peak power demand, shifting load to different times of day (or to outside the home); as insulation and the efficiency of space heating improve, the proportional role of occupant space-heating behaviour in determining energy consumption is diminishing; major water-using appliances are replaced more often than heating systems; and water use is more individually decided rather than requiring negotiation in a household.

There are clearly opportunities to design SES to change behaviour and reduce energy use for hot water but the effects are difficult to predict. For example, common advice is to save water and energy by using a shower rather than a bath. Greater use of showers has moved showering technology forward but in response to needs other than conservation (e.g. relaxation, invigoration or social status) and people have been washing more frequently, which may be related partly to the greater convenience of showering. As a result, water consumption has moved above the level previously due to having baths.

1.3.4. Stop heat escaping

Examples of frequent behaviours under this heading are closing windows or curtains, and placing a draught excluder at the base of doors (with related infrequent purchasing of the required items). However, the bulk of the evidence concerns occasional behaviours: insulating walls, lofts, roofs, and floors; installing new windows or doors; draughtproofing; and insulating hot water storage vessels or pipes. This is driven largely by comfort, health and cost savings, although advertising increasingly refers to CO_2 and climate change.

Renovation for aesthetic, lifestyle, status or functional reasons is generally prioritised over retrofit to save energy although the latter may be seen as an added benefit. The work itself may lead some people to feel more attached to the home while others see it as a dull duty. Conversely, a lack of interest in retrofit may go with a lack of personal connection with the home or an (often mistaken) perception that adequate energy efficiency improvements had already been made. Retrofit often falls short of the standards for new build and some simple retrofit has not yet been carried out at all (although progress is still being made). Barriers include inconvenience (e.g. reducing loft space or clearing the loft) and adverse effects on the appearance of a building, especially if it is an older building or there is uncertainty about the performance of the insulation. Consumers would prefer loft insulation to be thinner and less irritant. The potential of insulation to either reduce or increase the risk of overheating in summer is important but not widely mentioned by consumers.

1.3.5. Keep the person warm

Insulating or heating individual persons is a highly energy-efficient strategy, allowing room temperatures to be reduced. This is achieved mainly through frequent behaviours such as: putting on extra layers of clothing or extra blankets/duvets (at night or during the day); using local heat from a radiant heater, hot water bottle, electric blanket or even a pet's body heat; using hot drinks, showers and baths; and putting clothes, towels or bedding over a radiator to warm them before use. Support for the further development of technologies and practices encouraging these solutions (e.g. alternative clothing fabrics or changes in social expectations of dress) is important to emphasise, when much focus is placed on building fabric and systems.

Increasing metabolic rate (e.g. through exercise) would also be included but this does not appear to have been studied, perhaps because it tends to be incidental rather than deliberately to keep warm.

1.3.6. Cooling and ventilation

Frequent ventilation behaviours relate mostly to opening windows but also use of mechanical ventilation. Aside from ventilation and air conditioning, frequent behaviours to keep cool can include one or more of: using shading at windows (in response to overheating or in anticipation); using thermal mass (e.g. when leaving windows open at night to cool the building); using a dehumidifier or fan; reducing clothing or bedding insulation, or physical activity (including by sleeping); having a cool shower or using cool sprays or cloths; turning off heat-producing appliances or using appliances that produce less heat; and leaving the home during the hottest part of the day or using cooler parts of the home. None of these individually is likely to be sufficient on all occasions and most householders would not have sufficient knowledge to deduce the optimum cooling strategy (or wish to use it, because of conflicting needs such as privacy or security).

While the evidence is largely about frequent behaviours, some infrequent and occasional behaviours have a facilitating role, through: hiring or buying items; improvement or resetting of heating/cooling controls; maintenance (e.g. repairing or/adjusting windows to make them more easily or securely openable); or action to eliminate external noise or air pollution, so that windows can be opened.

A common response to being too warm is to open windows or doors (rather than other ventilation devices), even if the heating is on. Windows may be opened to reduce temperature or humidity or increase air movement, but also to avoid condensation and mould, reduce indoor air pollution, stuffiness or odour, talk to someone or hear what is happening outside, and habit. Equally important is when people want to open windows or doors for cooling or ventilation but opt not to, for reasons such as: external noise or air pollution; the weather; concerns over security, privacy or the safety of young children or vulnerable adults; keeping pets in or keeping animals/insects/pests out; and practical/ergonomic difficulties in opening the window. There are clearly connections here to noise, space/layout in the home, security, fear of crime, safety, local facilities and urban planning.

The balance of influencing factors depends on the purpose of the room – whether it is "lived in" (i.e. living rooms), characterised by low constant window-opening at all times of day; "functional" (e.g. kitchens and bathrooms), characterised by frequent short-term ventilation on an "as needed" basis); or "for sleeping", where windows are opened three or four times more than in other rooms, especially at night. The ability of users to respond to raised temperatures will also depend on the actual level of user control provided and the extent to which the users understand and are physically able to operate the controls, and this is perhaps why people prefer to have manual control over ventilation in their homes.

Some studies have found reduced window-opening where mechanical ventilation (MV) is in use, but there also appears to be a preference to continue opening windows when they are not strictly necessary for ventilation. This could be related to habit, a greater sensation of freshness compared with MV or the air flow rates and air movement (in the room) achievable with MV not being sufficient for cooling. There is also evidence that householders do not understand systems and use MV for less time than design intentions or do not efficiently use "boost" or heat exchanger bypass modes, or do not clean the systems.

One aim of ventilation is to improve indoor air quality (IAQ) but there is a current trend of using chemical air fresheners to achieve the same aim. The implications for energy consumption, IAQ and health are uncertain.

There is relatively little policy action to reduce cooling demand. In fact, some "energy efficiency" retrofit measures (e.g. internal wall insulation) can increase the risk of overheating. A trend for smaller homes, closer together, with more people experiencing air conditioning in other contexts, and continued climate warming, creates concern that there will be widespread demand for air conditioning in homes. It is critical, therefore, that any smart energy system should address passive cooling on an equal footing with heating. Where air conditioning is installed in homes, the limited UK evidence is that users report better quality of sleep with cooling in bedrooms, no adverse health issues or noise disturbance and no purchases prompted by health issues. Temperature settings suggest that systems are used to cool more than strictly required for comfort but some users set a low temperature mistakenly hoping to achieve more rapid cooling.

1.3.7. Other behaviours

Heat energy use is affected, directly or indirectly, by behaviours that need to be considered in SES design but householders would not necessarily count as heating. These include frequent behaviours such as: drying laundry (e.g. outdoors, in a tumble dryer or around the home); storing and cooking food; general use of lights and appliances (and turning them off when not in use); using daylight where possible; and using light to create a mood of cosiness, instead of (or in addition to) heating. Infrequent and occasional behaviours include purchase of energy-saving items (and long-term changes in purchasing); switching between indoor and outdoor drying with the season; switching cooking to a microwave oven; and maintenance.

Increases in the number (and sometimes power) of appliances mean that overall electricity consumption per household for lighting and appliances has increased in recent years. Such changes in ownership of technology that is not intended to have a role in heating has implications for heating: incidental gains are increased and heating accounts for a decreasing proportion of total energy use. The same kind of negative consequences could also arise in relation to new heat technology.

1.3.8. Overview

Individual behaviours are important, but should not be viewed in isolation. Rather, they should be seen as something that shapes and is shaped by a complex web of needs, purposes of home, and the physical and technological contexts within which behaviours occur. Critically for programmes such as SSH, it is generally unclear whether a behaviour would easily be adapted to an SES or whether the SES should be designed around the behaviour. The answer may be found in the extent to which the behaviour is an integral part of a lifestyle, meeting multiple needs (e.g. taking a shower to feel clean and fresh, sooth aches, wake up in the morning and feel confident to face the day) or more specific and functional (e.g. running a dishwasher).

1.4. Differences across the population

This section addresses Research Question *RQ4: How do consumer needs, behaviour, motivation and rationale vary across the population?*

1.4.1. Introduction

Needs, behaviours and the motives and rationale that link them can all vary across the population, with implications for the requirements of SES. The reasons for this variation can be viewed at three levels: individual; household – either direct (e.g. tenure or income) or indirect (e.g. MOSAIC groups); and community. The influence of some characteristics is structural, constraining the behaviours that can be performed (e.g. being in a rented property or being off the gas grid). Other characteristics influence an individual or household's ability to perform a behaviour (e.g. through a lack of knowledge, time or money), or the patterns of use established by individuals or households. The overall impact is large, with energy use in homes varying by 300% or more across similar properties, as a result of how the occupants use the building.

1.4.2. Individual characteristics

Energy savings in response to interventions and take-up of energy-saving, load shifting or renewable measures are higher among more highly educated. Education could be of increasing relevance to uptake of SES, with an increasing proportion of the population undertaking higher levels of education (unless the apparent effect of education is actually due to intellectual ability).

Older people tend to have warmer homes (finances permitting), thus using more energy, but are generally more likely to save energy in other ways (e.g. energy efficiency measures and renewable technology). However, where information or communication technology is involved, younger people are more likely to respond positively. People are also less likely to invest if the expected payback period is longer than they expect to live. Regarding hot water use, younger age groups shower and bath more frequency and are more likely to change clothes during the day. Women are more likely to vary shower length for washing their hair, men more likely to do so for shaving, and men also less likely to say they vary shower length.

The significance of age is likely to increase, with the share of the UK population age over 65 projected to grow, but this is uncertain because it is unknown whether the age effect arises from individuals changing practices with age or from younger generations adopting different practices. The future population of elderly people, for example, may differ in technology awareness, disposable income, tenure, time spent at home (e.g. in retirement), attitudes to the environment and waste, and concern for future generations.

There is generally a positive association between pro-environmental values and energy conservation behaviour (particularly frequent behaviours) but the direction of causation is often ambiguous: do people take action on energy because of their environmental values or do they change their values after taking action? Also, characteristics such as home size and household composition are better predictors of actions taken.

1.4.3. Household characteristics

Renters are less likely to adopt energy-saving technology, particularly if it has a large up-front cost, but also less likely to adopt IHDs. The key point is the "split incentive": the landlord would pay but the tenant would benefit (an issue particularly in the private rental sector). While it might sometimes make financial sense for tenants to invest, this depends on the payback period, contractual and expected length (and security) of tenancy and portability of purchases. It is also possible that tenants have less sense of attachment to a home. Effects of tenure may decrease if, as anticipated, Government addresses the split incentive between landlords and tenants and/or introduces minimum energy efficiency standards for privately rented properties.

The role of income is complex, different aspects tending to push consumption or conservation in different directions: income is related to baseline consumption, quality and size of housing and energy systems, motivation to save money or improve the indoor environment, environmental attitudes, home ownership, turnover of appliances and norms of quality of life. The overall effect is that behaviours that have little or no cost may play a more important role in low income households while investment is more likely in high income households. There is also some tendency for low income households to have flatter daily load profiles and respond less to incentives to shift demand from the peak period. Income is expected to grow at least until 2030 and energy demand is expected to rise as incomes rise but this could be offset by falling costs of SES.

Household size is related to how many people are at home, for how much of the time, and hence the number of rooms used (and heated) and windows opened. Unsurprisingly, energy consumption generally increases with household size while consumption per person generally decreases. However, one-person households can have disproportionately high consumption for particular appliances (especially for cooking and laundry); the implications of this are important, with single-person households expected to become more common. In relation to load shifting incentives, there is some evidence that smaller households are more responsive.

In relation to energy investment and behaviour change, there are conflicting pressures that would account for the inconsistent evidence relating to household size. In larger households, consumption is higher, more people benefit from an investment, appliances would be expected to depreciate faster, inducing replacement, and there are economies of scale in information acquisition concerning energy efficiency. On the negative side, larger households have more complex dynamics of decision-making, with less individual choice or responsibility, and shared cost, hence possibly a greater tendency to inertia.

Household size is confounded with the age of household members, with larger households more likely to have children or teenagers. Households with teenagers have higher electricity consumption, after controlling for household size, and less success in reducing standby energy use. There are also practical issues in making reductions in standby usage, where interconnected devices are not in the same room (making it inconvenient to turn them off). The presence of younger children can also increase energy use, partly as a result of keeping the home warmer, using the washing machine more, and a parent and child being at home during the day. Having children in the home may have a negative effect on adopting renewable energy systems but generally the propensity to save energy is higher – possibly because initial consumption is higher but also children can play a role in motivating energy reduction, driven by school-based initiatives.

Prepayment meters tend to be installed where customers have difficulty paying energy bills, so they generally have lower initial consumption, therefore less scope to reduce. However, they may be more practiced at monitoring consumption, more aware of costs and have greater (financial) motivation to save energy. In practice, savings are possible but not always achieved. Efforts to help prepayment customers reduce consumption might focus on means and opportunity, the motive already being present.

Findings are inconclusive on some other household factors – social class, culture and indirect demographic (MOSAIC) groups. Households with the highest baseline consumption tend to reduce consumption the most in response to interventions but it is difficult to separate genuine effects from “regression to the mean”.

1.4.4. Community characteristics

Rural households use more energy per person than those in urban locations and urban consumers may have a higher propensity for energy-saving behaviours. There are various possible factors underlying such differences: dwelling type and access to mains gas; easier access to information in urban areas; more active environmental policies in larger cities; awareness of measures that protect the local environment; and energy security being more salient in rural areas where power cuts are experienced more regularly.

1.4.5. Overview

A range of demographic factors, stated motives and environmental values are correlated with aspects of energy use but this does not mean that behaviour now, or response to SES, can easily be predicted from these variables: the findings have often been weak, inconclusive or inconsistent. Therefore, defining any simple and worthwhile predictive demographic segmentation, and tailoring and targeting interventions on the basis of prior assignment to a particular group, may prove unworkable. Instead, groups should be defined on the basis of clusters of needs. This grouping could guide the development of SES to make available some combination of: individual offers that are likely to be suited to many groups of individuals or households; sets of offers, at least one of which should suit any given group of individuals or households; and tailoring through interaction at the level of individual households (starting with the dwelling characteristics, but with a knowledge of what the range of consumer groups will be, along with their likely dominant needs).

1.5. Consumer response to smart energy systems and the design implications

1.5.1. Introduction

This section addresses two Research Questions – *RQ7: What is the likely consumer response to potential smart energy system solutions?* and *RQ8: How can smart systems meet current and future needs?*

How people respond to an SES will depend on the solution characteristics and this therefore informs what characteristics solutions should have. This may be seen as the culmination of CRaB – taking the evidence collected in relation to the other RQs and providing guidance on key requirements for the design and deployment of SES from a consumer perspective. It is therefore a key link to the wider SSH Programme.

Response to an SES refers to how consumers respond to a particular SES aimed at meeting unmet needs or meeting needs in a different way. Response is not just about changes in energy use (although this is important in itself and also an indicator of other aspects of response) – it includes accepting the SES (with or without paying for it), retaining and using it, using it to good effect (in terms of either the design aims or the user's personal aims) and supporting the spread of the SES to other households.

Characteristics of SES that might lead to a solution being successful can be described in terms of: the core functions; the simplicity/ease/disruption of installation; ease of use; approaches to consumer engagement; cost, payback and financial offerings; technological complexity and attractiveness; maintenance requirements, reliability and performance; service model; and the source of the solution. Each of these can be expected to have different determinants and account also needs to be taken of whether the response involves one-off decisions about acquisition or ongoing intentional or habitual behaviours.

Consumer response could change over years or decades, depending on a range of external factors: the strength and direction of policy and official communication (and balance between local, UK and EU level); regulation of energy markets; services offered by energy suppliers; trust between consumers and Government in relation to energy; energy prices and the availability, ease of access, cost and quality of technology, and cost structures (e.g. capital costs relative to running costs, grants, subsidies and taxes).

1.5.2. Energy efficiency advice

Advice is an essential element of the *means* of response: helping people to know what to do and how to do it. But advice is not enough: it can support *motive* (e.g. by suggesting motives or setting goals) and/or help to create *opportunity* (by facilitating access to the SES that the advice relates to), but these elements tend to come mainly from other sources. The success of advice is therefore, logically, dependent on motive and opportunity being either already present or separately provided.

Awareness campaigns and generic advice, distributed without knowledge of consumers' individual circumstances, typically increase knowledge, and can change attitudes, but have little effect on behaviour. In combination with other interventions, generic advice can become more relevant, resulting in energy savings of up to 5%. Tailored intensive energy audits have led to greater reductions in energy consumption but they are more resource-intensive. Intermediate approaches involve some combination of more directed verbal or written advice in the form of comprehensive guides, specific prompts in relevant positions, occasional individual "tips", explanatory justifications (e.g. reduce peak time electricity use to reduce the need for new power stations), and instructions for how to do something. The following general points apply to advice.

- Information needs to be clear and easily seen amongst other material sent to consumers.
- Consumers can benefit from comprehensive reference material but also simple, actionable, individual messages that inform, support and encourage. Specificity is also good: even when householders see no general scope to reduce consumption, they may agree with more specific propositions.
- Timing is important: many consumers do not read or absorb written advice unless it is relevant to them at the time they receive it (e.g. it is appropriate to the season).
- The credibility of advice can be undermined if it carries risks or its effectiveness is uncertain but advice may be discounted if it is seen as "common sense" or "nothing new".

Advice can also take the form of performance labels, for individual appliances and electronics, as well as whole homes (e.g. the Energy Performance Certificate or Code for Sustainable Homes). Labelling should be easy to understand and provide a simple way to identify energy-efficient products or homes, ideally with implied default options. A bigger effect of performance labels could be to prepare to take the least efficient items off the market entirely, as happened with boilers. Labels could usefully add information about running costs or the additional running costs relative to appliances with the highest rating.

1.5.3. Historic feedback

Historic feedback tells consumers how much energy they have been using (and, ideally, when and how they have been using it). Together with transparency over energy costs and tariffs, it serves mainly to enhance *motive* by raising awareness of energy use. Consumers can also use feedback to provide the *means* (by understanding the impact of changes they make) but this depends on having sufficient existing knowledge and motivation, in addition to time. Accurate feedback can also improve householders' sense of control over energy costs and this raises satisfaction among consumers (which could in turn facilitate deployment of other SES elements). The assumption is often made that feedback allows consumers to make better informed choices and that they will therefore choose to use less energy, but this is not necessarily always the case.

The distinction between historic and real-time feedback is important because it matters how closely the feedback linked to specific actions, in time and in level of disaggregation. Logically, historic feedback is more relevant to one-off changes that have a persistent impact, such as installing insulation. Real-time feedback is more relevant to routine behaviour and equipment used intermittently (e.g. washing machines, televisions). By extension, historic feedback may be more relevant to the fuel used for heating (most often gas) and real-time feedback to electricity. The two types of feedback are also complementary in the form of delivery: billing information adds to feedback by IHD because it is easier to read and it is possible to sit and study it.

Few studies have quantified the effect of feedback via enhanced routine billing in isolation (or monthly feedback via other routes) but savings of 2-3% are possible, plus shifting load from peak periods. Where there are energy savings, these tend to be achieved through changes in behaviour with current technology rather than new investments. The limited impact may be attributed at least in part to the feedback not being noticed or read but those who look at the information tend to say it was useful. Trials of more frequent feedback have found greater savings but this is more resource-intensive and effects may not be persistent where feedback is sustained for periods beyond limited experimental trials. It could become feasible to offer more frequent feedback with wider use of smart meters and online access to consumption data.

Historic feedback varies in frequency, duration, immediacy, content (kWh, cost, etc.), breakdown (by time, space and appliance), aesthetics, simplicity of access, combination with other actions and delivery – on paper or electronically (e.g. via the web, mobile phone, TV or IHD). Effectiveness appears to depend on these details in ways that are not fully understood but the following general points apply.

- If feedback is provided more frequently than monthly, it can be more effective but there is a risk of consumer fatigue, which might be addressed by delivering feedback in intermittent spurts.
- Although enhanced billing information may be the least effective means of providing historic feedback, it has low cost and so may be the most cost-effective method at a population level.
- General usage and cost information are rated more highly than energy units (kW hours or m^3 of gas).
- Historic feedback needs to balance the needs of consumers looking for detailed information, data and interpretability and those more concerned with aesthetics, simplicity and immediacy of impact.
- Data for each weekday may be less useful than contrast between weekdays, Saturday and Sunday.
- Feedback should be: based on actual consumption, given frequently over a long period, involve interaction and choice for the household, and ideally break down energy use by appliance.

1.5.4. Benchmarking consumption

Benchmarking consumption adds to historic feedback by showing consumers how their energy use compares with that of comparable households. This may provoke competition, social comparison or peer pressure, thus emphasising social *motive* but leaving scope for environmental and financial motive. A valid comparison group with similar composition, dwelling, climate, etc. is difficult to achieve; this is sufficiently obvious that customers may doubt the validity of their comparison group. There is limited evidence on benchmarking in isolation because it is typically combined with other interventions but in UK homes, electricity savings of 1% have been found and one study stands out as achieving gas savings of 9%. Combining benchmarking with historic feedback and advice (partially tailored to the household) has consistently resulted in 1-3% reductions in energy demand. Whereas high and medium consumers may reduce their consumption, low consumers may increase theirs (the negative impact may be overcome by use of simple normative messages or inclusion of “smiley” icons with low users’ bills.

1.5.5. Smart meters

The main point is that the smart meter allows and enhances a range of other interventions. There are also factors that could directly affect householders’ knowledge of *means* and/or their *motive* to act. In the course of getting a smart meter, bills should become more accurate (possibly more frequent) and customers might experience any or all of: being told they are among the first to get the latest technology; positive interaction with the supplier; reassurance that the meter accommodation is now safer; a friendly or unfriendly installer, who might also offer informal energy advice; and positive or negative attention from friends and neighbours. Also, if a smart meter is easier to read than the previous meter, householders may read it more often.

The more householders know about smart meters, the more they are likely to want one and support the UK roll-out. Among those who already have a smart meter, attitudes are generally positive (including being likely to recommend it to others). Smart meter installation can be enough in itself to deliver a small reduction in energy use, particularly gas use, persisting for at least a year. The clearer effect for gas consumption makes sense in the context that simple one-off changes can have big effects on heating and hot water demand.

In relation to consumer response, the key SES characteristics relate to the details of how smart meters are presented and installed. The installers themselves, and the documentation and online support provided, represent an opportunity to ensure that consumers know how to access and use the data provided, and take an interest in doing so. More generally, there is an opportunity to engage people with energy management and impart some selected key pieces of information that will enable them to reduce their energy demand.

1.5.6. In-home displays (IHDs)

IHDs go beyond historic feedback to show current consumption, often with other functions such as displaying historic consumption and room temperature, alarms and simple visual signals to indicate high consumption rates or changes of tariff period. IHDs range from "clip-on" battery-powered devices (usable with or without a smart meter, for electricity consumption only) to more sophisticated and accurate mains devices, showing both electricity and gas consumption using the signal from smart meters. Most studies of IHDs have not included gas consumption and, as noted earlier, real-time feedback is generally less relevant for gas use; so the evidence is less directly relevant to space heating (except for the understanding of how to present data).

IHDs support: *means* (by identifying what changes could be made) but only if consumers understand how to do this; *motive* (by showing how much energy is being used and possibly also by engaging other motives such as using or showing off new technology) but only if consumers already have sufficient motivation to want to check energy use; and *opportunity* (because they save time in understanding consumption). Thus, IHDs offer all three elements of change but incompletely in each case.

Many households refuse the offer of a free IHD or accept one but do not install it. Many users find it difficult to install an IHD or change settings – because of complexity in the device itself or unclear instructions. IHDs linked to smart meters are more likely to be fitted and retained. Where an IHD has been installed, a minority of householders forget or ignore it but, if it fails, there is generally little attempt to get it working again (this is less of a problem with mains devices). Not all IHD display features are equally noticed, used or valued.

Those who engage with an IHD tend to say it is useful (especially if linked to a smart meter) and check consumption more often; they are also more likely to retain and use written energy advice. Energy savings are positively correlated with the level of consumer interest in the IHD and the length of use. IHDs are most often located in the kitchen, other common locations being the lounge, hall or a drawer or cupboard. There is usually a short period of rapid learning where the IHD is used to assess the consumption of different appliances (this is facilitated if it can easily be carried from room to room). This is often accompanied by discussion between household members. This learning may be followed by changes in behaviour but household members do not always agree and some uses of energy are non-negotiable.

As time goes on, the IHD is used less but common routines include checking it before going to bed, before going out or when a new appliance is purchased. Using an IHD to track consumption over time and compare periods is not common; one consequence is that high-power appliances (which may be used for short periods) can distract attention from low-power appliances (which may be used for longer). Some households use IHDs to test and monitor the effects of trying to save energy: confirming that an action was worthwhile and maintaining behaviour rather than initiating it – this could be of particular relevance to heating.

IHDs need to appeal to the varying interests and motives with which users approach IHDs – some focus on protecting the environment, some on saving money, acquiring information or engaging with a new gadget (the aesthetics or technological appeal of the device). An IHD may also be valued in terms of control over energy usage or bills, and in encouraging other household members to act.

UK evidence is that the combination of smart meters and IHDs results in persistent electricity savings of around 3% above those achieved with the smart meter alone. Effects on gas consumption are less clear and this fits with real-time feedback being more relevant to electricity. The achieved energy savings are remarkable, given the evidence of limited interaction with IHDs. Most energy saving results from simple changes to routine behaviours rather than investments, and some individual users presumably achieve much more than the average; there is, therefore, potential for far greater impact of IHDs. Interventions that increase engagement with the IHD (e.g. energy advice or a savings target) could double or triple the benefit. Conversely, the addition of an IHD to interventions tends to increase savings. Combining an IHD with a time of use (ToU) tariff does not have a consistent effect but is most likely to shift consumption but not reduce it.

IHDs should be installed for consumers to ensure they are in place, working and understood. Any maintenance required (e.g. replacing batteries) and procedures for restarting a device (without losing settings of data) and returning to default screens must be kept simple. Good design principles include: clear, large, legible text and graphics; clear use of zones to separate information and reduce clutter; backlighting; easily detectible buttons with positive tactile feedback and an instant visual response; intuitive icons and navigation, and informative button labels; and batteries and adaptor sockets that are easy to access.

Key features should be easy to access with minimal effort. Only the first or second screens in an access sequence tend to be used, so the most useful information should be put there. The evidence is unclear on whether costs or kWh are the best default way to display current consumption; the balance is in favour of costs but longer-term tracking requires access to kWh data as unit costs change. CO_2 emissions data are poorly rated and rarely used. Consumption displays are seen as more useful for electricity than for gas. A display of room temperature may assist householders in understanding thermostats and their settings.

Graphic indicators of real-time consumption (power) may be more effective than numbers. Consumers also want data on consumption over time but the best way of communicating this is not clear. Costs or potential savings that look trivial or massive (e.g. full day costs calculated for a kettle that is on for a short time) will fail to motivate change. Indications of consumption against a target can be helpful for those seeking to reduce consumption but a source of stress if money is tight. Audible alarms of high consumption tend not to be used but visual signals are at least appreciated (although it is not clear what impact they have on energy use).

User guides need to be simple and intuitive for users who require only the basic functions, while also clearly describing and explaining other functions, using plain language and clear diagrams. Guidance should cover how to use the information from IHDs to manage energy demand, not just how to access the information.

1.5.7. Heating and hot water controls

Heating and hot water systems generally have controls, e.g. for timing, room or water temperatures, and which spaces are heated. Effective controls should allow households to achieve their aims for warmth and hot water (and to be confident that they are in control) while minimising waste of energy. The evidence is that controls are not as effective as they should be. Users often find ways of achieving their aims but not always in the easiest, most convenient or energy-efficient manner (e.g. controlling temperature with windows rather than a thermostat, using a thermostat as an on-off switch, heating while the home is unoccupied). Where controls are seen as inadequate or ineffective, householders may resort to leaving heat or hot water on constantly or using controllable but expensive electric heating. Some users stop using the controls and may see them as wasteful of energy. The diversity of controls on the market makes it difficult for users to carry over knowledge from one home to another, and this in itself may discourage replacement of controls.

The cause of these problems is shared between the controls, the instructions for them and assistance given by installers, landlords and service/repair personnel (who are often responsible for the choice of controls). While difficulties are greater for some people (e.g. because of visual, dexterity or cognitive disability) they are widespread in society. Perhaps because of all these problems, the energy savings achieved by controls are disputed and, in any case, they will vary widely with the controls, how they are used, the system that they control and the thermal efficiency of the dwelling. Greater sophistication of controls is not necessarily the answer, and new heating or microgeneration technology can make controls more complicated and difficult for users to relate to what they are controlling. An SES needs to start with what householders want to achieve, and their understanding of how to achieve it, before redesign of controls.

Controls should be easy to use in terms of the required dexterity: buttons that are not too small or difficult to press, or have to be held down, dials that are easy to grip and not too stiff. Printed or on-screen information should be easy to read (not too small, with good contrast) with clear meaning of (and distinction between) words and symbols. The logic of the controls should be intuitive, using terms that most people understand, with logical sequences of programming, and clearly distinguishing easily confusable information (e.g. actual vs set point temperature). Feedback should confirm to users what they have done or changed. The design should be consistent with the function (e.g. dial thermostats can reinforce the misconception that they are power controls) and suggest optimum settings (e.g. room thermostats having a default range of 16-22°C).

An alternative is that the controls themselves should become more "intelligent" and reduce the need for user interaction, with functions such as basic compensations (e.g. for outdoor temperature and/or windows being opened) advisory signals to users, reversion to default settings at some point after users have overridden them, or fully intelligent controls (with override options) that learn users' habits and detect whether they are at home and where they are in the home.

Control locations should be: logical in relation to what they control (close to the device controlled or in a representative location for the room); easy to see and access (in good light, without bending and stretching); and in keeping with the household's aesthetic expectations. These three criteria might not always be compatible but wireless controls should make it easier.

Instructions should ideally be given verbally, to demonstrate rather than just describe, and to show users how to achieve what they personally want to achieve. Written instructions are also important, backed up by access to online instructions and demonstrations. The instructions should: be in common language, avoiding jargon and supported by clear diagrams; relate to the specific installed device, explaining functions, procedures and purposes of the controls; have a short, simple, basic guide, backed up by greater detail and explanation; and be available in formats for people who have visual disability (e.g. large print or Braille).

1.5.8. Integrated feedback and control

Feedback is intended to affect action, so it is logical to link feedback with the means of action, such as a switch or control device, or specific sockets or appliances. This could link *means*, *motive* and *opportunity* into a single intervention. A complete home network could include sensors, display/feedback devices and communication with the energy supplier (and incorporate other applications such as energy storage, security, communication and entertainment). User operation can be within the home or remote (e.g. through a PC or mobile phone). There is little direct evidence on consumer response but a survey found a positive response to such a device (possibly more as a control than as an IHD). SES are likely to need to aim at easy data-sharing, inter-operability of components and standardisation of communication systems and protocols, together with the ability to build up a system over time. The roll-out of smart meters is an opportunity for this.

1.5.9. Time of use tariffs/incentives

Various interventions focus on when energy is used, by providing a direct financial incentive to shift energy use away from a period of peak demand. This is focused on *motive* – mainly financial but potentially environmental if users grasp the relative environmental impact of peak time power generation. The main two examples are time of use (ToU) tariffs (i.e. varying the unit price with time of day, and sometimes also by season, according to a fixed schedule) and critical peak pricing (CPP), i.e. setting much higher unit prices on a limited number of occasions, usually for short periods of excessive demand. While the aim is normally to shift consumption away from peak periods, total consumption can also be reduced if consumers either become more aware generally of their energy use and savings options, or because they take more care to eliminate energy wastage at peak times without compensating by increasing usage at other times. The opposite effect is also possible, if consumers take less care over energy use during off-peak periods; tariff levels and ratios may be important in this respect but the evidence is unclear.

Some issues with ToU tariffs have limited their impact. Tariff structures are sometimes not understood or perceived as too complex or the tariff may simply being forgotten about. Consumers also often have limited understanding of the purpose of ToU tariffs and may feel that the changes required of them involve too much effort (or they try to shift but give up when the bill seems to be the same – the most common issue reported). Consumers may not see sufficient motivation in the differences in rates or see the peak rate as too high or the peak period too long to make overall cost savings possible. This can be combined with uncertainty over how to shift demand, and lack of feedback on whether demand-shifting and/or cost-saving efforts have been successful. Some consumers have concerns about safety, convenience and noise if appliances are run at night, or believe that ToU tariffs are mainly for suppliers' benefit. Some of these responses may not be the effect of the ToU tariff as such but rather the design of trials. It is common for trials to ensure that trial participants cannot pay more overall as a result of their participation.

Evidence from surveys is that a wide range of changes occur in response to load shifting incentives, including changing laundry timing, adjusting thermostats and switching off lights. Willingness to shift appliance use (manually or by automation) varies by appliance, being higher for washing machines and dishwashers than for TVs and cookers. This variation in attitudes with type of appliance could relate to needs such as confidence in the technology and whether use is time-critical (e.g. for appliances used for entertainment). Any application to heating or cooling would face the issue that people would not want to be limited as to when they can be comfortable.

The proposition of allowing energy companies or network operators some control of domestic appliances is not widely accepted although this again varies with type of appliance. This is in a context where there has been little public discussion of how this would work and, in particular, the practical safeguards and the level of choice that consumers would have and perhaps whether the proposition is presented as outside parties taking control or offering help to reduce bills. A variant of this is community projects in which demand is locally managed to smooth out peaks and deliver heat to the coldest homes first.

Most evidence on load-shifting is not from the UK; the aim is usually to shift loads from daytime peaks, generally associated with air-conditioning in warm climates. Other studies also have limited relevance, being aimed at peaks in demand from electric heating in very cold winter climates. Internationally, the largest peak reductions are achieved through CPP, linked to enabling technology such as automated control or tariff-sensitive thermostats. ToU tariffs deliver smaller reductions in peak loads but slightly higher overall savings. ToU tariffs in the UK have resulted in load shifts from the peak period of up to 10% but little overall load reduction. UK estimates of the proportion of demand that is flexible are from 5-25%.

ToU tariffs tend to result in consumption being deferred rather than anticipated. Solar PV can complement this by shifting consumption into the daytime period, an effect that can be enhanced by automating switching to use PV for water heating by electric immersion when sufficient solar power is available. Signals to engage water heating manually when solar PV energy is available do not appear to have the same effect.

Tariffs should not be complex and should be designed first and foremost to make sense to customers. The following appear to be important aspects of the design of ToU tariffs.

- Information to help consumers understand how much energy is used during the different tariff periods (e.g. with IHDs and/or historic feedback) and bills showing the effect of load-shifting on cost.
- Communications devices, such as stickers or fridge magnets, to correct consumers' tendency to overestimate the significance of the peak period and underestimate the significance of the winter period.
- A rationale for pricing levels, explained in clear language, and realistic examples of the likely impact (ideally based on personalised usage), stressing that the tariff is an additional way to save money and not an extra burden on those who have already made an effort to reduce usage.
- Clear explanation of expectations at the outset, to avoid attrition or disengagement if the first bill is higher than expected, even if later savings should compensate for it.
- Guidance on how to save money in a way that looks achievable to consumers, possibly combined with consumer commitments to shift.

1.5.10. Target-setting

Some studies have set a target for energy savings, sometimes with a commitment from consumers to achieve the target, but no reward for doing so (other than lower energy bills). This would probably act mainly by reinforcing existing motives. Evidence on the effect of this is limited as it has usually been combined with other interventions but short-term trials with realistic, stretching targets have delivered energy savings, especially when combined with feedback. Target-setting, if used in an SES, should be combined with regular feedback and it may work best in groups with a common interest who self-select to reduce energy use. Challenging targets are more likely to motivate behaviour change than trivial, easy-to-achieve targets.

1.5.11. Financial incentives to reduce consumption

With a direct financial reward for reducing overall consumption (in addition to any saving from using less energy), the emphasis is clearly on the financial motive although sometimes the reward is in the form of vouchers to spend on energy-saving products, thus turning motive into opportunity. The limited evidence suggests that any effect from a financial incentive is lost when the incentive is removed; in any case the effect is confounded with any effect of the necessary target-setting. There is also concern that financial incentives can be counterproductive in the longer term by focusing attention on the financial motive, to the detriment of other motives that the consumer might have had prior to the intervention.

Financial incentives are of limited values in changing behaviour. If included as part of an SES, it may be better to target households that are already motivated to save energy but lack the resources to invest in their goal, i.e. to use the incentive to provide *opportunity* rather than *motive*. The basis of receiving the incentive must be clear to consumers and they should be able to track their progress (using feedback) against a realistic trajectory (and it should not be possible to obtain the incentive by increasing consumption during a baseline period). The incentive should be maintained for no longer than necessary to achieve impact, while also using it to put in place persistent change, through consumer investment (e.g. in efficient appliances or insulation), development of new habits, peer support or transition to another intervention.

1.5.12. Heat, renewable energy and insulation technologies

A range of alternative technologies can be deployed as part of SES but there is surprisingly little evidence on the specifics of user response. Factors that generally affect decisions about replacing heating systems are households' level of satisfaction with their current systems, annual heating costs, investment costs and functional reliability. General barriers include: high upfront costs; perceived costs outweighing energy savings; technologies being unlikely to last long enough to pay back the initial cost; a lack of knowledge, skills and incentives; a lack of consumer trust in energy companies and the building trades; confusing advice streams; and fragmented policy, delivery and funding.

Key requirements for heating include controllability, getting the home warm quickly, cleanliness, and low cost. Consumers may associate new technology with the nearest familiar old technology (e.g. electric heating tends to be perceived negatively because of association with electric storage heaters). Gas boilers are the preferred option, with a further preference for combi boilers. The next most popular option (micro CHP) has only half the approval rate and this may be partly attributed to it having features in common with gas boilers. Nevertheless, there are significant barriers to micro CHP in the form of cost, the uncertainties associated with new technology and issues of connecting with existing heating and electricity systems. Air source heat pumps lack credibility with many consumers, particularly those living in colder parts of the UK.

Despite the clear financial benefits and positive perceptions by early adopters, renewable technologies such as solar PV face barriers of perceived complexity around the process for selling electricity to the grid, the payback period and more generally the financial, economic and aesthetic characterisations of the technology. If solar power does not bring additional value for the property, then adoption will not be considered by householders who may move out before the payback period ends.

Heat pumps can appear relatively complex and they deliver heat in a way that differs from most users' experience and expectations, with heat sources (e.g. radiators) being cooler but larger and continuous operation being recommended. Some heat pumps can also be used for cooling; there is little evidence on this mode of operation but heat pumps should be considered as both heating and cooling technology, with the risks and benefits associated with air conditioning. Heat pump performance depends on user behaviour (in operating the equipment and through behaviour that affects heat loss). Additional heating sources are often used if heat pumps do not provide sufficient heat at all times but this needs to be balanced against the additional energy use that would result from heat pumps being oversized for demand most of the year.

The majority of users are satisfied with their heat pump for space heating and (where applicable) hot water. They are generally pleased with having constant warmth with heat pumps operating continuously, but not all users understand that this is the preferred mode of operation or believe it is not safe to leave the heating on when away from the home. Users also like the freedom from the messy work required with solid fuel systems (this would apply to most new heat sources). Operational costs greatly affect user satisfaction, particularly for tenants if the system is not adequately explained to them. More generally, consumers express difficulty in understanding displays, controls and instructions; some either heat rooms to higher temperatures than needed or complain of low temperatures. Noise can be a problem, especially with air source heat pumps.

District heating refers to a system where heat is generated outside the individual dwelling and then supplied to the dwelling (e.g. in the form of hot water to radiators or warm air). Such systems could be entirely within a block of flats or serve a neighbourhood, including non-residential premises. There are also systems whereby heating is centrally controlled but generated within individual dwellings (e.g. by electric heating). Key SES characteristic issues for district heating are likely to be: disruption during installation; reliability (given that the householder is relinquishing some control); usability and convenience of in-home control devices; responsiveness to changes in demand temperature; consumers' control over the seasons when heat is supplied; energy costs and consumers' ability to control costs by controlling how much heat they use.

Some other community aspects of energy use that are potentially of interest include how people come together to make energy decisions; what might determine whether neighbours would wish to collaborate; and whether broader community benefits encourage individual household action. Evidence on actual practice (or how this might affect response to propositions about district heating) is lacking but notions of 'community' and 'local' could improve the perception of retrofit measures, through benefits to the community (such as local jobs), the relevance of the measures to the community, and trust in local suppliers.

Insulation is one of the main technologies used in retrofit, and is also needed alongside many of the other technologies discussed in this chapter. While other SES can make energy use and the patterns of its use visible, with a view to reducing that usage, insulation is needed to maximise the benefit of the energy that is used. As it does not have the appeal of novelty, response to the user, or status-enhancing properties of some other SES technologies, it can be seen as a less interesting technology by consumers, which can reduce the priority it is given when home renovations are considered.

1.5.13. Water efficiency initiatives

Interventions aimed at water savings also have energy implications. There has been an implicit reliance on three means of change: free or discounted installation of devices believed to reduce water demand; raising awareness of the need to save water (not a proven means of behaviour change); and providing information on how to use less water. Devices that have been deployed include tap inserts, replacement shower heads, shower regulators and timers, replacement washers, leak repairs, leakage alarms and water-efficient washing machines. While some devices might save water without active use by householders (e.g. replacement shower heads), others require householders to use them (e.g. shower timers).

For devices that are simple to fit, householders prefer to do it themselves, whereas professional fitting is preferred for anything that appears at all complicated. Professional installations should save more per household because more devices are available, more get installed, they are more likely to be fitted properly and the installer has the chance to talk to the householder about using the device. But self-installers may be more motivated to reduce water use and engage in additional behaviours to do so.

Householders give various reasons for not fitting a device: being unable to fit it (e.g. incompatible with existing taps), no time to fit, irrelevance (e.g. already have the device), and water pressure being too low for the device to function. It is also common to remove devices for reasons of poor function, device failure, not wishing to shower in under four minutes, inconvenience (e.g. slower to shower or fill a basin), lower flow rates, or the device not being used. Greater effort to match devices to homes and households could reduce wastage and avoid devices being discredited through inappropriate attempts to install.

Apart from this evidence on installation and removal, there is an implicit assumption that the effect of the device depends solely on it being in place. In fact, in addition to disuse and misuse, there can be compensation (e.g. taking a longer shower to compensate for a lower flow rate) or rebound (e.g. being less careful to turn a tap off when brushing teeth if the flow rate is reduced). Consequently, water efficiency interventions that simply focus on replacing technology have limited impact. The result is disillusionment of users and a tendency to replace low-flow products with higher flow-rate models. Taps with ceramic washers (allowing taps to be quickly opened or closed) and efficient shower head design may be more effective than simple flow restriction. Other barriers related to the *means* include: not understanding the rationale for the device or behaviour; not knowing how to use the device or not believing it will save water (in general or in the particular household); and tenants not being allowed to install anything (or believing they are not allowed).

Barriers related to *motive* include householders believing they were already water-efficient or that saving water is someone else's problem or decision. Mention of environmental benefits can provoke negative reactions about high rainfall, planning controls, building on floodplains and not having enough reservoirs. Cost is a barrier if measures are not free of charge but householders may think there is a catch because of a free offer (emphasising the need for trust in the product and the source person or organisation). Time may be a more important barrier, expressed in words such as "hassle" and "commitment".

The true performance of each device (individually and in combination) needs to be established so that it can be offered with confidence that it will work. A key issue is showers: customers want showers to provide good water flow, at the right temperature, in order to wash, keep warm and enjoy the experience of showering and these need to be provided in ways that do not require or encourage excessive water consumption. Lateral thinking suggests alternative potential means such as dirt-repelling or deodorising fabrics, and soaps and shampoos that rinse off more quickly. Confident deployment also depends on having an understanding of how consumers are likely to react to different devices and financial arrangements. It may also help to improve consumers' knowledge of, for example, how much water they consume, where the water comes from, and the environmental impact of water use (particularly if it relates to local rivers drying up).

1.5.14. The rebound effect following thermal retrofit

In many cases, consumer choices relate to the heating (or hot water) strategy following thermal retrofit rather than the retrofit itself. Purely physical models underestimate heating demand following thermal retrofit by an estimated 15-30%. In extreme cases, there could be no energy savings or even increased energy use ("backfire"). A specific example concerns conservatories. These are potentially useful as passive solar spaces, if they are occupied only in the warmer months and closed off to the rest of the home during colder months. But conservatories tend to be used all year, and heated on a daily basis.

This "rebound effect" is well known but poorly understood in terms of what householders actually do, or why, but a key mechanism is that some of the potential energy savings are exchanged (consciously or not) for higher room temperatures or heating in more rooms. It is often assumed that consumers actively seek to achieve the higher temperatures and that this equates to greater comfort; this is not the whole story. To develop an appropriate and effective response to rebound, it is essential to have a proper understanding of the underlying behaviours and motives. Some combination of the following scenarios can be envisaged.

- Warmth is cheaper, therefore householders actively acquire more of it.
- The dwelling becomes warmer without householders doing anything differently but they willingly accept the higher temperature.
- The dwelling becomes warmer without householders doing anything differently; they would prefer (or be content) to be cooler but do not know how to achieve this or do not have the time to work it out.
- The dwelling would become warmer without householders doing anything differently but they take action to limit the temperature rise – either by reducing energy use or by increasing heat loss.

In any one of these scenarios, the achieved temperatures and indoor air quality, together with risk of moisture damage to the dwelling, could become better or worse. Also, saving energy is not the sole aim of thermal retrofit. The other aim is that people should be healthier and happier, perhaps reducing fuel poverty. In this sense, rebound may sometimes be the aim, without which there would have been no energy savings at all. So the factors involved are complex and the evidence, particularly longitudinal evidence, is limited. Indications are that central heating results in the greater rebound (probably due largely to more rooms being heated), with draughtproofing and insulation appearing to mitigate the effect. The rise in temperature following refurbishment can occur largely while the heating is off, due to some combination of slower temperature decay after the heating is switched off and greater impact of incidental gains.

Deliberate rebound, increasing comfort, has been reported following installation of heat pumps in Norway, where electricity is relatively inexpensive and almost entirely from renewable sources. A lesser effect was seen in Denmark (where electricity is more expensive and less is from renewables). The air-to-air heat pumps used in Denmark were also perceived as improving IAQ and this could account for some of the additional use of them. It is also notable that rebound seems more deliberate for lighting (using brighter bulbs and taking less care to switch lights off when not needed), where the control is more obvious and direct.

1.5.15. Power generation

Perceptions of electrical technology can extend to how the electricity was generated and implications for diversity, security and continuity of generation. The power generation method is therefore relevant, especially if a new technology uses less energy but more electricity (e.g. a heat pump replacing a gas boiler). Coal and oil are the least favoured but gas is judged more favourable than unfavourable. Renewable energy is generally favoured over use of fossil fuels, although there are mixed views on the aesthetics of wind turbines. Offshore wind farms are favoured over onshore but opposition to both is low.

Biofuels are seen as different from (and preferable to) fossil fuels but both are burned and entail vulnerability to countries that supply the fuel. They are therefore seen as stopgaps rather than a long-term replacement for fossil fuel. There is also some awareness of conflicts over use of land (for energy or for food). Nuclear power has a unique dread and multiple negative associations but some people are prepared to live with it (perhaps at a distance) because of the low likelihood of an incident, and it is seen as a reliable electricity supply. It is perceived more positively if positioned as being developed alongside renewable energy. Carbon capture and storage (CCS) shares some characteristics with nuclear power (both involve a waste product that needs to be transported and stored indefinitely) but tends to be preferred to nuclear power. Also, CCS addresses CO_2 but not energy security and the latter appears more salient to consumers.

1.5.16. Overview

No single SES element is likely to offer the full package; combinations therefore need to be designed that will complement each other in meeting needs and in delivering the means, motive and opportunity to manage energy better. Much of the evidence on response to SES relates to individual elements, with limited combinations or sequences studied in detail, so there is uncertainty in predicting responses to whole systems but response to the elements is a fair starting point.

A particular consumer response is not guaranteed simply by implementing a particular SES element: response depends on the detail of how it is designed, delivered and combined with other elements. The whole customer journey also needs to be considered, from first engaging with an intervention, to initial impact and sustaining actions over a longer period. The more closely an SES can be tailored to particular households or individuals, the more effective it is likely to be. Consumers need to feel able to act: that they can carry out the necessary actions, and that those actions will not be isolated or ineffective.

Clear presentation of benefits and value is essential, especially if there are barriers such as a large capital cost, long payback period, inconvenience or aesthetic objection. Many consumers are willing to invest only if their return on the investment is relatively rapid or at least that the technology is likely to be effective and last long enough to pay back the initial cost. It also matters *who* is paying (the consumer or some other party) and who the consumer thinks *should* be paying or really is paying. The acceptability of an SES can be higher, and the real cost lower, when moving to a new home or having a family, or undertaking a home extension or refurbishment (e.g. insulation and double glazing are considered the norm when extending a home). There is potential for more to be achieved at these points through intermediaries such as schools, estate agents, surveyors, lenders and those in construction and retail businesses.

An SES can save householders time by helping to select the best options, thus reducing an initial hurdle of having to invest time in decisions. There are other key points at which the householder’s time needs to be considered: at first contact, in further discussion and for the installation itself. The effectiveness of an intervention can depend on the extent to which the originator is trusted (trusted to be reliable as to the facts, competent to deliver, honest in expression and transparent in motive). Hence, even the best designed SES could fail if the target audience does not trust the source or messenger. Consistent messages from different parties is therefore important (e.g. while peers may be most trusted to offer genuine advice, the accuracy of their advice may be least reliable and needs to be consistent with official guidance). Trust in messages from public authorities is greater if the authorities are seen to act in a way that is consistent with the message.

Community-level action can be an effective tool, making use of social networks and social capital, and changing social norms. It may, however, require a higher initial investment and will not necessarily work in all localities. The key characteristics of this approach to make it cost-effective have not been determined. More generally, the evidence probably does not allow the full potential to be realised of connections between the household (neighbourhoods, localities) and the shift towards local policy responsibility. Another effective tool for the delivery of a range of types of interventions is the web. Receiving web-based information is a more active process for consumers, and can be tailored and linked to options for action. Additionally, web-based information can be less resource-intensive than other media.

Consumers readily assume that change itself is inevitable: the issue is the form and pace of change. Furthermore, while the possible form of change naturally raises concerns, there is also concern about doing nothing. Nevertheless, there are clear issues about the location of change in time and space. Some see the change as being in the distant future, for others to deal with, or needing to happen somewhere else.

2. Introduction

2.1. Aim of the report

This review was conducted as part of the Consumer Response and Behaviour (CRaB) project, within the Smart Systems and Heat Programme of the Energy Technologies Institute (ETI). While the Smart Systems and Heat Programme as a whole is largely technological, CRaB provides an essential basis in the consumer perspective. Future energy systems will deploy new technologies and business models and will potentially feature a much greater degree of consumer involvement in the provision and management of energy-based services during the period to 2050. It is therefore important to understand: the energy-related lifestyle services that consumers require (such as comfort or entertainment); the potential for changes to lifestyle; the preferred characteristics of their interactions with the energy system; the design features of successful consumer-focused energy products; and the likely barriers to changes in technology and products.

The aim of this review is to answer eight Research Questions (RQs) agreed for CRaB as a whole, to the extent that they can reasonably be answered from the existing literature. The relevant questions are listed below and explained in greater detail in Appendix A.

- RQ1. What needs do consumers want to meet, that involve energy use?
- RQ2. What do people currently do that uses energy?
- RQ3. Why do consumers exhibit particular energy-using behaviours?
- RQ4. How do consumer needs, behaviour, motivation and rationale vary across the population?
- RQ5. What external factors, that could affect consumer needs, behaviour, motivation or rationale are likely to change over time?
- RQ6. How would these factors be expected to impact consumer needs, behaviour, motivation or rationale?
- RQ7. What is the likely consumer response to potential smart energy system solutions?
- RQ8. How can smart systems meet current and future needs?

The review deals principally with behaviour in residential buildings but incorporates evidence from non-domestic buildings where it helps to address the questions.

2.2. Review method

Relevant literature for the review was initially identified by members of the CRaB project team, ETI and its advisers, and other experts. This initial collection of literature was supplemented by keyword searches of databases of published academic literature (Sage Journals Online, ScienceDirect, Web of Science and Google Scholar). The literature identified included peer-reviewed academic articles, papers presented at academic conferences, and commissioned research produced on behalf of government and other organisations.

The conduct of initial reviews of each source was shared among the project team and collated through a secure online system (Zotero) using an agreed template. The template (included as a text version in Appendix B) focused on how each source contributed to answering the Research Questions but also enabled an assessment of the quality of the source by the initial reviewer. This included an assessment of the believability of the findings and the evidence included to support those findings. Further literature for review was also identified during the initial reviewing process, through citations in publications and direct contact with authors and other experts.

Zotero includes the functions of reference manager software (storing author, title and publication details and exporting this information as formatted references) but also allows more detailed tagging and organisation of the references. This allowed the template questions and the answers for each paper to be saved on the Zotero system, and through its secure shared library facility, seen and added to by other members of the project team.

A first draft was created from the reviews collected on Zotero. A core team then synthesised the evidence, re-reviewing sources where appropriate as concepts emerged from the synthesis, and reading new material as it emerged. Further database searches were conducted where gaps in the evidence base were identified. As agreed with ETI, the process started with existing reviews and then moved to the primary literature as necessary. The literature cited is therefore sometimes a review and sometimes the primary source; where no literature is cited, this signifies deduction on the part of the authors of this review.

No strict age limit was placed on the sources, but the emphasis was on good recent reviews of relevant topics and primary material up to ten years old. Material published up to May 2013 was included. An assessment of the quality of the sources included was made on the basis of the believability of the research findings given the research design, methodology and sample, with attention given to the likely relevance of the findings to a UK setting.

The material included in the review is necessarily limited by the material available for review. In some areas, there was only a limited amount of research examining the topic from the viewpoint of the user or building occupant. A topic that is not discussed in detail in this review, then, is not necessarily unimportant, and if something is not included, this indicates that it was not addressed sufficiently in the literature reviewed. In addition, a large part of the literature is oriented at changing energy-related behaviour to reduce or shift energy demand and much of that is about influencing how people use existing technology, rather than investigating the impact of changing technology (with the exception of work on smart meters and IHDs). Because of this focus, the emphasis in on overall energy demand or specific behaviours, outside a more general context of the purposes or practices associated with home. Again, this necessarily limits what can be reported from the literature.

2.3. Report structure

This review is structured mainly by RQ, chapters 3-6 each representing one or two RQs.

- Chapter 3 addresses RQ1 to set out the evidence on the needs that people seek to meet as they use energy (particularly heat energy) in the home.
- Chapter 4 covers both RQ2 (*what* people currently do that uses energy) and RQ3 (*why* consumers exhibit particular energy-using behaviours). This chapter builds on RQ1's identification of needs by linking the performance of particular energy-using behaviours to the reasons (motives or rationale) for the behaviours.
- Chapter 5 addresses RQ4 with evidence on how needs, motives, rationales and behaviours vary in the population.
- Chapter 6 covers both RQ7 and RQ8: these are closely related. RQ7 asks how consumers are expected to respond to smart energy solutions (SES) and this will of course depend on the characteristics of each SES. RQ8 responds by asking "therefore, what should the characteristics of SES be?"
- Chapter 7 draws together the main conclusions.

RQs 5 and 6 relate to the influence of external factors, i.e. factors outside the direct influence of programmes to implement smart energy systems, that could affect consumer response. Evidence on these factors has been integrated into the other chapters and the process of identifying relevant factors is described in Appendix C.

Two examples of needs

To illustrate the connections between the Research Questions, two examples of consumer needs are taken through the report, at the end of Chapters 3-6.

3. Consumer needs

RQ1: What needs do consumers want to meet, that involve energy use?

3.1. Introduction

Fundamental to the design of any new approach to energy for domestic consumers is an understanding of the needs those consumers are meeting (or seeking to meet) through energy use, and the behaviours and technologies through which they currently address those needs. If these are not well understood, the design risks failing to meet needs or conflicting with how consumers wish to behave, ultimately resulting in failure of the design. This chapter focuses on the needs and the following chapter links those needs to behaviours.

The CRaB project has intentionally adopted a broad definition of the needs that people have, for which they use energy. Needs range from those that are objectively "essential for life" to preferences based on individual perceived needs or values. A need exists whether or not it is currently being met, and whether or not a person is conscious of either the need itself or how it relates to energy use. Needs may be addressed as high level "purposes" for a home (such as having a healthy, comfortable life, maintaining cleanliness, or caring for a family) or very specific targets, such as how much of the home is heated or the specific temperatures required. We have adopted an intermediate level (e.g. comfort, health, safety, productivity, security and happiness) that easily supports connections between needs, behaviours and energy systems, but is also sufficiently high level to facilitate connection to purposes of a home.

Needs might relate to a person's own individual needs, social norms and expectations, or standards set by regulators or professional bodies (e.g. a need to obey the law). They may be directly those of the person taking the decision that results in energy use (e.g. I'm cold, so I put the heating on), decided by negotiation (e.g. I'm OK but my partner is cold, so I put the heating on) or decided on behalf of someone else (e.g. I don't want my toddler to get cold, so I put the heating on). However, we found little evidence on the "social dynamics" of how energy-related decisions are made in households.

Needs also differ between domestic and non-domestic settings. The organisational nature of most non-domestic settings means that occupants are often fulfilling a particular role (e.g. employees performing tasks associated with their job) or following particular policies (e.g. a customer following rules for members in a leisure centre). While some needs, such as thermal comfort, are also important in non-domestic settings in order for people to carry out their activities, other needs may be less relevant. The organisation that occupies and operates a non-domestic building sets up expectations for behaviour, and individual needs are often secondary. In some non-domestic buildings, however, particularly those housing smaller organisations, the needs of the organisation may align more closely with or be subservient to those of individual occupants, particularly business owners or sole traders. The importance of needs in non-domestic settings can also differ between individuals: while one person may regard it as important to work for an organisation or be a customer of a business that shares their own attitudes to waste or the environment, for example, another may differentiate between attitudes and behaviours in the home and in the workplace.

Hence, the definition of needs and priorities is socially complex, depending on the nature of the setting, who is dominant in the decision-making, the needs of a range of persons, and care responsibilities (e.g. foregoing a hot meal so that children can be kept warm). Furthermore, whether the need is personal, social or standards-based, there may be a priority order of needs, although this may be observable only where there is a limit on the resources available to meet the needs (e.g. in cases of fuel poverty). The definition of priority order is complex, since it might be:

- either perceived by the person or objectively defined (e.g. by regulations or a contract);
- either observed (e.g. by researchers) or reported by the person;
- either fixed or flexible for a given person or household (e.g. depending on life-stage or time of day);
- dependent on relationships between needs, where one behaviour addresses more than one need (e.g. a fire may offer both heat and light, a bath may provide washing, comfort and relaxation);
- related to whether or not each need is currently met.

The science of behavioural response to energy-related interventions crosses boundaries of psychology, sociology, ergonomics and economics; it also interlinks with engineering and product design. For this reason, there have been multiple models of behaviour and behaviour change, each with different emphasis and often using similar terms with different meaning, or different terms with similar meaning. This report simplifies the framework to avoid being tied to any particular theoretical approach, while allowing easy comparison of the roles of different elements of SES. The framework used (Raw *et al* 2010) is based on the *means*, *motive* and *opportunity* for change (such as response to SES).

- The *means* is the technology and behaviour that will lead to some outcome in response to an SES. This includes the consumer having the necessary knowledge and skills.
- The *motive* is the reason why households will want to act.
- The *opportunity* is the resource (e.g. time, space or money) to act.

In other words, householders' response to SES depends on knowing what to do, having a reason for doing it and having the resources to do it. Motives can be seen as "needs in action": when a need leads to a behaviour, that need has become a motive for the behaviour. This framework is a way of thinking about SES – it does not imply a particular conscious or unconscious thought process on the part of energy users. In particular, it does not assume that behaviour is always rational from an observer's perspective. There is no reason to believe that people generally set out to be irrational but they lack – in various measures – knowledge and understanding, reasoning capacity and time or motive to think in detail about everything they do. They also have many competing needs and demands on their time, and do not necessarily prioritise energy issues for whatever capacity they have. One aspect of this is that behaviours can be bound up in particular practices that do not relate primarily to energy and a failure to understand this can lead to ineffective attempts to change behaviour (Shove 2010). Hence householder behaviour will often appear to an observer to be irrational.

This review has been guided by a provisional categorisation of needs, agreed early in the project from a first reading of the literature, which has been used to structure this chapter. In adopting and applying these categories, there is no implication that consumers are necessarily conscious of all the relevant needs or their energy implications, or that consumers treat needs as individual, distinct or independent of the overarching purposes or practices to which they relate. The review has sought to be neutral in relation to any particular theory of behaviour.

The categorisation includes both "functional" needs, such as comfort and health, and more "symbolic" needs relating identity and social relationships. In both cases, needs are conceived principally from the perspective of individual persons or households, while recognising that individuals act in a social context with a complex set of norms, practices, reinforcements and constraints. The final section in the chapter discusses priorities of needs and linkages between them. It is expected that subsequent stages of the project will review the categorisation itself.

3.2. Needs related to the wider implications of energy use

3.2.1. Introduction

This category of need relates to how consumers might feel a need to act in a way that protects or promotes interests that go beyond the household, at scales of the planet, the country or the neighbourhood. Specifically, the issues addressed are combating climate change, pollution and depletion of natural resources, avoiding the consequences of environmental damage, and preserving energy security.

The words that consumers (and researchers) use to refer to them can vary and this is a challenge in interpreting the evidence. For example, Butler *et al* (2013) found that people's understanding of "sustainability" included naturalness, cleanliness, healthiness and infinite resources, but also not generating conflicts/wars, or involving waste. "Carbon" was related to notions of cleanliness and pollution. People may also refer to attitudes, beliefs or rationales for action in terms that are unclear as to whether they are thinking altruistically and globally, about family or immediate community, or themselves.

3.2.2. Save the planet

This refers to a personal desire to reduce risk to the global environment, through:

- reducing CO_2 emissions to avoid dangerous climate change; and/or
- reducing global pollution of the environment (air, land and water) and depletion of natural resources.

While these are the needs that drive much policy and social action in the energy arena, they are of variable relevance to individual people or households. Research has consistently shown that climate change and CO_2 tend not to be mentioned spontaneously as part of householders' rationale for energy-related behaviour. However, when prompted, substantial majorities agree that climate change is a reason for reducing energy use, and even that they would be willing to pay more for energy-efficient products (Spence *et al* 2010, Demski *et al* 2013, Butler *et al* 2013). There are, nevertheless, many who also think that the seriousness of climate change has been exaggerated or that it is uncertain what the effects of climate change will be. There are others who either do not believe that climate change is a risk (globally or to them personally), do not think they personally or the UK as a whole can make a difference in a global context or see it as somebody else's responsibility (e.g. the Government, industry or other countries). And the impacts of climate change are frequently perceived as affecting future generations and other regions (Upham *et al* 2009).

Views expressed in a survey may not result in the expected action and, more generally, attitudes can be a poor guide to behaviour or change in behaviour. Nevertheless, the evidence at least shows that a substantial proportion of people see the role of reducing energy use to combat climate change. But the route from concern to action is unclear and there is evidence of disjuncture between concern and response to propositions about changes in energy systems, perhaps related to a belief that responsibility for action to address concerns rests principally with Government (Butler *et al* 2013). In particular, financial and other concerns can take on a greater importance in the public's mind, at national level as a challenge for the UK (DECC 2013) or at a personal level in relation to energy use (Demski *et al* 2013). There can also be conflicts over personal preferences: Butler *et al* (2013) report positive views of some uses of fossil fuel in the home (e.g. gas cooking, gas central heating and coal fires) that outweigh a generally negative view of fossil fuels.

If saving the planet is not the principal reason for most people's action to reduce energy demand, it is possible that it has a validating role, either in people explaining their actions to others or in reinforcing a person's belief that an action was worthwhile. This would explain why 58% of people who intended to reduce their energy use said that climate change and cost were equally important motives and, where only one reason was given, this was cost in 24% of cases and climate change in 17% (Demski *et al* 2013).

Along with climate change, global pollution and depletion of natural resources are major issues for some people while others have a lesser understanding or concern. Where there is concern about depletion of fossil fuel resources, Butler *et al* (2013) found an interesting degree of sophistication among their public workshop participants: presented with the possibility that fuel resources may not run out as soon as has been predicted, some participants maintained that the underlying issue was that fossil fuels are finite and thus will inevitably run out at some point (even if in the distant future).

3.2.3. Save the country

This refers to a personal desire to:

- achieve security of energy supply and national self-sufficiency; and/or
- avoid environmental degradation in other countries leading to wars and mass movement of people – some to the UK.

Again, these needs drive much policy and social action in the energy arena but there is highly variable awareness or concern at the individual and household level. Nevertheless, if questioned, a substantial majority of people are concerned about energy dependence on other countries, having alternatives in place when fossil fuels are no longer available, and the prospect of frequent power cuts (Demski *et al* 2013). The same study found that energy security was seen as more important than climate change. Energy security is also related to the cost of energy to UK consumers (Butler *et al* 2013) but concern over affordability did not necessarily mean that expensive routes to change at national level were rejected: expense in solving the problem appeared to be more acceptable than expense caused by the problem.

Environmental degradation in other countries may lead to wars and mass movement of people, some of them to the UK (Home Office 2010). The key themes here are conflict and competition: climate change can severely curtail the resources available to groups of people, who then compete for land or other resources held by others. Realistic scenarios for the 21st century involve people movements measured in hundreds of millions. However, this does not yet appear to be a factor in the public's thinking about energy use.

Logically, "saving the planet" does include "saving the country" but there is an additional national element that, for some people, is sufficient motive to shape the way energy is used (or not used). This thinking also extends to the constituent nations of the UK, where Butler *et al* (2013) found some expectations of national control and national benefit in return for national costs (including use of land) in Scotland and Wales.

3.2.4. Save my neighbourhood

This refers to more local issues, underlying a personal desire to avoid rising sea levels, loss of land, higher temperatures, changing rain or snow patterns, more frequent heatwaves, other severe weather, droughts, floods and property becoming uninsurable and losing value and/or maintain local security of energy supply.[3]

There is some tendency for the public to think that it would be nice for the UK to be a bit warmer and only countries that are already hot need to worry about climate change. In reality, there is a wide spectrum of risks to individuals in the UK. Combining this with the issue of energy security, there are good reasons for concerns focused on the local area (however people may perceive "local area"). Concern about climate change appears to increase when the emphasis is placed on the possible local implications (Butler *et al* 2013), suggesting that climate change is on the agenda but through the medium of more local issues.

It might therefore be expected that, if effects of climate change are felt at a local level, this would lead to action on climate change. This is not necessarily the case because people may opt for explanations other than global climate change, such as local explanations of local effects (Whitmarsh 2008), or perceive environmental problems as less serious if they are closer or there is a strong attachment to the local area (Bonaiuto *et al* 1996, Uzzell 2000).

Energy security issues can be seen in terms of personal energy security through having diverse forms of energy within the home (Butler *et al* 2013). While a local source of energy might be expected to enhance the value of living in that area, this can be counteracted by (a) the benefit of the generation being national rather than local and (b) the presence of the power source (be it nuclear, fossil fuel or renewable) itself creating "geographic stigma" (Butler *et al* 2013) and possibly downward pressure on property prices.

3.3. Resource-related needs

3.3.1. Introduction

The review by RAND Europe (2012) notes financial considerations as a key rationale for changing energy-related behaviour. We consider resources here in a slightly wider context, taking in a range of financial issues alongside concern about waste of resources and desire for self-sufficiency.

3.3.2. Save (or make) money

This refers to meeting financial needs such as:

- saving money on fuel bills;
- making money by generating energy;
- increasing (or maintaining) property value;
- getting a bargain or free offer;
- spending money on something other than energy.

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[3] Self-sufficiency is, in this context, a functional aim than being related to personal resources (as in Section 3.3.4.).

In this context, money is the motive for behaviour rather than the resource for the behaviour: the payback rather than the investment.

The logic of this need is clear: public concern about rising energy bills is at a high level (Demski *et al* 2013, DECC 2013) and reducing energy use will also reduce the energy bill. And surveys find that financial motives tend to dominate in householders' stated reasons for taking action to reduce energy use (e.g. Lutzenheiser *et al* 2003, Raw & Ross 2011). Rather than simply saving money, there is also the opportunity to make money through schemes to reward energy generation, such as the Feed-in Tariff in the UK.

Energy-efficiency or microgeneration might also enhance the value of a home for sale or rent (Hoen *et al* 2011, Morris-Marsham & Moore 2011). As awareness of energy technologies (and perhaps Energy Performance Certificates) spreads, and particularly if estate agents develop greater understanding of the technologies, they could have a greater impact on value. There is some evidence that higher ratings on Energy Performance Certificates (EPCs) are already associated with higher home values: research for DECC (2013) identified that, in comparison with homes rated EPC G, homes with better EPC ratings sold on average for between 6% (for homes rated EPC F and E) and 14% (rated EPC A and B) more. Regional differences suggested the effect was greater in areas with lower house prices.

Conversely, some action or inaction may reduce property value (e.g. through moisture damage or reduced aesthetic appeal) although the connection between energy use and degradation of a dwelling may not be obvious to all. Similarly, boiler servicing can reduce energy costs but ISMeT[4] found that the role of boiler servicing in reducing gas consumption was perceived as minimal: servicing was more typically driven by safety concerns or a wish to extend the life of the boiler. This is because the payback time for the servicing investment was considered unattractive.

Where installation or appliances are offered free or at substantial (and verifiable) discount, some may accept the offer because of the perceived value. Others do not easily connect with saving money but are motivated by having money to spend on other things (IPPR 2009): similar needs may be expressed in different ways.

The need to save money probably overlaps with a need to feel in control, in two ways. First, consumers can experience a sense of powerlessness in controlling energy costs (Butler *et al* 2013). If the unit costs cannot easily be controlled (and there will always be a limit to this), then controlling energy demand returns some control to the consumer. Second, if the amount of the energy bill cannot be controlled, consumers might at least like the amount to be predictable. There is also a link to energy sources and security, with consumers attaching importance to "affordability", not simply cost of energy (Butler *et al* 2013).

These issues have slightly different implications in non-domestic buildings. Energy costs are usually borne more directly by household members than by users in non-domestic settings such as workplaces (Lo *et al* 2012), and this makes it difficult to generalise from behaviour performed in a household setting to behaviour performed by the same individual in a non-domestic setting (Siero *et al* 1996). However, financial cost may still influence behaviour in non-domestic settings. In public sector buildings, it was found that many employees recognised the link between reducing the organisation's expenditure on energy and their own job security. While for some this motivated energy-saving behaviour to support the organisation, for others the combination of low morale arising from budget cuts and a feeling of lack of control over individual energy use in the workplace resulted in a backlash against saving energy at work (Littleford 2013).

3.3.3. Avoid waste

This refers to a personal desire to reduce wastage of energy or other resources. Avoiding waste is an element of the needs already described but there is also – for some people at least – an inherent dislike of waste, regardless of whether any money is saved or the prospects for long-term availability of a commodity (Butler *et al* 2013, Spence *et al* 2013). This may be particularly significant for more affluent households where saving money is less critical (alternatively they might see waste as a convenience or luxury). Waste avoidance could potentially also be a barrier if old, inefficient technology is retained when there would be a net energy or CO_2 benefit from replacing it. For example, when considering replacement of an inefficient boiler, households may feel that it still works and it is therefore a waste to replace it.

[4] The Irish smart metering trials, published in a set of reports by the Irish Commission for Energy Regulation (CER 2012).

In non-domestic buildings, the perception of inefficient heating, ventilation and cooling systems as wasteful can reduce concern for other energy-saving behaviours, with many occupants of such buildings perceiving their own actions to save energy to be insignificant in comparison (Lo *et al* 2011).

3.3.4. Self-sufficiency

This need may be expressed directly in terms of fulfilling a desire for self-sufficiency and/or indirectly in terms such as becoming more in tune with nature. This need is likely to relate most strongly to generating energy or using free energy but can guide choices more generally. Michelsen & Madlener (2012) found that adopters of gas- or oil-fired condensing boilers had a strong preference for energy savings while those choosing renewable technologies such as heat pumps and biomass boilers preferred being more independent of fossil fuels. Self-sufficiency can also be viewed at neighbourhood level, in terms of independence from energy supply companies (Oostra & Jablonska 2013).

Extreme weather events causing loss of power, could prompt householders to want to become more self-sufficient – for example by investing in micro-generation or energy storage. Alternatively, it could have the opposite effect, detracting from interest in energy and self-sufficiency as householders focus action on the resilience of their home to storms and floods.

3.4. Needs related to quality of life

3.4.1. Introduction

Quality of life is a broad concept which could be construed as encompassing all needs. It is used in a more restricted way here, to refer to needs in relation to well-being, aesthetic appeal, ease and simplicity, confidence and control, entertainment and happiness. Happiness itself combines all the other needs in ways that will vary greatly between people and households but for most people probably includes the quality of personal relationships. This can be seen as a summary of all needs but, for practical purposes, it is the contributing factors that are relevant: few people would say “I use energy to be happy”.

3.4.2. Well-being

This refers to personal needs such as:

- being comfortable, relaxed, rested and healthy;
- being free from worries or fears;
- being productive – in employment or in domestic work;
- having safe appliances, building fabric or lifestyle;
- having actual or perceived security and privacy.

Some needs are directly met through energy use, such as: cooking and eating; keeping food fit for consumption; keeping oneself clean and dry; washing clothes or dishes; and relieving aches and pains (e.g. by applying heat). Meeting other needs, such as thermal comfort, depends on the achieved indoor environment. Certain energy-related behaviours affect indoor environment, either directly (e.g. insulation making a home warmer, double glazing also making the indoor environment quieter and more secure, or heat-recovery ventilation improving indoor air quality and reducing problems with damp, mould and mites) or indirectly (by making more resources available for other needs). Other behaviours entail more complex interactions. Energy can be used directly, for example, for lighting to promote certain moods (but often in combination with the thermal environment) or to enable certain tasks to be carried out (tasks that also have an optimal thermal environment). Medical treatment such as home dialysis may contribute heat to the home but also require a warmer space as the patient is sedentary for an extended period.

The most obvious heat energy connection is with thermal comfort. Physiologically, the thermal state of a person depends on three groups of factors:

- the thermal environment (air temperature, radiant temperature, humidity and air velocity/turbulence);
- insulation of the body (by clothing, bedding, etc.);

- metabolic rate, hence physical activity for example.

Thermal comfort is also determined to a large extent by these same factors but it is a psychological factor that also depends on expectations, local norms and the physical, psychological or physiological demands of the context (e.g. watching TV or stepping out of the shower).

Given this mix of factors that determine thermal comfort, it is not surprising that people differ from each other in the exact thermal conditions under which they express thermal comfort, and that the optimum conditions vary over time as people engage in different activities or adopt different levels of clothing or other personal insulation. Indeed, the basic thermal state equations result in a predicted *mean* vote – PMV (on thermal comfort) – specifically because there is variation about the mean. Variation is such that, if clothing and metabolic rate are made constant across individuals, any given set of thermal conditions will satisfy only up to 80% of individuals. In a domestic context, this inter-individual variation is most obviously managed by individuals adopting different levels of clothing insulation so that all can be comfortable in the same space. In practice, individuals may also have particular expectations of what clothing they should be able to wear at home and this potentially leads to disputes over heating.

Looking at this from a different perspective, where the indoor thermal environment is well controlled by the building (i.e. effective, well controlled heating and/or cooling), calculations based on nominal physiological state are good predictors of average thermal comfort. In "free-running" buildings, where there is greater variation in the indoor thermal environment according to the outdoor conditions, occupants tend to adapt to the conditions rather than expect the conditions to adapt to them. For example, they vary their clothing or level of physical activity. According to this adaptive model (Nicol *et al* 2012), the need for heating or cooling effectively varies because the need for thermal comfort is met by means other than controlling the indoor environment.

Therefore, in a domestic context, predicting comfort is not the key issue and Fanger's PMV is, in any case, particularly unreliable in this context. The adaptive model is more relevant but, again, predicting comfort is not the principal issue for SES design. The home should instead be designed to allow people to achieve comfort as they define it, which would entail a range of temperatures being achievable. As now, people with different thermal requirements, occupying the same space, might need to negotiate over levels of heating and clothing but smart systems could also make it easier to achieve different temperatures in different rooms, or offer finer spatial control over radiant temperature and air movement.

Becoming more comfortable or healthy does not correlate perfectly with reducing energy use, indeed there can be a negative relationship (e.g. see discussion of the "rebound effect" in Section 6.14). Individuals with higher incomes may have inherently healthier and more comfortable homes, so that the need to enhance well-being does not materialise in practice, while other aspects of well-being (such as aesthetics or convenience) could have more influence. Perception of the impact of energy-saving activity more generally on quality of life has been identified as a barrier to saving energy where householders perceive that the required changes in energy consumption will lead to greater discomfort or the sacrifice of standard of living (Lorenzoni *et al* 2007, Gatersleben 2001).

Being healthy and comfortable should also increase productivity although the relationship is not simple or direct (Seppänen *et al* 2007). This applies mainly where the home is a workplace (for paid, voluntary or domestic work) but there may also be knock-on effects on work outside the home if consequences for health persist outside the home. Health, comfort and productivity are also linked to occupants' ability to control their indoor environment, at least in office buildings (Seppänen *et al* 2007, Toftum 2010). Also, reduced occupant control in fully air-conditioned office buildings has been associated with increased – not decreased – energy consumption (Steemers & Manchanda 2010); this can most likely be attributed to occupants getting heating and cooling that they don't want or need.

A sense of privacy can also be a factor, particularly in relation to any technology that involves yielding control to a third party (e.g. allowing an energy company to activate an appliance in the home when there is spare generation capacity or when the electricity is cheapest). Being advised when spare capacity is available may be more acceptable, even if this offers fewer options to save energy than with automatic control (Butler *et al* 2013). Concerns over data privacy have also been raised as a barrier to certain smart energy technology, especially smart meters.

There may be circumstances in which safety is a decisive issue. This can range from replacing an old boiler (because of fears of fire, explosion or carbon monoxide poisoning) to turning off appliances when they are not in use to reduce the risk of electrical fires or lightning strike. On the negative side, safety concerns may also be a barrier, for example, if someone does not want to run major electrical appliances such as washing machines overnight for fear of electrical fires or loss of water (CER 2012).

3.4.3. Aesthetic appeal

This refers to needs related to the look (or feel, or smell) of the home (as perceived from the inside or the outside) or something within it (from the perspective of the householder rather than an aspect of self-image, although the two should be connected). It may be expressed in a range of ways, such as “looking modern”, saving space in the home (to avoid clutter) and consumer tastes, linking to emotional or social attachments (Foresight 2008). While some other motives can relate to slow or small benefits, an aesthetic improvement can be immediate and (to the householder) very important. Similarly, adverse aesthetic perception can exclude an energy intervention without further consideration (Palm 2010, Crosbie & Baker 2010).

The historic nature of many buildings adds a further dimension to questions of aesthetic appeal, with some tension between conservation and measures to improve energy efficiency. English Heritage (2008) has noted that assessments of energy use in historic buildings, based on theoretical models, often contradict the actual energy performance. This highlights a risk in decisions regarding energy upgrades.

3.4.4. Make my life easier

This refers to reducing the burden of an activity or task. This need may alternatively be expressed as a need for the right technology to facilitate desired behaviours, saving time or reducing “hassle”. People dislike disruption from retrofits, for example, because this interferes with their home life even if it enables them to better meet their needs for heat. This follows from a combination of thinking about time as an aspect of opportunity (resource) and convenience (and comfort) as “quality of life” needs.

EDF Energy’s EDRP[5] trial concluded that desire for less hassle was one of three core triggers to uptake of new energy technology. Conversely, ISMeT found that concern about the inconvenience associated with installing a new meter was the reason given for not participating in the electricity trial in 40% of cases. This need may be particularly relevant to changing habits, where offering an alternative, easier habitual behaviour may be effective. If a technology or behaviour can make someone’s life easier, or is more convenient, it has an inherent attraction. This is different from the behaviour itself being easy to undertake. So, for example, turning down a thermostat is easy to do but effective heating controls could make life easier (by removing the need for continuous manual adjustment). Passive interventions, such as low-flow shower heads, do not necessarily make the householder’s life easier, but make it easy to save energy.

In non-domestic buildings, making someone’s life easier may be a key factor in whether attempts to change individual behaviour are successful. Work is of often primary interest to the organisation (Lo *et al* 2011) and carrying out tasks associated with work is therefore a primary motivation for staff’s patterns of energy use (Littleford 2013). Prioritisation of work over saving energy is evident in the relative absence of social norms towards energy behaviours (Lo *et al* 2011).

3.4.5. Confidence in the technology

This refers to people’s need to trust the building technology or appliances they are using, and their ability to achieve effective control through the technology. The sense of efficacy that people feel is important here: not simply confidence that the technology will work but confidence that they can make a difference by adopting the technology, or using existing technology differently (Thøgersen & Gronhoj 2010, Faiers *et al* 2007).

Someone may use old technology that they understand and have experience of (or that comes with personal recommendation), rather than unfamiliar new technology (offering greater efficiency and/or facilities). But it is not just about the newness of technology: people may see a move to a low carbon society as having an element of nostalgia, going back to a time of simpler lives (Butler *et al* 2013). Participants in this research

[5] Energy Demand Research Project (Raw & Ross 2011).

saw particular risks in being an early adopter, because of the difficulties in obtaining reliable information (technical, legal and financial) and potential exposure to unproven technology and inexperienced installers.

EDF Energy's EDRP trial concluded that desire for control was one of three core triggers to uptake of new energy technology. Other research has shown that functional reliability is considered in decisions about replacing heating systems (Mahapatra & Gustavsson 2008).

3.4.6. Entertainment

This refers to the need for enjoyable pursuits such as watching/listening to TV/radio or recorded material, or playing musical instruments. There would be consequences for heating energy demand, for example as a result of the required level of physical activity (watching TV will generally be comfortable at higher temperatures than playing drums). Conversely, entertainment that entails sedentary behaviour can lead to feeling cooler than more active entertainment.

3.5. Social needs

3.5.1. Introduction

Social needs are considered here in two key ways: needs focused on self ("how others see me") and needs focused on relationships with others. The distinction between the two is not always clear, such as when building good relationships with neighbours or gaining neighbours' approval are cited as reasons for energy-saving actions (Ward *et al* 2011, Nyrud *et al* 2008). RAND Europe (2012) notes social needs (altruism, competitiveness, cooperation and conformity) as key motives for changing energy-related behaviour. The focus on these direct social needs is not to deny the pervasive role of socially defined or modified concepts relating to the other needs discussed in this chapter, such as the social context of how comfort is understood (e.g. Shove *et al* 2008).

3.5.2. Self-image or recognition

This refers to a person's identity (individually or as a household) and aspirations in a social context (e.g. as a member of a particular social group). The need can be seen as a mixture of self-esteem and 'kudos', alongside conforming with social norms and aspirations, for example through:

- gaining social acceptance or avoiding social rejection (generally or within a particular social group);
- teaching skills and responsibility to the next generation;
- developing a sense of technical competence, choice or control;
- association with role models (sports stars, entertainers, intellectual leaders, political leaders).

This need does not necessarily imply selfishness: it stems from the importance of the social context of actions, and can be altruistic and derive from a feeling of doing something for the wider good or taking pride in the neighbourhood, city or country. It can also relate to national, ethnic or religious identity (e.g. in relation to cooking or cleaning practices).

The way people view themselves (self-construal) can predict attitudes around environmental concern, resource sharing and pro-environmental behaviour (Arnocky *et al* 2007). Self-identification as a pro-environmental person was also found to be related to the performance of regular energy-saving behaviours in domestic settings (Whitmarsh & O'Neill 2010) but not one-off purchases such as energy efficient technologies, which were more dependent on contextual factors such as home ownership. But a positive self-image does not necessarily equate to energy savings: the impact may be positive (e.g. showing off new solar panels) or negative (e.g. turning up the heating instead of putting on a jumper, out of concern for appearing poor, quirky or mean). It can also relate to the cost or aesthetics of new technology. All considerations in this area need to recognise that perceptions of good image can change rapidly and be subject to different rules for self and others: "I have style, you are fashionable, he is a fashion victim"!

This need is important in both domestic and non-domestic settings; among office workers, for example, the notion of 'professionalism' and 'being good at one's job' also include an expectation of being energy-efficient (Littleford 2013). For organisations, the need to be seen in a positive light by customers, stakeholders and other organisations within their sector encourages many large companies to promote a 'green' image through corporate social responsibility policies (Pellegrini-Masini & Leishman 2011). Smaller organisations, however, often struggle to turn pro-environmental or pro-energy-saving attitudes into action because of low levels of knowledge, financial barriers and limited business support services.

3.5.3. Social interaction

This relates closely to self-image but is more specifically about direct interaction with people inside and outside the home. An important aspect of this is taking care of other people's needs, especially children, elderly people or those who are unwell. But this extends to caring for others more generally (related to any of the other needs described in this chapter) and needs such as:

- living harmoniously within the home;
- socialising with friends and family in the home (in person or remotely by telephone, etc.);
- being involved with, or feeling connected to, local or more dispersed groups;
- being supported by other people or groups;
- a wider social concern for potential inequality in the benefits of new energy technology and/or the impact on local or national employment opportunities.

In the case of community-based energy initiatives, the social motive can be the dominant one: the community element can lead to a combination of mutual comparison (wanting to do better than others in the community) and encouragement (wanting others to do better) – see also Appendix D.

3.6. Regulatory needs

This refers to a need to comply with mandatory requirements – either legal (such as those in the Building Regulations) or industry-based (e.g. those imposed by professional bodies or lender/landlord organisations). This is quite a different type of need to the others discussed here, and relates more to constraints on choice than motives to act. It is, nevertheless, an important consideration. It is not an absolute determinant of behaviour because someone may be unaware of requirements or choose to ignore them. So impact will depend on the extent to which regulations are disseminated, explained and enforced.

3.7. Linkages and priorities

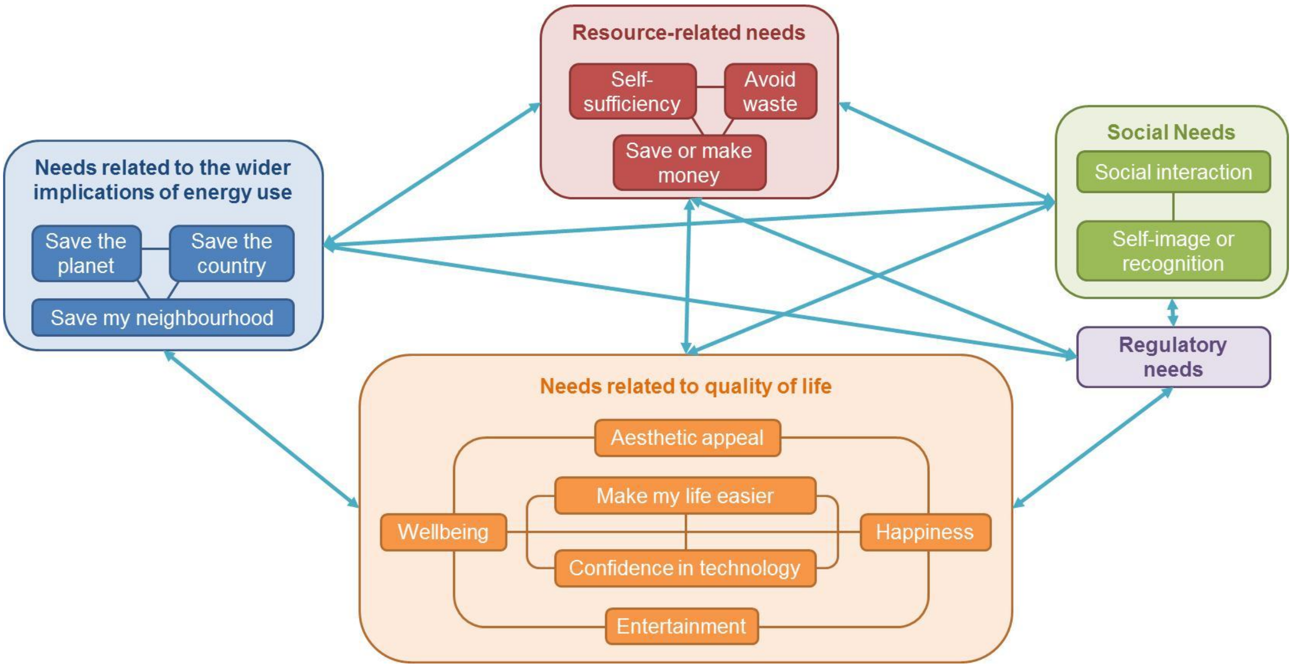
This review commenced with a provisional categorisation of needs. In most respects, this has served well as a framework for collecting evidence on consumer needs. Each need, individually and in detail, should be considered in SES design. However, the needs have so far been conceived in a relatively abstract and isolated way that consumers might not easily relate to, and that might be distant in people's minds as they use energy. It is now possible to look back at the evidence and make additional observations on the needs and how they are inter-related.

Figure 3.1 shows linkages among needs that have been identified in this review. These linkages are not shown in detail and they are not necessarily comprehensive. However, they do illustrate the potential complexity, even at high level and for the general case. This has important implications when talking about priorities among needs. The needs that tend to dominate appear to be those related to resources, quality of life and social factors, with needs related to wider implications having a supporting but background role, and regulatory needs having a constraining role.

But the details of priority would vary widely between individuals, contexts and the specific behaviours or choices in question. For example, in the SSE's EDRP trials, the most common reason that credit customers with smart meters gave for joining the trials was saving money, followed by helping the environment. However, customers with IHDs installed were more likely than others to say the reason was to obtain detailed information about energy consumption and to identify excessive energy use.

In particular, a need that is currently being met might not even be thought of as a need. Critically, the need that is foremost in consumers' minds does not necessarily stand alone: take away that layer of need and others would likely be revealed. The implication is that "priorities of need" is a risky way of thinking, in relation to SES design. A design focused on what appears to be the priority could fail because it does not meet what appeared to be a subordinate need. The more effective approach would appear to be to identify common patterns of need, taking into account all the defined categories. Where an SES has implications for the whole energy system (e.g. including power generation and the National Grid) the values that householders apply seem to relate closely to the needs identified here but with the addition of social justice, fairness, honesty, transparency and expectations that Government will have a coherent long-term plan (Parkhill *et al* 2013).

Figure 3.1 Examples of linkages among needs



In making more detailed linkages, there are further issues and it is important to realise that the obvious is not always true. This can be illustrated through the case of uses of hot water in the home. If personal cleanliness is a dominant need for a particular person, it could drive a high frequency and/or intensity of both bathing/showering and laundry. Alternatively, people who wash often might not feel so compelled to change their clothes as regularly because it is the shower that makes them feel clean (or vice versa). In addition to uncertainty related to needs, diversity of practice could arise from technological, lifestyle and social context, reinforcement and constraints. The question of whether apparently connected behaviours are actually correlated in a certain way, through needs, is therefore an empirical one.

A detailed study of water-using practices (Pullinger *et al* 2013) concludes that relationships between practices are generally “quite weak or absent” although there were some correlations between variants in personal washing and laundry practices.[6] Based on these correlations, it is possible to speculate about the needs that underpin the correlations (and the differences between groups), the main candidates being:

- keeping clean (e.g. washing oneself and washing clothes), with implications for self-image and health;
- relaxation and rest;
- make my life easier (e.g. through having a routine for both laundry and showering, avoiding effort or just doing things as the need arises rather than having a plan);
- confidence in the technology (e.g. using simple solutions such as baths and washing laundry by hand);
- saving money (e.g. using cheap, simple solutions and avoiding use of outside laundry services);
- expressing technical competence and control (e.g. exercising a diverse range of options, according to the specific aims of the behaviour);

[6] A weak relationship between practices is also implied by Brook Lyndhurst (2012): those who used a lot of heating did not necessarily use a lot of hot water and vice versa.

- social interaction (e.g. being out of the house a lot, therefore frequent but quick washing, perhaps by showering – at home or elsewhere – and outsourcing laundry).

Thus an apparently simple behaviour (bathing or showering) with an apparently obvious single aim (getting clean) has been transformed by historical changes in multiple domains, to the extent that it is difficult to disentangle which changes came first: water infrastructural and technology; consumer expectations of the infrastructural and technology (e.g. to have constant water pressure); thinking about health, cleanliness and freshness – as perceived personally by the individual who is washing and in a social context; or commercial pressures linked to soap, shampoo, cleanliness, and the appearance of one's hair (Gram-Hanssen 2007, Hand *et al* 2005, Shove 2003).

The following chapter begins to make these links between needs, as mediated by behaviours, and how behaviours are linked by needs (i.e. more than one means of meeting the same need), creating a complex web of needs and behaviours that SES should recognise if they are to have wide or rapid acceptance. That discussion also looks at the role of higher level "purposes" for a home (such as having a healthy, comfortable life, maintaining cleanliness, or caring for a family), where needs and behaviours may appear to be indistinguishable.

Two examples of needs

Needs related to quality of life → Well-being → Being relaxed and comfortable at home

This is not just a functional need for thermal comfort in the home environment, but also includes other aspects of comfort such as the psychological comfort of a familiar setting that the person feels emotional attachment to, or the physical comfort of resting after a day of activity, or the relief of the stresses of the day as the person relaxes, or the enjoyment that comes from pursuing interests (e.g. watching television, reading, playing a musical instrument) when settled in a physically comfortable environment. This could entail, for example, having a warm room or lighting a fire just to create a cosy environment, or relaxing in a warm bath.

Social needs → Social interaction → Being a good host to visitors

When friends or family come to visit, there is a functional need for the home to be at a suitable temperature for the visitors to be comfortable. However, the householder may also be guided by a need to care for others (e.g. by ensuring the home is warm enough for visitors who are very young, elderly or in poor health, rather than the temperature the host personally prefers), or by the need to appear to themselves or others as someone who is thoughtful, considerate, generous (e.g. by not appearing mean with the use of heating), or environmentally-conscious or waste-averse (e.g. by not appearing wasteful with the use of heating). Being a good host could also entail opening windows to remove odours or avoid condensation, which would also have implications for heat energy if the heating is operating at the same time.

4. What do people do and why they do it?

RQ2. What do people currently do that uses energy?

RQ3. Why do consumers exhibit particular energy-using behaviours?

4.1. Introduction

This chapter brings together evidence to address RQ2 and RQ3, exploring *what* people currently do that uses energy (or avoids use of energy) in the home, and *why* they exhibit particular energy-using behaviours. It thus brings together the needs explored in RQ1 with the behaviours identified in RQ2: by making links of the form "behaviour x helps to fulfil need y", the need is now represented as a motive for the behaviour.

The question of why consumers exhibit particular energy-using behaviours applies whether or not the behaviour is a conscious choice or the person is aware of the energy impact or energy is an issue in the decision to act. For example, switching on an electric fire might obviously use energy but opening a window (on a cold day, if the heating is controlled by a thermostat) will indirectly use energy; a sedentary lifestyle (e.g. watching a lot of TV) may require higher room temperatures but less frequent washing of clothes; renovation may have an impact on energy use although carried out for other reasons.

Energy-using behaviours are diverse in character and the reasons for them are similarly diverse. Behaviours are not all equally amenable to change – in general or by a specific intervention. Neither do behaviours that are apparently related necessarily have the same implications for SES design. So however they are grouped or categorised, individual behaviours need to be understood. To present a structured review, the evidence has been framed by two factors: the domain and the frequency of the behaviour.

The domains of the behaviour are: putting heat into the home (space or water heating), keeping heat in, keeping the individual person warm, cooling and ventilation, and other behaviours that somehow relate to heat energy use. These domains are all interrelated – e.g. heating the space and heating the person are alternatives, people sometimes use water to get warm or cool down, and they use heating and hot water for a range of reasons, just as they use windows for various reasons. Nevertheless, a simple separation of domains is helpful in summarising the evidence.

Frequency of behaviour is considered under three categories. "Frequent" behaviours are those that may happen on a more-or-less daily basis, such as switching on an individual heater, turning a thermostat up for a day, overriding a hot water timer, having a shower or drawing curtains. "Occasional" behaviours are those that happen only a few times – or even only once – during a person's occupation of a home, such as installing a new boiler, heat pump or solar thermal system, insulating the home or making a conscious long-term change in habits or routines. "Infrequent" behaviours cover a wide range between these extremes, such as setting heating controls, servicing a boiler or switching to different season's clothing or bedding.

There is always some combination of behaviour and technology, even if the technology is a warm sweater, hence the two need to be considered together. First, the possible behaviours will depend on the technology that is available (e.g. whether there are heating timing controls) and the consumer's understanding of the technology. Furthermore, one piece of technology may allow several needs to be met and one need may be met by a combination of technologies. Additionally, the motivation for a behaviour can be connected to other events (e.g. purchase of new appliances) and linked to "trigger points" such as moving home, renovation of a property (for energy or stylistic reasons), changing jobs or starting a family (Ehrhardt-Martinez & Laitner undated, Hormazabal *et al* 2009, Southerton *et al* 2011). In fact, good insulation and double glazing are considered the norm when extending a home or converting a roof space (Brook Lyndhurst 2012).

As the frequency of a behaviour decreases, so the likelihood of it entailing acquisition of something (and therefore the cost) increases: frequent behaviours tend to involve some technology that is already present while occasional behaviours are almost certain to involve acquisition of technology. Such distinctions are important in behaviour change interventions: the most common behaviours taken up have been identified as: turning off lights or replacing traditional light bulbs with energy efficient light bulbs; reducing standby consumption and turning off appliances; and changes in water use (RAND Europe 2012). Fewer studies indicated some changes with regard to heating (lowering the thermostat or putting on an extra jumper) or cooling (turning up the air conditioning thermostat).

The frequency of a behaviour is also related to the resources or 'opportunity' (time and money) required to execute it but these are not fixed or objective – they may be perceived differently according to the amount of money and spare time a householder has, and the facilities available in the home. Turning down a thermostat should cost nothing if there is already a thermostat; it costs more if there is a central heating system without a (functional) thermostat or no central heating at all. A third key element of opportunity (space) is also relevant in some cases. The cost of installing a heat pump, for example, depends on the amount of land available, and the financial return on solar power depends on the size, pitch and orientation of the roof. A DECC study of UK willingness to take up more efficient heating systems found that home owners particularly wanted information about the space required inside and outside the property by any new heating systems before deciding whether to purchase (DECC 2013). Critically, it matters whether the householders own the space – i.e. whether they are owner occupiers.

Cost and time will also depend on the knowledge and skills of the householder. The cost of insulating a loft, for example, is higher if the householder is not physically able to do it him/herself (but paying someone else to do it will reduce the time demand). The time demand is greater if s/he has to learn how to do it, clear a lot of stored items out of the loft, then work at a slow pace to ensure everything is done correctly.

Distinctions between behaviours by frequency matter also because the implications for SES vary: frequency affects the amount of time and thought that a consumer is likely to give to the behaviour (e.g. whether it is a habit, routine or an extensively researched investment), which in turn affects whether an SES could easily change the behaviour or whether it would need to work within the confines of existing behaviour. Frequency therefore influences the kind of interaction the consumer would need to have with an SES and how it should be presented to the consumer in order to gain acceptance.

Frequent behaviours might be changed with little financial cost but might present a greater barrier to adoption of SES if they conflict with current behaviour in a way that requires repeated consumer actions until new routines are established. Occasional behaviours, on the other hand, are likely to be an integral part of adopting the solution, requiring action only once. Even so, adoption does not depend solely on rational cost-benefit evaluation: Claudy *et al* (2011), for example, identified barriers of the social risk of neighbours or other local residents reacting adversely, perceptions of the technology being difficult to operate, and market prices being higher than homeowners are willing to pay. Infrequent behaviours face different challenges because they might require repeated action by consumers but with insufficient frequency to establish new routines.

Potential ways of explaining behaviour include various aspects of the needs being met, along with people's awareness, knowledge, beliefs about how much energy they use (and whether this is high or low), experience of different thermal climates (in other countries or in different buildings or means of transport), habits, barriers and constraints. For example, someone may use gas central heating because it is "normal", trusted, affordable and understood. While attitudes are a good predictor of intentions to change energy-related behaviours, the sociostructural characteristics of the dwelling itself (particularly home size and family composition) are a better predictor of actions actually undertaken (Thøgersen & Gronhoj 2010). Similarly, positive attitude and intentions are not always translated into less consumption or lower expenditure (e.g. Raw & Ross 2011). So stated motives (rationale) for behaviour are a useful starting point but not definitive (although they can be useful in presenting proposed changes or new technology to consumers).

In non-domestic buildings, many of the behaviours discussed in this chapter are carried out (or not) by the organisation that occupies or owns the building rather than by individual building users, particularly where changes to building fabric or systems are involved. Motives for promoting energy-saving or low-carbon initiatives vary among buildings as a result of the diversity of businesses and organisations occupying them. Larger organisations tend to be better equipped to absorb infrastructure costs, more likely to appoint dedicated energy managers and more advanced in adopting low carbon management. Smaller organisations are often not primarily motivated by financial savings. Leading examples of SMEs with successful low carbon initiatives had made such changes on the basis of commitment to environmental sustainability, not profit or costs, although action taken did need to be at least cost-effective (Cox *et al* 2012). While it was found that large firms were generally more advanced than SMEs in adoption of environmental initiatives, the closer connection between many SMEs and the communities from which they and their customers were drawn gave further non-financial incentive to be seen to act in a pro-social or pro-environmental manner.

The level of control that individuals have over the technology is particularly important in non-domestic buildings. The amount of control will vary between building types and individual buildings, ranging from centrally-controlled systems managed by a Building Management System with no opportunity for local or individual control by occupants, to decentralised systems where equipment, temperature and ventilation can be controlled by individual occupants. Commonly, occupants will have some control over plug loads and lighting. The amount of control is likely to be higher generally in smaller premises. Facilities arrangements can influence normative (implicit) beliefs about a behaviour; for example, if access to a thermostat is difficult, occupants often assume that they are not supposed to interfere with the settings (Lo *et al* 2011).

The organisational nature of many non-domestic buildings, however, also provides an opportunity for behaviour change that does not exist in domestic buildings. The organisation can introduce policies or procedures that lead building occupants to perform behaviours that are desirable for the organisation. In practice, however, this is not so straightforward: in addition to the difficulties of shifting the behaviours or habits of large numbers of individuals, organisation-specific factors such as the structure of the organisation or its internal culture might form additional obstacles to (or opportunities for) behaviour change. There is some evidence that home energy behaviours are brought into the workplace (CSE 2012) but also that workplace behaviours tend not to transfer into the home (Littleford 2013).

There is further evidence that behaviour is context-specific in research examining pro-environmental behaviours among hotel guests. While normative motives are important in household settings, hedonic motives appear to be stronger in hotels, with the context influencing or inhibiting pro-environmental behaviours (Miao & Wei 2013). In the context of tourism, a 'holiday from responsibilities' may make transferring pro-environmental behaviours from the home into a new setting less likely (Barr *et al* 2010).

4.2. Space heating

The extent to which space heating is governed by frequent behaviours will depend to a large extent on the installed heating system and the associated controls. At one extreme, in the absence of timing or thermostatic controls, choices may be made daily or more frequently to turn individual heaters (e.g. gas fires) on, off, up or down, or manually open or close the valves on radiators. Controls, in addition to a sense of control, can help users meet needs related to saving money, avoiding waste, wellbeing, aesthetics, self-image and making life easier, while environmental motives are secondary (EST 2010).

Where there are timing and thermostatic controls (e.g. with a central heating system), adjustments should be less frequent, and this is often the case. But it is not uncommon for householders to use controls in other ways, either heating more-or-less constantly or making frequent manual adjustment, using timers or thermostats as on-off switches or using thermostats as though they are power controls (Ehrhardt-Martinez *et al* 2010, Hinton *et al* 2013, Peffer *et al* 2011). Mixed strategies also occur, such as using a timer to set minimum heating hours but frequently overriding the timer to get extra heating hours; half the participants in the ISMeT gas trial indicated that this was the primary control mechanism, even when a timer was fitted: there was a direct association between pressing the button and heat availability. A strategy is not necessarily fixed within a household but could vary with season, who is at home and how they make decisions about heating.

Space heating is therefore determined not simply by the desired temperature but also by the level of user control provided and the extent to which the users understand and are physically able to operate the heating system and controls. Difficulty in understanding and using controls is widespread (Combe *et al* 2011a,b). Householders also appear to strike some balance between energy use and a desire not to return to a cold home; for example, 52% of householders in one survey said they would leave the heating on if they went out for a few hours (DECC 2013).

The net effect is that the mere presence of controls does not signal how they will be used or the indoor environment that will be achieved. Using a thermostat tends to result in a slightly lower mean temperature (Kelly *et al* 2012) and offers a specific simple option for saving energy: at the end of E.ON's EDRP trial, 68% of participants reported they had turned the thermostat down and/or reduced the time the heating was on. But timing controls (or a programmable thermostat) may result in heating systems being on for longer (Shipworth *et al* 2010, Guerra-Santin & Itard 2010). Logically, the impact of installing a heating timer should depend on what the household did prior to the installation. If the heating was kept on all day with no thermostatic control, controls should reduce energy use. The opposite effect would be expected at the other extreme, where households previously put the heating on strictly when needed (when they feel cold). Heating is typically operated for about nine hours per day in the heating season (Martin & Watson 2006) so there is scope for heating hours to change in either direction. Controls are discussed further in Section 6.7.

In non-domestic buildings, occupants tend to have less actual or perceived control over heating and, as a result, thermal comfort is a major source of complaint (Lo *et al* 2011). Thermal comfort is generally higher in homes, with occupants of offices often having a low level of perceived control over the thermal environment, little interaction with thermostats and few other opportunities to adapt, e.g. by opening windows (Karjalainen 2009). However, occupants often find ways to compensate for inadequate facilities, e.g. by bringing in a heater or fan (Lo *et al* 2011). The increase in energy use can be justified by users as providing an environment in which they are productive (Littleford 2013). This effect is also seen in situations where the control of a service is not in the hands of an individual but of a group (such as in open-plan offices); sufficient means of control need to be provided to avoid such unsustainable behaviours (Leaman & Bordass 1999).

Maintenance of the heating system (e.g. boiler servicing) would count as an infrequent behaviour but with an understanding that it may never be done in some homes (with the effect that it is replaced by occasional repair or replacement).

But the main occasional behaviours would be major installations such as a new heat source (e.g. a boiler or heat pump) or complete heating system. Heating systems themselves are discussed in Section 6.12. Retrofit tends to happen in response to failure of the existing system or action by a landlord (particularly in social housing). Action by an owner-occupier is most likely to be as near as possible a like-for-like replacement. One common choice (between a system that stores hot water and a combi boiler) is often guided by the installer but could also reflect the user's balance of preferences in relation to hot water (a combi heats water as needed and should therefore waste less energy but can limit total flow rate through all outlets and is not compatible with solar thermal water heating).

A complication of heating behaviour is the "rebound effect", i.e. that thermal upgrade can fail to deliver the expected energy savings because some of the potential savings are converted to having warmer homes. This is not a behaviour as such but it is important, and discussed in Section 6.14.

4.3. Water heating

The majority of domestic water use involves heated water (Waterwise)[7] – both centrally heated water, supplied through outlets such as taps and showers, and water heated in appliances. Frequent behaviours that produce or use hot water are of four main types:

- managing hot water availability (e.g. manually timing hot water or overriding hot water timing settings);
- personal hygiene (e.g. full body wash by shower, bath or flannel; washing hair; shaving; brushing teeth);
- laundry (e.g. use and settings of washing machines; washing laundry by hand);
- food and drink (e.g. food washing, boiling water for drinks or cooking; washing up – by hand or machine).

Variations relate to the duration of showers, the depth of baths, whether dishwashers and washing machines are fully filled before use, temperature settings, how often people use items before washing them, and whether taps are turned off when the water is not being used (e.g. while face-washing). There is also scope for "outsourcing" in these areas, for example through showering outside the home (e.g. at a gym or workplace), laundry services (e.g. dry cleaners, launderettes, laundry collection and nappy cleaning services), take-away meals and dining out.

In their execution, these are frequent behaviours but there can also be infrequent or occasional changes in routines. Infrequent behaviours would include setting the timer on a boiler or the thermostat on a boiler or hot water vessel; servicing a boiler; using a dishwasher on special occasions only; or fixing a dripping tap.[8] Occasional behaviours would principally be installing a new boiler or solar thermal hot water system, new controls or insulation on a hot water vessel. The ability of householders to manage water heating and hot

[7] http://www.waterwise.org.uk/pages/at-home.html

[8] Myers (2010) found that 7% of homes had at least one dripping tap and 1% had more than one.

water will depend on the actual level of user control provided and the extent to which the users understand and are physically able to operate the controls.

Using a large representative survey in summer in southern England, Pullinger *et al* (2013) documented the incidence of various behaviours associated with hot water, and the reasons people gave for their practices. These may be summarised as follows.

Personal hygiene practices.

- While the bath might once have been the main means of whole-body washing, and the shower an extra feature, 88% of homes had a shower (29% a power shower) and 8% had no bath. Taking a bath, shower or both was an almost daily occurrence and only one in 20 said they have a bath or shower fewer than three times per week.[9] Over 50% never had a bath while only 17% never had a shower. Other forms of washing (e.g. a flannel) were unusual as alternatives to a bath or shower.
- The most common reasons given for washing were to get clean, freshen up, avoid smelling or smell nice. Others were to wake up (or prepare for sleep), get warm (or cool), get time to oneself or religious/cultural reasons. Baths were more likely than showers to be used to relax or ease aches and pains. Reasons for choosing a particular means of washing also related to which was quickest, safest or easiest. Contexts for washing related to getting home (e.g. after work, sport or traveling) or getting ready to go out.
- Nearly half vary their shower length, primarily for washing hair, shaving and the amount of time they have, but also others wanting to use the bathroom, the amount of hot water available, how cold it is in the bathroom, whether it is a working day and how long it takes for the water to run warm.[10] When taking a bath, people typically fill the bath about half way but only just enough to wash if bathing children.
- Almost a quarter (23%) sometimes shower outside the home (15% at a gym, 9% at the home of friends, family or partner and 4% at work).

Laundry practices.

- A washing machine was the dominant means (most commonly run two-three times per week). Only a third ever washed by hand, usually to preserve delicate items or because the label said to do so. Three-quarters never changed the settings on the washing machine. Myers (2010) reports that about half the respondents said they always washed a full load in the washing machine.
- There is substantial diversity in how often people use clothes and bed linen before washing them: typically only once for underwear, socks and sports clothes but more than five times for cardigans, jumpers and jackets. In general, the further the piece of clothing is from the skin (and perhaps from the nose) the more often it tends to be worn between washes but the greater the variation in number of times worn.[11] Over half the respondents would change clothes during the day (particularly on working days).
- Commonly cited reasons for washing clothes are that they look dirty, smell or need freshening, but often simply because they have been worn, suggesting influence from norms about washing rather than an item's actual state of cleanliness. Few attributed this to routine or habit.
- Respondents varied widely in the time of day or week that they do their washing and, for many, there was not a specific time – it was whenever it was convenient, or there was a lot to wash, or just "all the time". Few people base the timing on days when they are not at work (other than weekends), running out of clothes, having space to dry clothes, the weather or using cheap electricity at night.[12]
- It was common to use some laundry services outside the home, particularly dry cleaners, especially if there was not a washing machine in the home (which was only 6% of homes).

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[9] And water use for showers has been projected to double over 20 years (Critchley & Phipps 2007).

[10] Myers (2010) calculated the average time spent under the shower as just under 7 minutes (range 1-30 minutes).

[11] There may also be an effect of some items being harder to wash/dry but this is not the explanation the authors deduced from the data.

[12] The implication is that options for drying have relatively little influence on when washing is done. If households treat doing the laundry as an end-to-end process, rather than a set of individual steps, it would make sense to start washing when cheaper electricity is going to be available throughout, or when it will be good drying weather. However, other factors (e.g. when clean clothes are needed and when the household has time to do the laundry) appear to be more influential, meaning that the choice of means of drying is constrained by being at the end of the laundry process.

Kitchen practices.

- Of those with a dishwasher,[13] a third use it for most of their washing up and slightly fewer report a fairly equal mix between dishwasher and sink use, but almost a quarter rarely or never use the dishwasher. The timing and frequency of washing up varies substantially with dishwasher ownership and other factors.
- Outsourcing is common – while three-quarters of households prepared all, or nearly all, their meals in the home 12% make only about three-quarters at home, 9% half, and 6% a quarter.

This survey also notes the complexity of factors driving apparently simple choices. The frequency of using a washing machine, for example, depends on whether any washing is done by hand, how often (and over what period) a person wears items between washes, the number of items a person owns and whether these items require different washing machine settings, space to store dirty items, the capacity of the machine, personal acceptability of washing less than a full load, the number of people in the household, and whether they wash clothes independently or together. But there is also an energy cost to having more clothes, especially if they are replaced on the basis of age (of clothing or wearer) or fashion rather than when they wear out.

While these findings appear to offer many opportunities to design SES, change behaviour and reduce energy use for hot water, it also makes action risky because the ramifications of effects are difficult to predict. The common advice to save water and energy by using a shower rather than a bath, for example, has not been entirely successful. Greater use of showers has moved showering technology forward (e.g. the power shower and the waterfall shower) but in response to consumer demands other than conservation (e.g. relaxation, invigoration or needs related to social status). Also, people have been washing themselves more frequently and this may be related partly to the greater convenience of showering compared with bathing. As a result, water consumption has moved above the level previously due to having baths (Critchley & Phipps 2007). There may now be some reversal in this, with shorter showers being reported as the most common behavioural change to save water (Jordan 2012). Similarly, consideration of purely functional hygiene needs would not have predicted a move towards outdoor bathing ("hot tubs") but this potentially has important implications for energy use.

This complexity arises even before taking into account the variations in needs that underpin the behaviour. For example, someone might cite "refreshing" as the main reason for washing clothes but this does not necessarily mean that hanging clothes out in the sun would be accepted as an alternative.

As an area for action in relation to behavioural impacts on energy use, water heating may be (or become) more important that space heating. There are three key reasons for this.

- Water heating could be more open to interventions targeting peak power demand. For many uses of hot water, there is greater potential flexibility in when the water is used, less need for negotiation within the household, and hot water is also more easily stored than energy for space heating. What may be lacking is market penetration of the technology to manage the timing (indeed combi boilers do the opposite) and consumer confidence in an appliance not flooding or catching fire if unattended.
- As the efficiency of space heating improves, along with levels of insulation, the role of occupant behaviour in determining energy consumption is diminishing (Love 2012). In the case of water heating, there remain major variations in behaviour, some of which will be little mitigated by improvements in technology. In fact, changes in technology may have the opposite effect.
- Major water-using appliances are replaced more often than heating systems.

The greater uncertainty is over how much people will actually change behaviours that use hot water but, at the end of E.ON's EDRP trials, 73% of participants reported they had showers instead of baths and the same percentage filled the kettle less fully. Participants in the ISMeT gas trial identified "turning off hot water when not needed" as a way in which energy consumption could be reduced, and many realised for the first time that they could heat water without needing to have space heating at the same time. Householders' stated motives for water conservation reveal connections between water conservation and energy conservation: the most frequently reported have been to save money, help the environment or avoid waste (Jordan 2012, Myers 2010) but other common reasons included saving energy, reducing CO_2 and preventing climate change. The relative importance of saving money should logically depend on whether the household has a metered water supply, although energy costs are also relevant.

[13] This was 44% households, which is many more than the 28% quoted in the Market Transformation Programme (2008).

4.4. Stop heat escaping

Examples of frequent behaviours that would be included under this heading are closing windows or curtains, and placing a draught excluder at the base of doors. Infrequent behaviours parallel these, being the purchase of curtains or draught excluders. In contrast with the previous two categories of behaviour, however, the bulk of the evidence concerns occasional behaviours such as: insulating cavity or solid walls, lofts or roofs, and floors; installing new windows or doors (multiple glazing); draughtproofing the fabric of the building; and insulating hot water storage vessels or hot water pipes.

Occasional behaviours are particularly important for the efficiency of UK homes as such a large proportion of the housing stock was built prior to current standards for insulation and airtightness. While refurbishment of properties may have been carried out, this falls short of the standards required for newly built properties (Faiers *et al* 2007) and some simple retrofit has not been carried out at all. There is, nevertheless, an apparent willingness to insulate. The number of homes with cavity wall insulation in Great Britain more than tripled between 1995 and 2012; while almost a quarter of these are estimated to have been insulated at construction in new homes built since 1995, there is still clear evidence of uptake of this measure, and in 2012 at least 68% of homes suitable for the measure are estimated to have had cavity wall insulation installed (DECC 2012). The percentage of homes with at least 125 mm of loft insulation rose from 44% in 2008 to 65% in 2012 (DEC 2012). In EDRP surveys, 23% of customers had installed loft insulation or topped it up during the project and 34% of participants had fitted a hot water cylinder jacket.

This willingness is reduced if it will cause inconvenience (e.g. reducing loft space or having to clear out the loft) or affect the appearance of the building, especially if it is an older building or there is uncertainty about the performance of the insulation (Caird *et al* 2007, Farsi 2010). Consumers do have ideas about what would make insulation – specifically loft insulation – more attractive, such as thinner and less irritant insulation (Caird *et al* 2007). Some also mentioned that loft insulation helped to keep the home cooler in summer and wider understanding of this could lead to greater uptake.

In a Danish study, some renovations carried out by homeowners were for maintenance or improvement of the building fabric while others were to do with lifestyle, status and choice (Gram-Hanssen 2013a). For some occupants, the process of carrying out DIY projects led them to feel more attached to the home. For other occupants, however, maintenance or renovations were seen as a dull duty. Of the types of renovations carried out, 52% were of kitchens, 40% were of bathrooms, 32% included installing new windows, and 22% included installing a new roof. The authors state that figures for renovations in other European countries, including the UK, followed a similar pattern, with aspirational types of renovations including indoor aesthetics and functions prioritised over renovations to save heating energy: energy efficiency might have been an added benefit but energy renovation is not a main consideration in most decisions to renovate.

These findings are supported by research conducted for the ETI (Junemann 2012) into optimising the thermal efficiency of existing housing in the UK. This research found that most planned or recently completed (within the last three years) renovations were characterised by respondents as 'decoration' or 'general building work', while renovations that included energy efficiency improvements, such as installing double glazed windows or a new boiler, were often described as 'essential maintenance'. A lack of desire to carry out retrofit work was often accompanied by a lack of personal connection with the home. Furthermore, many respondents perceived that work had already been done to their home to make it energy efficient, with justification for this view focusing on the installation within recent years of loft insulation or replacement boilers. A lack of understanding of the possible renovations that could be carried out, then, limited the uptake of measures. This finding was supported by segmentation analysis that identified that those who could be characterised as 'early adopters' of technology aligned with those who were existing retrofit customers. This suggests that wider uptake of such measures could result if the technologies became more familiar with the wider population. Larger scale studies of motivations for and experiences of energy efficiency renovations and retrofit in the UK would address an important gap in the current literature.

4.5. Keep the person warm

Heating is not just about heating the space: insulating or heating individual persons is a highly energy-efficient strategy. This is achieved mainly through frequent behaviours (e.g. Hinton *et al* 2013) such as:

- putting on extra layers of clothing or extra blankets/duvets on the bed (or while seated during the day);

- using local heat from a radiant heater, hot water bottle, electric blanket or even a pet's body heat;
- putting clothes, towels or bedding over a radiator to warm them before use.

There is an overlap with hot water use, with hot drinks, showers and baths also providing heat direct to the person. Increasing metabolic rate (e.g. through exercise) would also be included but this does not appear to have been studied, perhaps because it tends to be incidental rather than deliberately to keep warm.

Infrequent or occasional behaviours would essentially be a changing in habit in relation to one of the frequent behaviours, either permanently or with the changing seasons, and possibly involving purchase of alternative clothing, bedding or means of warming. This might be combined with a decision to reduce the room temperature – 40% of participants in an EcoTeams study reported that they did this (GAP 2008).

Support for the further development of technologies and social practices encouraging these solutions (e.g. alternative clothing fabrics or changes in social expectations of dress) is important to emphasise, when much focus is placed on building fabric and systems.

4.6. Cooling and ventilation

Frequent behaviours for ventilation relate mostly to opening windows (Brundrett 1977, Davies & Davies 1987, Dick & Thomas 1951, Dubrul 1987, Erhorn 1988, Grey & Raw 1990, Ridley *et al* 2013) but also use of mechanical ventilation – these studies are the main sources for the evidence presented here.[14] Aside from ventilation and air conditioning, frequent behaviours to keep cool might include one or more of the following (Roaf *et al* 2005, Arup 2005, Hacker *et al* 2005):

- passive cooling, particularly closing curtains/shutters at windows with direct incident solar radiation (as it becomes too hot or in anticipation of overheating, e.g. before leaving for work in the morning);[15]
- reducing humidity with a dehumidifier or creating air movement with a fan;[16]
- reducing physical activity (including by sleeping) and/or clothing or bedding insulation;[17]
- having a cool shower or using cool sprays or cloths;
- turning off heat-producing appliances (e.g. cookers, washing machines, tumble driers) or using appliances that produce less incidental heat gain;
- leaving the home during the hottest part of the day (which could depend on the availability of a cool indoor or outdoor space) or using cooler parts of the home (e.g. north-facing rooms or lower floors).

None of these individually is likely to be sufficient on all occasions and most householders would not have sufficient knowledge to deduce the optimum strategy (even if the necessary technology is present). In fact, even where known, the optimum strategy may not be adopted. In a study of the first new London dwelling certified to the Passive House standard, occupants were found to use window blinds more frequently than predicted in winter (for privacy) and less frequently than predicted in summer (to enjoy the view out of the window). This resulted in higher energy use for space heating than expected in winter and higher indoor temperatures than predicted in summer. Despite this, occupants indicated an unwillingness to change their use of blinds and windows (Ridley *et al* 2013).

While the evidence is largely about frequent behaviours, some possible infrequent behaviours would have a facilitating role, through: hiring expensive items (e.g. stand-alone air conditioner); buying less expensive items (e.g. curtains, blinds, cooling fans, cool sprays, lighter clothing or bedding); improvement, installation or resetting of heating/cooling controls; and maintenance (e.g. servicing air conditioning; repairing/adjusting windows to make them more easily or securely openable, day and night).

[14] Studies of window opening typically treat windows as either open or closed, rather than having variable opening.

[15] Use of thermal mass is also relevant but consumers would generally not be conscious of this although it would be part of the reason for ventilating overnight to cool the building, for example.

[16] Except at extreme high temperatures, where air movement serves only to create a "fan oven" effect.

[17] The reasons for such behaviour are likely to be complex, being related to: culture (e.g. what is considered socially acceptable for reasons of decency or self-image); availability of alternative clothing; understanding of what clothing is good for keeping cool; physical/mental ability to change; sleeping during the day; habit or inertia.

Occasional behaviours would follow similar lines but involve more expensive purchases (e.g. external shading, mechanical ventilation, air conditioning or replacement windows that are more easily or securely openable or have reflective coatings) or action to eliminate external noise or air pollution, so that windows can be opened.

To some extent, the need for such actions arises from the traditional architecture in the UK being unsuited to warm climates. Requirements for increasingly high levels of insulation (especially internal insulation) in the absence of new provision for passive cooling tends to make this situation worse (Beizaee *et al* 2013, Firth & Wright 2008, Oikonomou *et al* 2012, Orme *et al* 2003): adding insulation to the inside of external walls reduces thermal mass and therefore increases the risk of overheating. This, in turn, makes it more likely that households will demand air conditioning, thus increasing long-term energy demand.

A common response to being too warm is to open windows or external doors, even if the heating is on (although the likelihood of this decreases in very cold weather). Windows tend to be opened during the day when it is hot, and increasingly as external temperature rises (Ridley *et al* 2013), but can also usefully be kept open at night to cool the fabric of the building. Another option is to open doors onto the cooler side of the home or the common parts of buildings (e.g. corridors, atria). In the latter case, there is a risk that common parts will actually be warmer than the home (e.g. because of hot water pipes or external glazing). Another option would be to close windows in spaces where air conditioning or the building characteristics keep the building cooler than the outdoor air; this should be uncommon in dwellings – both because air conditioning is uncommon and because it would require households to have a relatively sophisticated understanding.

Windows may be opened explicitly to reduce air temperature or humidity or increase air movement (especially in rooms facing the sun or where someone is busy with housework), but also to avoid condensation and mould, reduce indoor air pollution, “stuffiness” or odour (or “get fresh air”), talk to someone or hear what is happening outside, and habit (e.g. sleeping with the window open regardless of the weather) or preference for no particular reason. Equally important is when people want to open the windows or doors for cooling or ventilation but opt not to do so, for a wide range of reasons such as:

- external noise or air pollution/odours (most relevant if someone has respiratory or cardiovascular illness);
- the weather (e.g. wind, cold, rain, snow);
- concerns over security, privacy or the safety of young children or people with a confused mental state;
- keeping pets in or keeping animals/insects/pests out;
- practical/ergonomic difficulties in opening the window (e.g. jammed catches, the window being difficult to reach or there being no way of fixing the window in a narrowly open position).

There are clearly connections to noise, space/layout in the home, security, fear of crime, safety, local facilities and urban planning – not just the thermal provisions of buildings, occupant activities or clothing insulation. Given the many building, climatic and personal variables affecting window-opening, it is not surprising that there has been limited success in predictive modelling (e.g. Sorensen 2011, Valentinaa *et al* 2010). Conflicting pressures (to keep cool or save money) also apply to air conditioning: York & Kushler (2005) note that turning up the air-conditioning thermostat, and turning the system off altogether, are common ways to save money in demand-response programmes.

The ability of users to respond to raised temperatures will depend on the actual level of user control provided and the extent to which the users understand and are physically able to operate the controls, and this is perhaps why people prefer to have manual control over ventilation in their homes (Hormazabal *et al* 2009). Also, overheating can itself impair a person’s ability or motivation to engage in positively adaptive behaviour.

IEA Annex 8 (Dubrul 1987) was a substantial investigation of domestic ventilation behaviour in the UK and other temperate climates. It revealed three different patterns in different types of room.

- “Lived in” (i.e. living rooms), characterised by low constant window-opening at all times of day. Airings are kept to a minimum and the percentage of windows that are never opened is highest for these rooms.
- “Functional” (e.g. kitchens and bathrooms), characterised by frequent short-term ventilation on an “as needed” basis (e.g. when cooking).
- “Sleeping” rooms, where windows are opened three or four times more than in other rooms (increasing overnight with a peak in the morning). Variation between households is also greatest in these rooms.

A more focused survey of small new homes in winter in the UK (Grey & Raw 1990) found that windows are more likely to be used for cooling than other ventilation devices, bedroom windows were more likely to be opened during the day than at night, and security was the most common reason for keeping windows closed. There was little effect of socioeconomic and demographic variables but further analysis (Roys *et al* 1990) found that the reasons given for opening and closing windows varied with region: cold and draughts were more important in Scotland while a “preservation” factor (related to security, energy conservation and windy conditions) was more important in London (other parts of England were intermediate).

Having mechanical ventilation (MV) should mean there is less need to open windows but the evidence on what actually happens is mixed (Dubrul 1987, Lemaire & Trotignon 2000, van Dongen 1990). While some studies have found reduced window-opening where MV is in use, there also appears to be a preference to continue opening windows when they are not strictly necessary for ventilation. This could be related to habit, a greater sensation of freshness compared with MV or the air flow rates and air movement (in the room) achievable with MV not being sufficient for cooling. There is also evidence that householders do not understand systems and use MV for less time than design intentions or do not efficiently use “boost” or (in summer), heat exchanger bypass modes, or clean the systems (Guerra-Santin & Itard 2010, Lemaire & Trotignon 2000, Macintosh & Steemers 2005, Soldaat & Itard 2007).

In comparison with windows, trickle vents are poorly understood and tend not to be used effectively – they are generally left on one position (e.g. Hinton *et al* 2013). Building Regulations AD Part F on ventilation (ODPM 2006) specifies that trickle vents should be left open to provide background ventilation in occupied rooms in dwellings, being closed only when windy conditions produce draughts; however, to be effective this relies on occupants remembering to re-open trickle vents once the weather conditions have changed.

One aim of ventilation is to achieve good indoor air quality (IAQ) but there is a current trend of using chemical air fresheners to achieve the same aim. The implications for energy consumption, IAQ and health are uncertain.

While requirements for heat energy are being addressed through multiple policy interventions, together with downward pressure due to rising energy costs, there is relatively little action to reduce cooling demand. In fact, some “energy efficiency” retrofit measures (e.g. internal wall insulation), are truly only heating efficiency measures and they can increase the risk of overheating. A trend for smaller homes, closer together, with more people experiencing air conditioning in other contexts, and continued climate warming, creates concern that it is only a matter of time before there is widespread demand for air conditioning in homes (Boardman *et al* 2005, Defra 2009, GLA 2010, Metroeconomica 2006, Orme *et al* 2003, Pathan *et a*l 2008). It is critical, therefore, that any smart energy system should address passive cooling on an equal footing with heating.

Where air conditioning is installed in homes, evidence from the USA indicates that user behaviour is a major factor in energy demand (Kempton *et al* 1992, Yun & Steemers 2011) but there is limited evidence on user response to domestic air conditioning in the UK. A small-scale study by Pathan *et al* (2008) provides the following evidence on typical cooling patterns and occupant satisfaction.

- User satisfaction was higher for a split-unit system than for a portable unit, consistent with the actual power and efficiency of the equipment.
- Users reported better quality of sleep with cooling in bedrooms, no adverse health issues or noise disturbance and no purchases prompted by health issues.[18]
- Users stated that they would switch on the air conditioning when feeling hot, which measurements implied meant approximately 24-25°C, with switch-on temperatures only 1°C lower at night than during the day.[19] But thermostats were set at 18-25.5°C, with users setting a low temperature mistakenly hoping to achieve a more rapid temperature drop.
- Actual average night-time temperatures were significantly lower in bedrooms (20.3°C) than living rooms (24.6°C) and lower than the temperatures usually maintained in living rooms during the winter.

[18] Improved quality of sleep may arise because people sleep better in cooler conditions (or at least when the room is not overheated) or because the windows can be closed to keep out noise, or both. The evidence is not clear on this but it has implications for the effects of opening windows at night, which could make it cooler but noisier.

[19] This is consistent with a small-scale US study (Kempton *et al* 1992) in which most users relied on manual switching rather than thermostats, possible because of inconvenient and complicated controls that did not reflect users’ needs.

- On average, air conditioning was used for five hours during the day and throughout the night in bedrooms. The rooms usually cooled were living rooms, bedrooms, kitchen/dining and conservatories.

4.7. Other behaviours

This section discusses other behaviours that have been identified as related to heat energy but less directly. Frequent behaviours that would be included under this heading are:

- drying laundry (e.g. on a line, in a tumble dryer or over radiators);
- turning lights and appliances off when not in use;
- using daylight where possible;
- using light to create a mood of cosiness, instead of (or in addition to) heating;
- reducing energy wastage in refrigerators and freezers, and while cooking.

Infrequent behaviours largely parallel these frequent behaviours, examples being purchase of low-cost energy-saving items (e.g. powerstrips and adaptors to turn off multiple appliances, light bulbs, drying appliances); switching between indoor and outdoor drying with the season; switching more cooking to a microwave oven; and maintenance (e.g. cleaning light bulbs, fittings and air filters, and defrosting the freezer). Occasional behaviours entail changes in purchasing intentions (e.g. to buy only low-energy lights) or purchase of more expensive or long-lasting items such as major appliances, light fittings, outdoor lighting with solar power, photocells or motion detection, or a home with space for hanging out laundry to dry.

Frequent behaviours may be particularly amenable to change: Whitmarsh *et al* (2011), for example, cites evidence that consumers prefer changing lighting use over changing heating/washing to reduce energy demand. At the end of E.ON's EDRP trials, over 70% of participants said they now put lids on pans when cooking and used lights less. GAP (2008) reported that 52% of EcoTeams participants now switched off appliances at the wall when not in use, and 37% said that they had installed CFLs, which was also the main purchase reported by York & Kushler (2005) in demand-response programmes. A survey of UK attitudes and behaviours (Defra 2008) found that 62% of the population said that they already bought energy-efficient appliances, and 70% were willing to do so in the future.

But the current trend is not entirely positive in relation to energy demand. There is a widely documented increase in the number (and sometimes power) of domestic appliances, particularly information and communication technology, including technology for entertainment (Ehrhardt-Martinez *et al* 2010, Owen 2012, Raw & Ross 2011, Van Dam *et al* 2010). While most household white goods (e.g. washing machines, dishwashers, fridges, ovens, and electric hobs), lighting and ICT have become more energy-efficient over the past 20 years, increases in ownership, multiple purchasing of similar items (e.g. owning several TVs) and the extended use of appliances (or leaving on standby) have overtaken the efficiency increases (Maxwell *et al* 2011). Gram-Hanssen (2013b) found that household electricity consumption was strongly correlated with the number and use of appliances but not with their energy efficiency. As a result, overall electricity consumption per household for lighting and appliances has increased (EEA 2010, JRC/IE 2009). Similarly, in non-domestic buildings, ICT giving increased functionality, speed and greater capacity to print more (Schneidewind 2002) has led to an increase in printing volume.

Such changes in ownership of technology that is not intended to have a role in heating actually has implications for heating:

- incidental gains are increased;
- heating accounts for a decreasing proportion of total energy use;
- the same kind negative (for energy demand) consequences could arise in relation to new technology for heating, cooling and hot water.

Cooking with electricity rather than gas has health advantages (gas cooking causes emissions of water vapour and oxides of carbon and nitrogen), especially if the cooker is used as a heater. However, electric cooking tends to be perceived negatively because of the association with the lack of control offered by older electric hobs (Butler *et al* 2013). Quantitative evidence from a related survey (Demski *et al* 2013) backs this up: only 62% of respondents were willing to cook with electricity. When the survey proposed improvements, so that performance matched existing cookers, acceptance rose to 75% (82% if electric cooking was made cheaper).

In non-domestic buildings, research has identified patterns of behaviour that waste energy, including evidence of high levels of energy usage for lights and other equipment at times when the building is empty (Masoso & Grobler 2010) or when workers are away from their desks (Menezes *et al* 2011). Much of this energy use is caused by the omission of actions, including leaving lighting or blinds the way they are set rather than altering them according to conditions (Pigg *et al* 1996, Moore *et al* 2002, Boyce *et al* 2006, Hadi 2010). However, the use of energy for lighting and computers can also have alternative meanings, such as signalling an employee's presence in the office (CSE 2012, Littleford 2013) in the same way that leaving lights on at home can be intended to deter burglars. While this evidence is not specifically about heat energy, it does raise the possibility that similar issues arise with heat energy (e.g. not readjusting heating controls according to outdoor conditions or when leaving the office).

4.8. Overview

This chapter has categorised and described behaviours in a particular way, in order to present a structured review of the evidence. But it is clear that household behaviour does not fit into these neatly demarcated categories. Neither do the needs addressed by a behaviour map one-to-one. Drying laundry in a tumble drier, or cooking a meal, for example, contribute to heating the home. Having a shower can be to get clean, relax, warm up or cool down. Heating a room can be for personal comfort or to welcome guests or to avoid condensation and mould.

Additionally, this is suggestive of the different meanings and purposes that can attach to the idea of 'home': the use of energy in the home is not a purely functional matter, but one that is shaped by and also shapes the relationships and practices that occur within the home. In conceptualising at this higher level, the distinctions between needs and behaviours become less clear, and either can be characterised as "purposes of home", extending beyond energy-related behaviour. Figure 4.1 presents a simplified overview of these purposes of home to provide a perspective on the relationship between people's needs and behaviours. Even in this simplified form, with links drawn only between category headings, the complexity of these relationships can be seen in the complexity of the diagram.

Two examples of needs

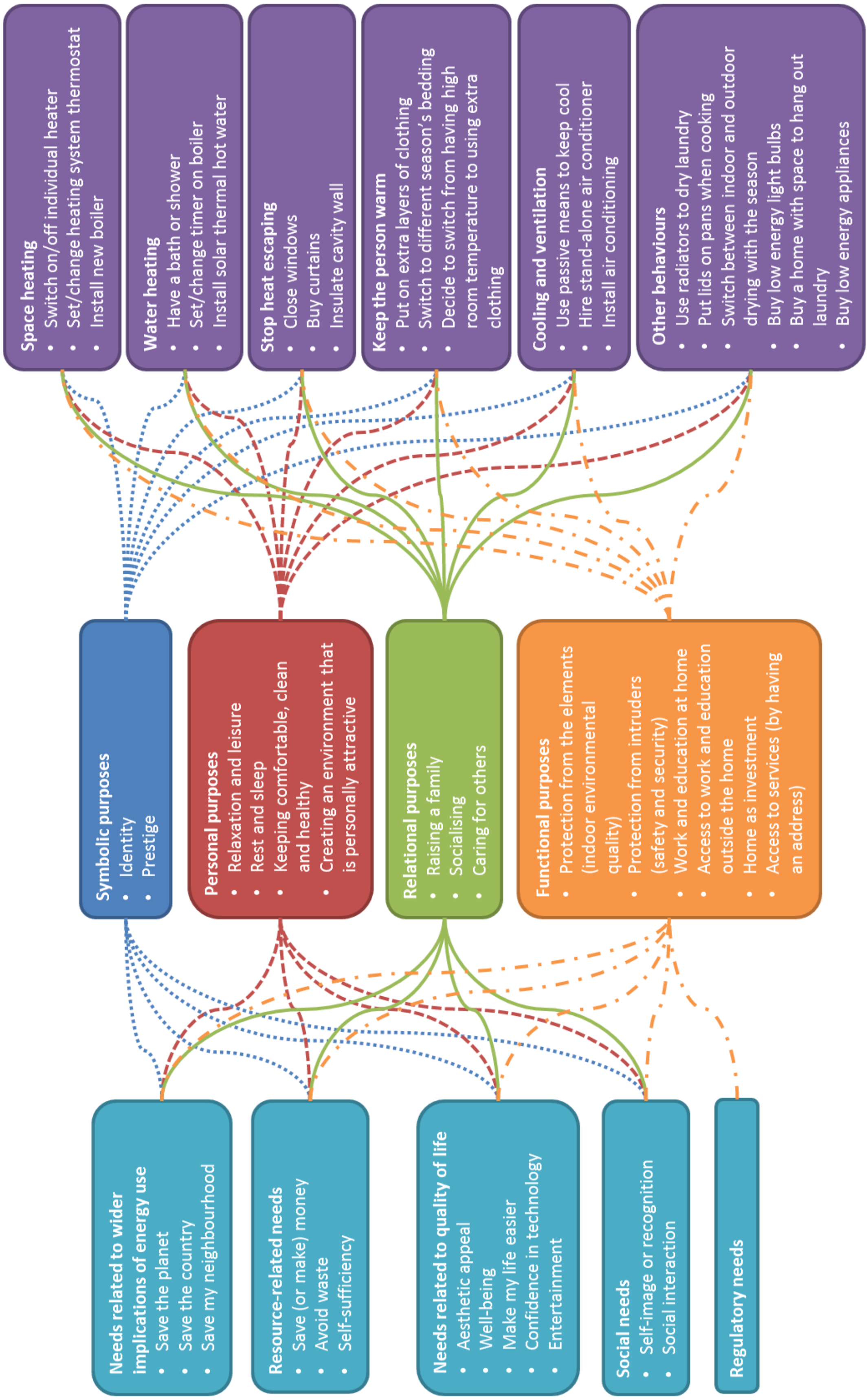
Needs related to quality of life → Well-being → Being relaxed and comfortable at home → Cuddling up on the sofa

The behaviours people perform can meet several needs at once. The need to be warm can be met by heating the home, but also by wearing extra clothing or by cuddling up on the sofa with a blanket. Some people find physical and psychological comfort from behaviours such as wrapping up to watch television, identifying this as self-indulgent and luxurious in a way that using heating may not be. This behaviour also relates to the need to save money: for some people, the cost of energy is a constraint, and tactics such as only heating one room or wrapping up in a blanket are ways to maximise comfort while minimising cost.

Social needs → Social interaction → Being a good host to visitors → Making the home suitable for visitors

Being a good host has symbolic and relational purposes as well as functional ones. Exact standards may differ from person to person but most people will want their home to be suitably warm, clean and tidy when visitors call. In addition to meeting visitors' physical needs, hosts are meeting their own social needs, interacting with others and presenting themselves to the world through their hospitality and the state of their home. The constraints of cost may cause tension with the importance of how others see the host: the need to be seen as generous and welcoming can conflict with the ability to afford as much heating as desired.

Figure 4.1 Connections between purposes, needs and behaviours



5. Differences across the population

RQ4: How do consumer needs, behaviour, motivation and rationale vary across the population?

5.1. Introduction

The previous two chapters have addressed the range of needs, behaviours and the motives and rationale that link them. All these can vary across the population, with implications for the requirements of SES. This chapter explores the evidence on that variation but the first point to make is that the overall impact of the variation is large. Energy use in domestic buildings can vary by 300% or more across similar properties, as a result of how the occupants use the building, even when factors such as number of occupants and floor area are accounted for (Socolow 1978, Gill *et al* 2010, Brook Lyndhurst 2012). Gram-Hanssen (2013a), using Danish household data, found that user behaviour is particularly important in relation to electricity consumption for lighting and appliances, which varies by a factor of five as a result of behaviour. In some cases at least, the occupants will also have chosen – even designed – the building or energy systems. So analysis that starts from effects of the building and systems misses a key aspect of variance due to users.

Demographic factors need to be considered alongside other factors, to account for the interaction of internal and external influences, including the technologies and behavioural processes themselves. We have therefore reviewed variation at three levels:

- individual (e.g. education, age, gender);
- household – either direct (e.g. tenure, household size and composition) or indirect (e.g. MOSAIC groups);
- community (e.g. affluence, social capital, coherence, support groups, urban/rural location).

These categories are not independent of each other; for example, the household composition has an influence on the type of property, which in turn influences the type of heating system installed in the property. And older people may live in smaller households, older homes and more coherent communities. Also, the level at which a characteristic is considered is defined largely by how the literature has reported it (e.g. income and social class might be individual characteristics but they tend to be reported at household level).

Each characteristic may exert its effect in different ways, or in ways that vary over time or across the population. The influence of some characteristics is structural, physically constraining the behaviours that can be performed (e.g. being in a rented property or not having a gas supply may prevent the household from upgrading a heating system). Other characteristics influence the individual or household's personal ability to perform a behaviour (e.g. through a lack of knowledge, time or financial resources), or the patterns of use established by individuals or households (e.g. families with high levels of occupancy of the home). Also, where research shows an association between a characteristic and a behaviour, this does not necessarily imply any causal relationship.

In addition to how population groups might be defined from the outside, groups may self-define in ways that have practical importance. For example, the EDRP review concluded that some interventions (e.g. web-based interventions) could be most effective with selected subsets of the population who are effective internet users and have an existing connection of some kind (e.g. working together or belonging to the same club).

While many potentially relevant population characteristics can be stated, the literature limits what factors we can actually refer to. For example, reports might give the age and gender of subjects but not household composition) and the literature tends to address observable characteristics rather than underlying needs, skills or knowledge. The most important factors might not have been researched (e.g. because they are less easily measured or less likely to be included as standard demographic variables).

Dwelling and energy system characteristics themselves will, of course, affect energy consumption. This is an important aspect of overall variation but can be treated largely from the perspective of building physics (which is not the subject of this review) and the behaviours that are facilitated (as discussed in Chapter 4).

Additional effects would be mediated by factors such as larger households tending to occupy larger homes and the quality of housing varying with age and income.

5.2. Individual characteristics

5.2.1. Education

The literature is fairly consistent that energy savings in response to interventions and take-up of energy-saving, load shifting or renewable measures are higher among more highly educated householders (EPRI 2009, European Commission 2006, Hirst & Goeltz 1982, Scott 1997, Wüstenhagen *et al* 2009). Some examples are higher educational levels being associated with: greater energy savings once an in-home display (IHD) has been acquired (Raw & Ross 2011); greater take-up of loft insulation, wall insulation, double glazing and PV panels (Brechling & Smith 1994, DECC 2012); and greater load-shifting at critical peaks (Faruqui & Sergici 2010).

These findings could arise from associations with higher income or baseline consumption. Higher education levels could also facilitate awareness of global issues (Defra 2009, Park *et al* 2001) or acquisition and comprehension of specific information on energy options. Boardman & Darby (2000) also found that people with low levels of numeracy and literacy communicate less effectively with smart systems, and could have a low opinion of their own ability to change anything and be less likely to trust others. Alternatively, there is a possible association between education and low discount rate – hence positive association with energy-saving measures with long pay-back; either of these would account for one of the few null findings: a lack of association between education and take-up of energy-efficient light bulbs, which have a short pay-back period (Wüstenhagen *et al* 2009).

Education could be of increasing relevance to uptake of SES, with an increasing proportion of the population undertaking higher levels of education (Vincent-Lancrin 2008, Wolfgang & Samir 2010). However, evidence concerning the effect of education may in fact be capturing partly the impact of other factors such as intellectual ability on energy-using behaviours. Since intelligence levels change only slowly, if at all, over time the impact of improving education on needs and behaviour in future would be less than if education were the key factor.

5.2.2. Age and gender[20]

There are several reasons for expecting age effects, including changes in thermoregulatory capacity (i.e. the ability to maintain core body temperature under different environmental conditions, which can decrease in old age and also depends on health),[21] personal preferences, dress, income and housing factors.

The actual evidence on age effects on energy use is mixed (EPRI 2009) and this appears to be due partly to a distinction between energy-saving in general and the use of technology (particularly for feedback). Where feedback is provided, there is evidence of more positive response by younger people (EPRI 2009, Raw & Ross 2011, Ipsos MORI 2012). In a demand-side response trial in the US, older participants responded less than average to a web portal and IHDs and more than average to a smart thermostat (Farrell 2011). Ehrhardt-Martinez *et al* (2010) note a trend to use online games and social networks to engage younger people, although this may just be assuming age differences.

In a wider context, older people have warmer homes (finances permitting), thus using more energy (Kelly *et al* 2012) but are more likely to save energy in other ways, generally (Barr *et al* 2005, Painter *et al* 1983, Ritchie *et al* 1981, Wüstenhagen 2009) and specifically through energy efficiency measures (Herring *et al* 2008) or renewable technology (DECC 2012). However, the actual age of "older" people is important: in the USA, Walsh (1989) found that older householders are less likely to make energy efficiency investments, especially for products with long lifetimes (Wüstenhagen 2009). Scope for load shifting should be greater in retirement but the evidence is lacking.

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[20] This section addresses age as an individual characteristic. The presence of children is covered in Section 5.3.6.

[21] Collins *et al* (1985).

Age may affect knowledge, attitudes and beliefs about energy efficiency measures, but the evidence is mixed. There is some evidence that younger groups have greater knowledge about energy efficiency and a greater propensity to explore alternative energy sources, but less concern, interest or capacity in relation to making actual changes (Barr *et al* 2005, CER 2012, Defra 2008, Hegedus & Temple 2011, Research Councils UK 2009, Wüstenhagen *et al* 2009). In a study of thermal comfort among older people in Wales, Burholt & Windle (2006) noted that the combination of poor housing stock, low income, sensitivity to the cold and more time spent indoors made elderly people particularly vulnerable to fuel poverty.

In the specific area of hot water use, Pullinger *et al* (2013) found substantial variation by age, with frequency of showering and bathing being higher in younger age groups. The proportion of respondents who wear the same clothes all day (thus potentially reducing demand for clothes washing) increased with age, rising sharply after retirement. There were also differences by gender in reasons for varying shower duration, with women more likely to vary shower length for washing their hair, men more likely to do so for shaving, and men also less likely to say they vary shower length.

The significance of age is likely to increase, with the share of the UK population age over 65 projected to grow from 10 million (17%) in 2010 to 19 million (24%) by 2050 (ONS 2011). However, the effect of this (aside from overall population growth) is uncertain because it will depend on whether tomorrow's population of elderly people matches todays in terms of technology awareness, disposable income, tenure, time spent at home (e.g. in retirement), attitudes to the environment and waste, and concern for future generations. It is unknown whether the age effect arises from individuals changing practices with age or from younger generations adopting different practices.

5.2.3. Environmental values

Faiers *et al* (2007) conclude that attitudes (including political orientation, environmental concern and perception that actions will have some effect) play a major role in households' energy behaviours. However, the role of environmental values and the direction of causation is often ambiguous: do people take action on energy because of their environmental values or do they change their values after taking action? Thøgersen & Gronhoj (2010) conclude that, while attitudes can predict intentions to change energy use, characteristics such as home size and household composition are better predictors of actions taken. Nevertheless, where values have been assessed, there is generally a positive association between pro-environmental values and energy conservation behaviour (EPRI 2009, Raw & Ross 2011).

5.3. Household characteristics

5.3.1. Energy consumption

Unsurprisingly, households that initially have the highest consumption tend to reduce consumption the most in response to interventions (Raw & Ross 2011, CER 2012) although this is not universally found (EPRI 2009). It is generally difficult to separate genuine effects from "regression to the mean".

5.3.2. Tenure

The key point here is that the landlord would pay for upgrading the building or appliances but the tenant would benefit from improved performance and/or reduced bills. Social landlords might be under obligation to undertake measures but private landlords are less likely to invest unless they anticipate being able to charge higher rents. While it might sometimes make financial sense for tenants to invest, this would depend on the payback period, contractual and expected length (and security) of tenancy and/or portability of items purchased (and tenants' understanding of these factors). It is also possible that tenants will have less sense of attachment to the home (or that people are more inclined to rent if they do not see home as a fixed place).

Whatever the reasons, the EDRP review found that home owners show more interest than tenants in purchasing an IHD, that investment is more likely when moving into a new home and that those who do invest tend to save most energy. Wüstenhagen *et al* (2009) also report that renters were less likely to adopt energy-saving technology, particularly if there is a large up-front cost.

Tenure is likely to be of continuing importance as housing remains split between rented and owner-occupied properties and major changes are not expected (Whitehead *et al* 2011)[22]. However, DECC's consultation on electricity demand reduction outlines a range of policy options to address split incentives between landlords and tenants. In addition, there are provisions in the Energy Act 2011 for minimum energy efficiency standards to be introduced for privately rented properties from 2018 (DECC 2012). This suggests that the differences in energy behaviour between renters and homeowners may decrease over time.

5.3.3. Income

Income, disposable income and income distribution in the UK would be expected to influence consumer purchasing decisions and perceptions of affordability. But the role of income is complex, with different aspects tending to push consumption or conservation in different directions (Borrell & Lane 2009, Wüstenhagen *et al* 2009, Carroll & Berger 2008, Cayla *et al* 2011, Defra 2008, Faiers *et al* 2007, White *et al* 2011, Whitmarsh *et al* 2011). Higher income households tend to be more likely to:

- live in better quality housing, requiring less energy per unit area to keep warm, but also in larger homes;
- depend less on electric heating and therefore require less expenditure for the heating energy supplied;
- have less motivation to reduce energy use to save money or improve the indoor environment but generally to hold pro-environmental attitudes;
- own their homes and therefore see investment in the home as worthwhile (DECC, 2012), have greater existing resources and/or opportunity for investment, and perceive investments as less risky;
- have a higher baseline of consumption, therefore greater scope to reduce consumption;
- have a higher turnover of appliances so that older, less efficient ones are more likely to be replaced.[23]

It is therefore unsurprising that the literature is inconsistent with regard to overall income effects on behaviours affecting energy demand and savings (e.g. EPRI 2009). The key distinction may be between behaviours that have little or no cost (which could play a more important role in lower income households) and those that require some investment, which are more likely in higher income households (Raw & Ross 2011). Hirsch *et al* (2011) estimated that 15% of households heated their homes above the estimated level of need, and that this percentage was similar across the income distribution (but the underlying factors could vary with some homes lacking control and others being overheated deliberately).

Frontier Economics & Sustainability First (2012) conclude that the limited evidence available (all from the USA) showed that low-income consumers did respond to economic incentives to shift demand from the peak period, although responsiveness tended to be smaller than the average response (Faruqui *et al* 2010). However, the evidence was mixed on whether their responses were smaller or no different from the average. In the ISMeT electricity trial, fuel poor households made savings in peak time consumption but not overall consumption. One trial in the USA (Farrell 2011) found that low-income participants shifted their demand away from peak hours less than average when provided with an IHD and a web portal where they could access a breakdown of their consumption. In contrast, they responded more than average to a smart thermostat that allowed them to automate their response to different tariff periods.

Frontier Economics & Sustainability First (2012) concluded that income effects on load shifting could be the result of:

- lower overall electricity usage (which may not apply in the UK where low-income households have higher electricity consumption than high income households on average);
- flatter initial load profiles as low-income consumers are more likely to be at home during the day;
- different housing standards and appliances;
- limited economic incentives to shift load for low-income households (e.g. this may be the case where low-income households receive a discount on their electricity bill);
- differing responses to automation and information provision.

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[22] This assumes that there is economic growth by 2018 and that the scale of social housing provision remains static.

[23] This might be interpreted positively but overall energy impact could be negative, taking into account embodied energy.

Income, as represented by UK GDP per person, is expected to grow at least until 2030 (OECD 2012, PricewaterhouseCoopers 2011) and energy demand is expected to rise as incomes rise (Hunt *et al* 2003). At the same time, costs of SES and other energy efficiency measures are expected to fall and should therefore become a lesser barrier to uptake; this could at least partly offset effects of income on energy demand. It is not clear whether the observed effects of income are the result of lower absolute incomes or a household's position in the income distribution (i.e. relative income). Projections are not available on future changes to the income distribution, but changes are plausible.

5.3.4. Cultural differences

Cultural differences between households can affect cooking and bathing practices and potentially encourage occupation of certain kinds of housing (e.g. choosing homes with two separate reception rooms to provide separate entertaining spaces for men and women). The different homes chosen could then shape energy use, for example through heating two rooms rather than one. However, Hormazabal *et al* (2009) caution against over-generalising.

5.3.5. Social class

Social class is complex, being related to income, employment, education, heritage and status. Prediction of social class effects is therefore difficult whereas *post hoc* rationalisation is perhaps too easy. CER (2012) found a trend for households headed by individuals of higher social grade to achieve greater electricity savings. This was in part related to the higher level of energy usage associated with these households. In contrast, in the gas trial there were trends for the percentage savings to be greatest in social group C1.

One survey found that protecting the environment was often given as a reason for reducing electricity, gas or car use by those in the highest two social classes, while those in the highest social class were less likely to have cut down on their electricity, gas or water use and those in the lowest social classes were more likely to give saving money as a reason for cutting down on car use (DfT 2002). Other evidence has already been noted: those with low levels of basic skills may be less likely to trust others (which was observed within 10% of those in socioeconomic group E) and have a low opinion of their own ability to change anything (Boardman & Darby 2000); and Herring *et al* (2008) found that older, middle socio-economic class consumers were more likely to take up energy efficiency measures.

5.3.6. Household size and composition

Household size (and the number and ages of children) is related to how many people are at home, for how much of the time, hence the number of rooms used (and heated) and windows opened (Fleury & Nicolas 1992). Unsurprisingly, energy consumption generally increases with household size, although consumption per person may decrease, demonstrating economies of scale in larger households (Druckman & Jackson 2008). However, a detailed UK study (Owen 2012), while based on a small, self-selected sample of owner-occupiers, found that one-person households used as much, and sometimes more, energy as typical families on particular appliances (especially for cooking and laundry). The implications of this are important, with single-person households running at over 29% in 2010 and expected to increase (DCLG 2010).

Nevertheless, in general, the value of investment in energy savings should also increase with household size because more people benefit, and Wüstenhagen *et al* (2009) note other possible reasons for larger households having a greater propensity to adopt energy-saving measures:

- the appliances of larger households would be expected to depreciate faster, inducing replacement;
- there are economies of scale in information acquisition concerning energy efficiency which is usually a constant cost irrespective of household size (Wüstenhagen *et al* 2009).

However, an alternative consideration is that larger households have more complex dynamics of decision-making, with less individual choice or responsibility, and shared cost, hence possibly a greater tendency to inertia. A UK-based cluster analysis of environmental behaviours found that committed environmentalists were more likely to live in smaller households (Barr *et al* 2005).

These conflicting pressures would account for the inconsistent evidence. One review (Raw & Ross 2011) found that, once an IHD has been acquired, higher subsequent energy savings are associated with larger households whereas the new data collected in this study showed a trend for smaller households to have a greater general propensity to save energy. Larger households have also been found to be more interested in having a smart meter (Ipsos MORI 2012). In the ISMeT electricity trial, savings (financial) increased with household size. Mountain (2007) found that smaller households in Newfoundland made greater savings in response to an IHD but the same effect was not seen in British Columbia. A US study found that larger households invest less in saving energy (Simpson-Housley & Drever 1984) and another US analysis found a negative impact of household size on energy-saving expenditure (Long 1993). Pullinger *et al* (2013) found that the frequency of running the washing machine increases (although gradually) with household size.

In relation to load shifting, EDRP found that smaller households (1-2 people) achieved a greater reduction than larger households in the percentage of consumption that occurred during the evening peak period in response to a time-of-use tariff. This is logical in terms of the relative ease of making decisions and lesser competition to access services (e.g. showers or cookers). Trials in California also found that smaller households were more responsive to incentives to shift load than larger households.

Household size is confounded with the age of household members, with larger households more likely to have children or teenagers. Households with teenagers have been found to have higher electricity consumption, after controlling for household size, and less success in reducing standby energy use, possibly because of social pressure to keep up-to-date with electronics (Gram-Hanssen *et al* 2004, Gram-Hanssen 2005, Gram-Hanssen & Gudbjerg 2006, Thøgersen & Gronhoj 2010). There were also practical issues in making reductions in standby usage, as many of the devices being used were interconnected but not in the same room; turning these devices off was therefore inconvenient, which acted as a deterrent to change.

The presence of younger children can also increase energy use, partly as a result of using the washing machine more, and a parent and child being at home during the day (Lockwood *et al* 2009). Families with small children in Ontario reported that it was difficult to reduce laundry use during peaks (IBM & eMeter Strategic Consulting 2007). Households with children also tend to have warmer homes (Kelly *et al* 2012). But the evidence is inconsistent: Herring *et al* (2008) found that the likelihood of adopting renewable energy systems was lower if children under 16 years live in the home but in the ISMeT electricity trial, households that included children (under 15) achieved greater savings overall and in peak hour. The authors suggest that this is because children played a significant role in motivating energy reduction, and that this is driven by school-based initiatives, consistent with the conclusions from EDRP. Alternatively, it may be that households with children have higher initial consumption and therefore greater capacity and motivation to change; this would be consistent with the finding that electricity savings increased with household size and that households with children made lower *percentage* gas savings.

5.3.7. Energy payment model

In the EDRP trials, there were mixed findings in relation to prepayment customers. Only SSE included prepayment smart meters (for electricity only) in its trial, with one trial group being given smart meters and an IHD. This group made savings similar to those in the credit customer groups. Scottish Power made more extensive investigations of prepayment customers without smart meters. These customers did not make savings under any interventions, even the financial incentives that brought about temporary reductions in demand in the credit customer groups. Nevertheless, some prepayment customers did meet their savings targets (arguably more consistently than credit customers).

Prepayment meters tend to be installed where customers are having difficulty paying energy bills, so they generally have lower consumption anyway (and this was certainly the case in the Scottish Power EDRP trial). Therefore they have less scope to reduce. However, they may be more practiced at monitoring consumption, more aware of costs and have greater (financial) motivation to save energy. With these counterbalancing factors, savings appear to be possible but not always achieved. Efforts to help prepayment customers reduce consumption might focus on means and opportunity, the motive already being present.

5.3.8. Generic demographic groups

The EDRP trials found some variations in energy consumption between demographic (MOSAIC) groups and postcodes although the form of analysis did not identify specific MOSAIC groups that had higher or lower than average consumption. The trials found no evidence of propensity to save energy in response to interventions varying with MOSAIC group.

5.4. Community characteristics

While there have been many community trials of energy savings (as discussed in Appendix D), there is relatively little evidence on differences between communities in energy use or propensity to change. Particular issues such as how to approach retrofit when communal measures are needed, for example in blocks of flats, could shape consumer responses and affect the suitability of interventions. A study of tenements in Scotland found that residents were unlikely to push for communal measures, even when they were free, because of perceived challenges in generating consensus or the risk of upsetting neighbours. As a result, many residents absorbed energy cost increases or reduced their use of energy rather than seek to improve the energy efficiency of their buildings (Consumer Futures 2013).

The evidence presented here is based mainly on urban-rural distinctions. Those who live in rural areas use more energy per person than those in urban locations, partly due to differences in dwelling type (Druckman *et al* 2008) and urban consumers may have a higher propensity to undertake energy-saving behaviours. Some studies have argued that environmental concern is higher in cities, whereas others have disputed this conclusion (Hegedus *et al* 2011) or reported opposite findings (Berenguer *et al* 2005).

There are several possible reasons for varying differences between urban and rural locations. Urban dwellers may tend to have avenues which make information gathering easier than rural households, reducing overall transaction costs (Wüstenhagen *et al* 2009). Larger cities (or the utility companies within them) tend to be more active in administering environmental policies which in turn can raise awareness (Wüstenhagen *et al* 2009). Living in a smaller city may give individuals a greater link to rural areas in terms of proximity which could contribute to a stronger awareness of measures that protect the environment (Wüstenhagen *et al* 2009). Energy security appears to be more salient to people in rural areas, who had experienced power cuts more regularly than those from urban areas (Butler *et al* 2013). While fuel poverty is prevalent in major cities, vulnerabilities also occur in rural areas, where a lack of access to the national gas network can force households to rely on more expensive alternatives such as oil (Foresight 2008).

5.5. Summary

A range of demographic factors are correlated with various aspects of energy use but this does not mean that behaviour now, or response to SES, can easily be predicted from demographic data: the findings have often been inconclusive or inconsistent (Faiers *et al* 2007). For example, Pullinger *et al* (2013) found some variation in hot water use with demographic factors (gender, age, working status, income, dwelling type, tenure, and household size and composition), health, disability and being socially or physically active, but these factors weakly predicted behaviour. Stated reasons for particular behaviour patterns, and personal environmental values, were also weak predictors. Medd & Shove (2006) also found that households with similar overall water use, near the national average, used water in very different ways. Waterwise (2011) conclude that approaches to customer segmentation focusing on attitudes, values, and socio-geo-demographic variables are fairly poor predictors of water usage. Neither does taking current energy consumption (rather than consumers' needs, behaviours or practices) as a starting point fare better: a detailed assessment of high and low gas users identified many reasons why energy use varies between homes but could not identify a coherent way of categorising homes as high or low users (Brook Lyndhurst 2012).

It seems that the chances of defining any simple and worthwhile predictive segmentation are remote. Allowing for the characteristics of other household members, and of course the available facilities, should explain further variance but also increase the complexity and the information necessary to assign a person or household to a segment. So tailoring and targeting interventions on the basis of prior assignment to a particular group may prove unworkable.

Instead, options for offers of SES could be decided on the basis of:

- individual offers that are likely to be suited to many groups of individuals or households;
- sets of offers, at least one of which should suit any given group of individuals or households;
- tailoring through interaction at the level of individual households, but with a knowledge of what the range of consumer groups will be, along with their likely dominant needs.

Thus, defining groups on the basis of clusters of needs is important because this can guide the development and deployment of SES. Using groups defined in this way, it may not be possible to assign each person or household to a group in advance; however, as stated above there seems to be little value in groups to which cases can easily be assigned. The focus should therefore be on developing and deploying a range of SES that, collectively, address the needs and behaviours of all identified groups. Deciding the best solution for a particular person or household would most likely start from the dwelling characteristics. In a research context, demographically based stratification could nevertheless be useful in ensuring that a wide range of relevant characteristics are represented in a sample.

Two examples of needs

Needs related to quality of life → Well-being → Being relaxed and comfortable at home

Differences across the population can lead to different definitions of 'comfortable', which in turn may affect the amount of heat energy required and how this is achieved. For those who are elderly or in poor health, a lower tolerance for the cold and a more sedentary lifestyle may result in comfort being reached only at a higher temperature, but blankets on the sofa and heating only one room may be a manageable solution. Families with young children may put the comfort of the children above that of adults in the household, and may need to heat more rooms in the house and at different times to ensure the comfort needs are met. Constraints caused by lower incomes or by rented rather than owner-occupied homes may lead different households to different solutions.

Social needs → Social interaction → Being a good host to visitors

Visitors may change the usual make-up of the household and so change responses within the household. Elderly visitors may lead to an increase in the temperature that the home is heated to; visitors with young children may lead to a change in the number of rooms that are heated or the times at which heating (or the heating of water) occurs. Additionally, the level of education or social class of the household may trigger different responses: more educated households, or households from higher socio-economic groups, may be more likely to invest in new technology and, in the case of visible technologies such as solar hot water panels, this may be an extension of the need to have a desirable home that will be admired by others.

6. Consumer response to smart energy systems and the design implications

RQ7. What is the likely consumer response to potential smart energy system solutions?

RQ8. How can smart systems meet current and future needs?

6.1. Introduction

This chapter addresses two Research Questions because they reflect two closely tied aspects of SES, i.e. how people respond to an SES (RQ7) will depend on the solution characteristics and this therefore informs what characteristics solutions should have (RQ8). The chapter therefore brings together three issues: the SES itself, consumer response to the SES and indicators for the best design characteristics of an SES.

An SES is defined here as a system of technologies combined with social interaction. The technologies might include elements that themselves could be called smart, together with simple elements such as insulation or written advice; the whole solution would then be "smart" and a key aspect would be how the elements are integrated. The whole package could combine elements aimed primarily at energy use with other elements as part of a larger smart control system (e.g. providing communication or security). The social interaction elements relate to how the solutions might be presented and facilitated: whatever is put in place to either promote or support the smart system and the service that it aims to provide. This could include, for example: general and personalised consumer engagement strategies, communications and education; logistics, implementation strategies and delivery processes; personal and household social networks; and financial mechanisms and policy instruments.

Response to an SES refers to how consumers respond to a particular SES aimed at meeting unmet needs or meeting needs in a different way. Response is not just about changes in energy use (although this is important in itself and also a useful indicator of other aspects of response). Both behaviour change and energy savings have been studied as responses but not so much the connection between them (or the initial facilities or behaviour). However, in principle, the following aspects of response (and their negative alternatives) may be distinguished.

- *Accepting the SES*. The meaning of "accepting" depends on the SES – it could mean the consumer buying something, accepting a free offer, using a purchase or loan subsidy, or accepting the SES as part of a package such as house purchase or rental. Included here would be everything from taking an initial interest, evaluating offers, acquisition, to having the SES in place. Evaluation of offers would depend on the needs being addressed – it could focus on price, payback, revenue or non-financial issues.
- *Retaining and using the SES*. These aspects of response are interdependent: clearly the SES cannot be used unless it is kept, but also it may not be kept if it does not get used (or prove useful).
- *Using the SES to good effect*. This might be defined in terms of either the design aims or the consumer's personal aims. Personal aims may be identical to the design aims or a subset (e.g. design aim = reducing energy demand and saving money; consumer aim = saving money) or different (e.g. being warmer). The consumer's decisions on future use of the SES (or another SES) are more likely to depend on whether personal aims are met, although meeting design aims could also have some influence.
- *Passing it on.* Any or all of the above responses could affect the extent to which the consumer promotes the SES to other people, either passively (by not speaking negatively about it), responsively (if asked) or proactively. This in turn could affect wider response in the consumer's household or community. For example, satisfaction with the results of retrofit has been identified as a good way to encourage other households to carry out such renovations (Consumer Focus Scotland 2013).

Each of these aspects of response can be expected to have different determinants. In characterising response, account also needs to be taken of whether the behaviours involved in the response are purely one-off decisions about acquisition or there are ongoing implications for intentional or habitual behaviours.

Response to SES in non-domestic buildings may have similar features to those seen in domestic buildings, but with the important difference that adoption of an SES would require buy-in from the building's owner and (if different) the occupier; in the case of buildings occupied by larger organisations, this includes buy-in at policy or strategic level as well as by building or energy managers at implementation level. Some new technology may be used only by these groups, with employees or customers using the building unaware of the technology. For other technologies, the behavioural response of building occupants to feedback given by the SES may be important. In buildings occupied by smaller organisations, response to an SES may more closely reflect that found in domestic settings. The types of technology adopted by larger organisations may also be different, reflecting the different nature of the buildings they occupy, which may be more suited to automation or control by Building Management Systems. Where the organisation aims to change workplace behaviour, combinations of intervention types, for example including technology change, information and advice, and feedback on historic or real-time energy usage, have been most successful (CSE 2012).

RQ8 refers not to specific technological or social solutions but to the solution characteristics, i.e. the characteristics that solutions should (or should not) have if they are likely to be successful (now and in the future). These characteristics might, for example, relate to: core functions; simplicity/ease/disruption of installation or use; consumer engagement; cost and financial offering; technological complexity and attractiveness; maintenance, reliability and performance; service model and source. Thought also needs to be given to the values that the technology represents, not just the functional aspects of the technology, e.g. the positive connotations of renewable energy (Demski *et al* 2013).

RQ8 may be seen as the culmination of CRaB – taking the evidence collected in relation to the other RQs and providing guidance on key requirements for the design and deployment of SES from a consumer perspective. It is therefore a key link to the wider SSH Programme.

This chapter is written from a perspective of the current situation but consumer response to SES in general could change over years or decades, depending on a range of factors. The wider implications of energy use in particular could become more or less salient, depending on the strength and direction of policy at local, UK and EU level – partly through enhancing a culture of concern over energy and carbon, and partly through policy action (e.g. through regulation, standards, investment and research) validating evidence on both the wider implications and the effectiveness of solutions. Policy action (along with other factors including media coverage) would also influence energy prices and the availability, ease of access, cost and quality of technology in ways that would profoundly alter consumer response.

Conversely, some authors have identified the absence of action taken by local, national and international governments as creating a lack of trust between consumers and Government in promoting energy efficiency and renewable energy (Spence & Pidgeon 2009). This lack of trust has been exacerbated, for example, by the Government's feed-in tariff policy, with the level of tariff being significantly reduced because the Government had not expected the high level of uptake.

The locus of policy action may be critical, with greater resources being available at EU level but greater awareness of local priorities and possibilities at the level of local government. In a survey conducted by the European Commission, 66% of respondents in the UK believed that energy issues should be dealt with by the national government, compared with only 8% of respondents who felt it should be addressed at a local level, strengthening the notion that the public expects the national government to take initiative and provide leadership. Overall, the majority of people across those interviewed felt that governments should promote energy efficiency. In terms of new measures to help reduce consumption, 46% thought the government should provide more information on how to use energy efficiently, while 37% said the government should adopt higher efficiency standards for energy-consuming equipment (European Commission 2006).

A shift towards local policy responsibility is already evident within the UK and it is possible that some consumers respond more to locally driven initiatives than national or EU policies, since the local policy approach can often be more integrated, holistic and faster to react. If it is more flexible or specific to a local area, the more likely it is that the policy will succeed. Examples of local policies can be seen in the Woking Corporate Energy Efficiency Strategy (Gardner *et al* 2009) and London's 'Low Carbon Zones'.

A key aspect of policy is the regulation of energy markets and any focus on specific regulatory goals, which could change over time. This would affect a range of factors that are relevant to consumers, such as energy prices and tariff types, energy security, switching tariffs and suppliers, the roll-out of smart meters, consumption data sharing, the services offered by energy suppliers (those related to energy use, such as technology sales or contracts for providing heat, and those not, such as telecommunications) and consumer obligations on the energy industry (in general and in relation to fuel poverty).

Similarly, changing costs of technology for SES would be expected to affect consumer response – absolute prices, prices relative to conventional alternatives, and the associated cost structures (e.g. capital costs relative to running costs, grants, subsidies and taxes). There are expected to be significant reductions in the costs of low-carbon technologies according to DECC's 2050 pathways model[24].

Balancing a possible rise in incomes and fall in the price of SES technology, energy prices are projected to rise in real terms between now and 2050, although there are also scenarios in which prices could fall (DECC 2012). Rising prices (including any taxes) could influence consumers via the potential financial savings from making changes that reduce energy use; shifting load from peak periods; or shifting towards to low-carbon or low-cost energy sources (Wüstenhagen *et al* 2009, Hunt *et al* 2003). Historically, this occurred during the 1970s oil crisis but consumer response would depend on the extent to which they are "locked in" to a particular technology (e.g. energy demand trended downwards over the decade 2000-09, when there were large increases in gas prices, but consumers stayed with gas central heating). Heiskanen *et al* (2009) also refer to an alternative effect, where consumers reduce energy demand and this results in them becoming more willing to support policies increasing energy costs.

6.2. Energy efficiency advice

Advice is an essential element of the *means* of response: if people do not know what to do or how to do it, it is unlikely they will do it. But advice is not enough: it can support *motive* (e.g. by suggesting motives or setting goals) and/or help to create *opportunity* (by facilitating access to the SES that the advice relates to), but these elements tend to come mainly from other sources. The success of advice is therefore, logically, dependent on motive and opportunity being either already present or separately provided.

Delivery of advice can vary in level, medium and combination with other interventions; there is no reason why each approach should be equally successful in general or with particular individuals or groups. At one level, there are awareness campaigns and generic advice, distributed to consumers without knowledge of their particular circumstances. This could be called "information" rather than advice. At the other extreme would be a thorough audit of a household and home, followed by detailed advice and support to undertake the most relevant actions. Advice can take the form of comprehensive guides or simple, specific prompts, located in relevant positions (e.g. signs at exits saying "Turn off lights when leaving"), occasional "tips" of persistent relevance (e.g. draw the curtains to keep heat in), explanatory justifications for particular behaviours (e.g. reduce electricity use in peak time to reduce the need for new power stations), and instructions for how to do something (in general or in instructions for specific devices).

On their own, energy awareness campaigns and generic advice typically increase knowledge, and can change attitudes, but have little effect on behaviour: they *support* but do not *deliver* reductions in energy demand. In combination with other interventions (e.g. thermal retrofit or enhanced consumption feedback), generic advice appears to become more relevant (and used), resulting in energy savings of up to 5% (Raw & Ross 2011, CER 2012). Savings can be greater when external factors independently motivate consumers to reduce demand, for example when particularly cold weather raises concerns about energy bills or when there are interruptions to fuel supply (Carroll & Berger 2008).

Tailored energy audits have led to reductions in energy consumption (Boardman & Darby 2000). These audits are typically offered on an opt-in basis and are combined with additional support including access to resources or retrofit opportunities. They are targeted, intensive interventions. Where it is not feasible to give personal verbal advice, delivering advice by means more imaginative than leaflets and booklets may achieve higher savings – for example, using acted scenarios or providing written advice in conjunction with home energy audits.

Advice can also be delivered in the form of product performance labels, for individual appliances and electronics, as well as whole homes through the Energy Performance Certificate (EPC) or Code for Sustainable Homes. There is evidence that good EPC ratings for homes are associated with increases in home values of between 6% and 14% (DECC 2013), as discussed in Section 3.3.2. Mandatory and voluntary

[24] Available at http://2050-calculator-tool-wiki.decc.gov.uk/uploaded_files/8.

labelling can have an important influence on consumer behaviour if it is easy to understand and provides a simple way to identify energy-efficient products or homes. Default options implied by labels are powerful tools because, when consumers feel overwhelmed by choice or unable to make informed decisions, they will often assume that the default is preferable. A bigger effect of performance labels could be the ability to prepare to regulate or otherwise take the least efficient items off the market entirely, as happened with boilers.

In most cases, consumers find information about a product's energy use easily, but have more difficulty finding running costs – the EU energy label does not give running costs in monetary terms despite this being the main reason consumers use the energy label when making their purchase.[25] Even more useful might be the additional running costs relative to appliances with the highest rating.

Regarding SES characteristics, the following can be said (Raw & Ross 2011).

- Response to SES should be more positive, and result in greater energy savings, where well constructed and presented advice is used to support other aspects of the solution. Information needs to be clear and easily seen amongst other material sent to consumers. Verbal advice may be more effective than written advice, and tailored advice with clear actionable steps is likely to have a greater impact than generic advice: energy audits with follow-up advice and access to resources tend to be most effective.
- It can be useful for consumers to have comprehensive reference material (particularly to show what appliances are high users of energy) but simple, actionable, individual messages that inform, support and encourage may be more effective.
- Specificity is good: even when householders see no general scope to reduce consumption, they may agree with specific propositions for reducing consumption (e.g. using a timer or thermostat, increasing insulation or not using radiators to dry clothes in summer).
- The credibility of advice can be undermined if it carries risks (e.g. draughtproofing, regardless of potential condensation or build-up of toxic combustion gases) or its effectiveness is uncertain.
- Timing is important: many consumers do not read or absorb written advice unless it is relevant to them at the time they receive it. But advice may be discounted if it is seen as "common sense" or "nothing new". So a balance needs to be struck between frequent repetition of messages and keeping the message fresh. Matching advice to the season and/or location could also make it more relevant. It also needs to be kept up to date as the options for action change (e.g. because of new technology or incentives).

6.3. Historic feedback

Feedback tells consumers how much energy they have been using (and, ideally, when and how they have been using it). The standard quarterly billing procedure (often including estimates) or monthly identical payments (based on estimated consumption) do not give high grade feedback. Historic feedback means access to past consumption data (where the past could be yesterday or last year). There are many permutations of how such feedback may be provided – it can vary in frequency, duration, immediacy, content (kWh, cost, etc.), breakdown (by time, space and appliance), aesthetics, simplicity of access or use, and combination with other instruments. It may be delivered on paper or electronically (e.g. via the web, mobile phone or TV). IHDs also normally offer historic feedback.

Historic feedback, together with transparency over energy costs and tariffs (Wüstenhagen *et al* 2009, Stromback *et al* 2011) serves mainly to enhance *motive* by raising consumers' awareness of energy use and perhaps indirectly by improving relationships with suppliers. Consumers can also use feedback to provide the *means*, i.e. to understand the impact of technical or behavioural changes but this depends on having sufficient existing knowledge and motivation, in addition to time (even if only a little time is needed).

Real-time feedback is discussed later. The distinction is important because, although there is a general finding that households take a positive view of feedback, it matters how detailed it is and how closely linked to specific actions, in time and in level of disaggregation. Logically, historic feedback (e.g. quarterly consumption) is more relevant to one-off changes that have a persistent impact, such as installing insulation or upgrading a heating system. Real-time feedback is more relevant to routine behaviour and purchases of

[25] http://ec.europa.eu/environment/enveco/pdf/RealWorld_Briefing5WhiteGoods.pdf

equipment used intermittently (e.g. washing machines, televisions). By extension, historic feedback may be more relevant to the fuel used for heating (most often gas) and real-time feedback to electricity.

The assumption has often been that feedback allows consumers to make better informed choices and that they will therefore choose to use less energy. However, they may instead decide that the energy costs are so low that it is not worth the effort to reduce consumption, or even see that the cost is so low that it is OK to use more energy. Add to this the fact that people may be unfamiliar with energy data and unsure what to do with it, and the uncertainty of impact increases. Furthermore, there are likely to be people who already think that energy costs too much and therefore perceive enhanced billing information as unwelcome.

Few past studies have quantified the effect of feedback via enhanced routine billing in isolation. This is logical from the perspective that billing in itself does not provide a complete *means-motive-opportunity* package. There is some evidence of effects of enhanced billing that includes historic comparisons with current period consumption: savings of 2-3% are possible (Fischer 2008, Raw & Ross 2011), and shifting load from peak periods (eMeter Strategic Consulting 2010). However, effectiveness depends on the details of the feedback, the match to what customers want and understand, and their motivation to use new information. Similarly, monthly or less frequent feedback through other routes has led to sustained energy savings of 2-3% but evidence is limited and not all studies show effects. Where there are energy savings, these tend to be achieved through changes in behaviour with current technology rather than new investments, although people who invest also tend to save the most energy (Ehrhardt-Martinez *et al* 2010).

The general lack of impact may be attributed at least in part to the feedback not being seen or read. In SSE's EDRP trial, only around one in three recipients said that they had seen any different information on their bills or that it made them think about energy use. However, those who looked at the information tended to say it had been useful. If they also had an IHD, again about one in three thought the bill information added to the visual display because either it was easier to read or it was possible to sit and study it, and a similar proportion thought the bill reinforced the display information.

Trials of more frequent feedback have found greater savings but this is more resource-intensive and effects may not be persistent where feedback is sustained for periods beyond limited experimental trials. While it may be impractical through the billing system, it could become feasible to offer more frequent feedback with wider use of smart meters and households having online access to their consumption data.

Regardless of its impact on behaviour, accurate historic feedback has been found to improve householders' sense of control over their energy costs and produced high levels of satisfaction among consumers (Garay & Lindholm 1995). In SSE's EDRP trial, some households received additional bill data (graphs on bills); 38% said that the graphs made them think about energy use and having this additional information nearly doubled the percentage who rated the information on electricity statements "in helping you to reduce your energy consumption" as "quite" or "very" useful (from 34% to 60%). This suggests that accurate historic feedback is likely to be welcomed by consumers and could therefore help facilitate other SES elements. Historic feedback can be useful but the details of delivery, and combination with other interventions, are critical. There are significant barriers to be overcome in delivering information with bills in such a way that customers notice, read, understand and apply the information. The following guidance on SES characteristics is drawn mainly from CER (2012), Fischer (2008) and Raw & Ross (2011).

- If feedback is provided more frequently than monthly, it can be more effective but there is a risk of consumer fatigue, which might be addressed by delivering feedback in intermittent spurts (e.g. daily for four weeks each year, or weekly for four months each year).
- Although enhanced billing information may be the least effective means of providing historic feedback, it has low cost and so may be the most cost-effective method at a population level.
- General usage and cost information are rated more highly than energy units (kW hours or m^3 of gas).
- The format of historic feedback needs to balance the needs of consumers looking for detailed information, data and interpretability and those more concerned with the aesthetics, simplicity and immediacy of impact – providing adequate information without overwhelming the consumer.
- Daily consumption over weekdays may not show enough variation to warrant each day being displayed; contrast between weekdays, Saturday and Sunday may be more important.
- Feedback should be: based on actual consumption, given frequently over a long period, involve interaction and choice for the household, and break down energy use by appliance.

6.4. Benchmarking consumption

Benchmarking consumption adds to historic feedback by showing consumers how their energy use compares with that of comparable households. It could in principle also be incorporated into real-time feedback. Such comparative feedback may provoke competition, social comparison or peer pressure, thus emphasising social *motive* but leaving scope for environmental and financial motive. A valid comparison group of households with similar composition, dwelling, climate, etc. is difficult to achieve (especially with the limited data available to energy suppliers). This is sufficiently obvious that customers may doubt the validity of their comparison group (perhaps more so for gas because it depends more on the home and household).

There is limited evidence on benchmarking in isolation because it is typically combined with other interventions. One US study of students in university accommodation (Peschiera *et al* 2010) found that, while individual feedback alone did not result in a significant reduction in electricity use, a significant change was achieved in the groups where this individual feedback was combined with comparative information on the consumption of neighbours and peers. In UK homes, electricity savings of 1% have been found (Raw & Ross 2011) but one study (Dolan & Metcalf 2011) stands out as achieving gas savings of 9%. Combining benchmarking with historic feedback and advice (partially tailored to the household) has consistently been found to result in 1-3% reductions in energy demand, mainly in American trials (RAND Europe 2012).

People tend to place normative information low on their list of what they believe influences their behaviour, which could lead to a tendency to ignore it. Effects are also dependent on households' positions relative to the benchmark: whereas high and medium consumers may reduce their consumption, low consumers may increase theirs. There is evidence that such negative impact may be overcome by use of simple normative messages or even minor changes such as the inclusion of "smiley" icons with low users' bills.

There is no clear evidence of how to use benchmarking to obtain the best consumer response and deliver net energy savings. However, Dolan & Metcalf (2011) suggested potential reasons for why they achieved higher savings than similar American trials (other than the possible nationality effects), i.e. in the UK:

- the participants were typically poor, living in social housing;
- the "home energy report style" information was presented on the actual energy statement from the energy provider, while the American ones were sent separately;
- the home energy report design was different: it did not use the most energy-efficient neighbours on the statement, and did not place any other information on the front page apart from the norm;
- the homes did not have gas IHDs and so lacked immediate feedback from any changes in behaviour.

Another difference is that the UK study reinforced low consumers with "smiley" faces but did not do the opposite for high users. It is also possible that the focus on a small geographic area created some sense of a community being specially selected.

6.5. Smart meters

The main point is that the meter allows a range of other interventions, as described in other sections. The question here is whether getting a smart meter can itself influence energy use – there are several factors that could affect householders' knowledge of *means* and/or their *motive* to act. In the course of the exercise, bills should become more accurate (possibly more frequent) and customers might experience any or all of: being told they are among the first to get the latest technology; positive interaction with the supplier; reassurance that the meter accommodation is now safer; a friendly or unfriendly installer, who might also offer informal energy advice; and positive or negative attention from friends and neighbours. Also, if a smart meter is easier to read than the previous meter, householders may read it more often, which could have a positive impact on energy demand. This could be encouraged as part of smart meter installation; it would not be a "high tech" use of smart meters but potentially effective in relation energy demand reduction.

Smart meter installation can be enough in itself to deliver a small reduction in energy use, particularly gas use, persisting for at least a year (Raw & Ross 2011). The clearer effect for gas consumption makes sense in the context that simple one-off changes can have big effects on heating and hot water demand. Smart meters also enhanced the effectiveness of other interventions: those using smart meters were successful more frequently and with larger percentage savings in energy consumption. This may be explained partly by some aspect of receiving the smart meter itself but also the different options that were available once a smart meter was installed, e.g. more sophisticated IHDs (fitted by an installer).

Attitudes to the smart meter were generally positive, the majority saying they preferred it to their old meter, it had helped them to save energy and they would be likely to recommend it to others. Householders also reported more positive changes in attitudes and awareness if they had received a smart meter, particularly if they also had an IHD. On the other hand, some respondents were happy to benefit from an end to meter readings and estimated bills and wanted nothing else from the smart meter. Most UK consumers do not yet have a smart meter, and awareness of them is limited, so it is not surprising that only 42% in a survey were interested in having one, if they did not already have one (Ipsos MORI 2012). More positively, the more respondents knew about smart meters, the more they were likely to want one and to support the UK roll-out.

The design of smart meters will be governed to a large extent by statutory requirements, although there is some flexibility. In relation to consumer response, the key SES characteristics relate to the details of how smart meters are presented and installed. The installers themselves, and the documentation and online support provided with smart meters, represent an opportunity to ensure that a wide cross-section of the population know how to access and use the data provided, and take an interest in doing so. More generally, there is an opportunity to engage people with energy management and impart some selected key pieces of information that will enable them to reduce their energy demand.

6.6. In-home displays (IHDs)

6.6.1. Introduction

Real-time feedback can allow consumers to visualise energy use – overall or for individual appliances – and thus have the option of managing that use differently. IHDs go a stage beyond historic feedback by showing the current rate of energy consumption, generally with the option of expressing this in kW, cost or CO_2 emissions. They often have other functions such as displaying historic consumption for various periods, showing the room temperature, alarms and simple visual signals to indicate high consumption rates or changes of tariff period. IHDs range from “clip-on” battery-powered devices (usable with or without a smart meter, but showing only electricity consumption) to more sophisticated and accurate mains-powered devices, showing both electricity and gas consumption by using the signal from smart meters.

As noted earlier, IHDs are probably most relevant to routine behaviour and purchases of equipment used intermittently (e.g. washing machines, televisions). Householders can check the power consumption or cost of using an item, at a point in time or over a short period, and make informed decisions such as whether to turn something off or down, or replace it. For this reason, and because most studies of IHDs have not included gas consumption, the evidence is of less direct relevance to space heating (although the understanding of how to present data is still relevant). Consumers can also use IHDs to confirm the benefit of changes they have made and this is likely to be of greater relevance to space heating.

As with historic feedback, the response may be choosing to use less energy but some consumers may decide that the energy costs are so low that it is not worth the effort, and others may even see that the cost is lower than previously thought, so it is OK to use more energy.

IHDs can support: *means* (by identifying what changes could be made) but only if the consumer understands how to do this; *motive* (by showing how much energy is being used) but only if the consumer already has sufficient motivation to want to check energy use (and possibly also by engaging other motives such as using or showing off new technology); and *opportunity* (because they save householders time in understanding their consumption). Thus, IHDs offer all three elements of change but incompletely in each case and, logically, depending on the extent to which households actually refer to them, particularly when they are first installed and there is most to learn.

6.6.2. Consumer response

Possibly more than any other potential element of SES, response to IHDs has been studied through most of the expected timeline. The evidence used here comes mainly from the reviews and research reported by Anderson & White (2009), CER (2012), Hargreaves *et al* (2010), Ipsos MORI (2012), Kidd & Williams (2008) and Raw & Ross (2011). The actual use of IHDs within households is highly variable. The following points describe a typical pattern of IHD use and the drivers of variation.

- Many households refuse the offer of a free IHD or do not install one that they are given, with the net effect that only around half of those offered are fitted. This applies mainly to clip-on IHDs because those linked to smart meters tend to be installed for the consumer.
- Where an IHD has been installed, a minority of householders forget or ignore it. If an IHD fails, or the batteries are exhausted, there is generally little attempt to get it working again (this is less of a problem with mains devices).
- Many users find it difficult to install an IHD or change settings – because of complexity in the device itself or unclear instructions. This emphasises the benefit of IHDs being fitted and explained by an installer.
- The dominant reason for not using a clip-on IHD was the functionality of the device itself whereas, for IHDs linked to a smart meter, it was the information provided.
- IHDs were most often located in the kitchen, other common locations being the lounge, hall or in a drawer or cupboard.
- Those who do engage with an IHD tend to say it is useful (especially if linked to a smart meter), and are also more likely to retain and use written advice on saving energy.
- For those who engage with an IHD, there is usually a short period of rapid learning where the display is used to assess the consumption of different appliances (by turning them on and off and watching the changes in power consumption). For this reason, the option of appliance-specific monitoring is attractive to users. The early rapid learning is often accompanied by discussion between household members including between parents and children; the impact of IHDs is extended in time where this happens.
- This learning may be followed by changes in behaviour but this depends on the household and the opportunities available. Household members will not always agree about how to respond to feedback. Some appliances and some patterns of living will be considered non-negotiable.
- As time goes on, the IHD is consulted less often as key lessons about appliance consumption have already been learnt. In this later period, common routines include checking the IHD before going to bed, before going out or when a new appliance is purchased.
- Consumers tend to check their consumption more often if they have an IHD (although this is largely limited to one householder, the bill payer). IHDs can be an important support to achieving peak reduction and shifting to night rates.
- The use of an IHD to track energy consumption over time and compare periods is not common. One consequence of this is that high-power appliances (which may be used for short periods) could distract attention from low-power appliances (which may be on for longer).
- Some households use IHDs to test and monitor the effects of applying their existing knowledge of how to save energy. Here the focus is on confirming that an action was worthwhile, thus maintaining conservation behaviour rather than initiating it. This could be particularly relevant to heating.
- The various display features are not all equally valued and used, although it is unknown which features actually have the greatest impact on energy consumption. This variation is not described here but incorporated into recommendations for SES characteristics.
- EDRP found small electricity savings (around 1%) for clip-on IHDs whereas the combination of smart meters and IHDs consistently resulted in persistent electricity savings of around 3% above those achieved with the smart meter alone.[26] Effects on gas consumption were less clear and, as noted earlier, the greater savings came from the smart meter itself. This fits with theoretical considerations, that real-time feedback is more relevant to electricity consumption than to gas.
- The stronger effects in the smart meter trials may be explained by the presence of the smart meter or by the differences in the display devices. The latter is inherently more likely and this explanation is backed up by the survey evidence: IHDs linked to smart meters were consistently more likely to be fitted, retained, used and rated positively. Energy savings are positively correlated with both the level of consumer interest in the IHD and the length of use within the household.

[26] Evidence from north America indicates IHD savings of up to 18.1% in electricity demand but if the evidence is restricted to trials where space and water heating were not provided by electricity, the maximum saving was 8.8%. Savings in areas with climates more comparable to the UK were in the range 0-2.7%.

- Supplementary interventions that increase engagement with the IHD (e.g. energy advice or a savings target) could double or triple the benefit (Raw & Ross 2011). Conversely, the addition of an IHD to other energy-saving interventions (e.g. written advice, target-setting and some more complex packages) tends to increase savings. Combining an IHD with a time of use (ToU) tariff does not have a consistent effect but is most likely to shift consumption but not reduce it (Frontier Economics & Sustainability First 2012).

The achieved energy savings are remarkable, given the evidence of limited interaction with IHDs and the consequently limited potential for the IHD to affect consumption. Most energy saving resulted from simple changes to routine behaviours rather than investments, and some individual users presumably achieved much more than the average; there is, therefore, potential for far greater impact of IHDs at population level.

An alternative product, the Power-Aware cord, offers real-time feedback on the relative electrical consumption of an appliance, using LED lights that vary in intensity and pattern. Lofstrom & Palm (2008) surveyed a group of households using the Power-Aware cord for a period of two months. Although the users considered the cord informative, after an initial period they considered it to be purely decorative. In contrast, a small-scale study of a simple visual signal (a blue light) to indicate when windows could be opened rather than using air conditioning for cooling (Seligman *et al* 1978) did find significant energy savings from this form of feedback.[27]

6.6.3. SES characteristics

Users vary in the interests and motives with which they approach IHDs – some focus on protecting the environment, some on saving money (and may be frustrated if price rises undermine their efforts), or acquiring information (and may be frustrated if there is no appliance-specific information), or engaging with a new gadget (the aesthetics or technological appeal of the device, rather than the outcomes of using it). An IHD may be valued in terms of reassurance that actions to reduce energy use have been effective, control over energy usage or bills, and in encouraging other household members to act. Hence, IHDs need to appeal flexibly to different motives, and maintain effectiveness when operated according to different motives.

The installation, information and support processes for IHDs are critical to their success, along with the design of the device itself. IHDs should be installed for consumers to ensure they are in place, working and understood. Any maintenance required (e.g. replacing batteries) and procedures for restarting a device (without losing settings of data) must be kept simple. IHDs should be combined with other (well-designed) SES elements to maximise consumer response and energy savings.

User guides need to be simple and intuitive for users who require only the most basic functions, while also clearly describing and explaining the use of other functions. Plain language and clear diagrams will be of critical importance. Furthermore, guidance needs to cover how to use the information that IHDs provide to manage energy demand, not just how to access the information.

IHDs need to be kept simple; while more sophisticated devices may be imagined, it is more important that users have easy access to the aspects of the display they find most useful and are most likely to use; it is also important that they can easily return to those aspects if they get lost in trying to access other information. Furthermore, not all IHD display features are equally noticed, used or valued. The following guidance is derived from CER (2012), Consumer Focus (2007) and Raw & Ross (2010) but with the caveat that apparent user preferences would be biased by the ease with which the information is accessed from the IHD (and how well it is explained in user guides).

- Key features should be easy to access with minimal effort. Only the first or second screens in the access sequence tend to be used, so the most useful information should be put on those screens.
- Good ergonomic design principles include: clear, legible text and graphics, large enough to read comfortably; clear use of zones to separate information and reduce clutter; backlighting; easily detectible buttons with positive tactile feedback and an instant visual response; intuitive icons and navigation, and informative button labels; and batteries and adaptor sockets that are easy to access.

[27] An outside thermostat was placed in a location free from direct solar warming; the thermostat was connected to a blue light located in the kitchen. If the outside temperature was less than 20°C, and the air conditioner was operating, the blue light would flash. In order to stop the light from flashing the occupant needed to turn off the air conditioner. The occupant was then anticipated to open the windows if additional cooling was required. When the outside temperature was above 20°C the light would not flash, no matter whether the air conditioning was on or off.

- There is some disagreement about whether costs or kWh are the best default way to describe energy consumption. The balance is in favour of costs but longer-term tracking of energy use requires access to kWh data because unit costs change. The ideal for tracking purposes might be costs adjusted for price changes but this could present other problems over comprehension and confusion with billed amounts.
- Display of consumption is seen as more useful for electricity than for gas, possibly because gas displays typically update less frequently. CO_2 emissions data are poorly rated and rarely used.
- Consumers want data on energy consumption over time (alongside current consumption) but the best way of communicating this is not clear. Rates of consumption are quickly understood but costs or potential savings that look trivial (pennies per day) or massive (full day costs calculated when an appliance such as a kettle is on for a short time) will fail to motivate change. Consumers may fail to engage with this type of data if there is not an effective accompanying explanation or if the more prominent current power/cost information distracts attention from it.
- Graphic indicators of real-time consumption (power) may be more effective than numbers in communicating changing levels of consumption.
- Indications of consumption against target level can be helpful if someone is trying to reduce consumption but can be a source of stress if money is tight – a constant reminder of money being spent. Audible alarms of high consumption tend not to be used but visual signals are at least appreciated (although it is not clear what impact they have on energy use).
- IHDs are used to gain appliance-specific data, especially in the initial period of use. This is facilitated if the IHD can be carried from room to room but, after the initial period, it tends to be left in one place.
- A display of room temperature may assist householders in understanding thermostats and their settings.
- IHDs need to fit with the aesthetics and use of a home. This is especially important in sustaining use when the IHD becomes a background feature, occasionally checked.

CER (2012) presents an alternative way of viewing IHD characteristics, in terms of identified purposes for consumers using the IHD, in the following order of priority.

- Cost management – to see the level of usage (in cost terms) and how that translates into the next bill.
- Tariff management – to recognise the current tariff level at a glance and see the cost per unit.
- Usage management – display of energy use over time, particularly daily use across tariff periods.
- Limit setting – capability to set limits for tariff periods or days, with a signal if the limit is exceeded.
- Appliance-level usage – to develop knowledge as to the relative consumption of different appliances.
- Monitoring – to compare usage over different time periods.

6.7. Heating and hot water controls

Domestic heating and hot water systems may have any of a range of controls, for example to control times of operation, room or water temperatures, and which spaces are to be heated. Effective controls should allow households to achieve their aims for availability of warmth and hot water (and to be confident that they are in control) while minimising waste of energy. The potential, of course, depends on the controls that are present (and correctly installed), and the capacity of energy systems to deliver what the controls request, but the subject addressed here is the ability of the household to understand and use the controls. The evidence is that controls are generally not as effective as they should be in this area, with two major problem areas:

- interacting with the controls can be difficult, for example in terms of understanding what they do, reading displays, using the control buttons, and accessing controls that are poorly positioned;
- using the controls to achieve particular aims for heating or hot water.

Users will often find a way of achieving their aims, sometimes with adaptive variations over time (according to weather and season) and across spaces in the home in relation to which space is occupied, who is present and what other activities are being undertaken (Hinton *et al* 2013). But they do not necessarily find it easy, it is not always in the most convenient or energy-efficient manner (e.g. people tend to overheat, rather than risking under-heating) and some users disengage from using the controls at all and may see them as potentially wasteful of energy because they control heating by time of day rather than specifically when it is needed (Association for the Conservation of Energy 2004, Bell *et al* 2010, Caird *et al* 2007, Market Transformation Programme 2006, Meier *et al* 2010, Rathouse & Young 2004, Scottish Government 2007). Where controls are seen as inadequate or ineffective (e.g. for controlling heat output from storage heaters), householders may resort to leaving heat on constantly or using controllable but expensive direct electric heating (Hinton *et al* 2013).

The cause of these problems is shared between the controls themselves, the instructions that accompany them and the assistance given by installers, landlords and service/repair personnel. While difficulties are greater for some people (e.g. because of visual, dexterity or cognitive disability) they are widespread in society (Combe *et al* 2011c, Ricability 2004). It is also worth noting that controls are often not chosen or fitted by the user, so there is some responsibility on those who install them. Perhaps because of all these problems, the energy savings achieved by controls are disputed and, in any case, they will vary widely with the controls, how they are used, the system that they control and the thermal efficiency of the dwelling.

There is considerable opportunity for SES to improve upon the current situation but it should not be assumed that smarter controls will always result in reduced energy use. Greater sophistication is not necessarily the answer, and new heating or microgeneration technology can make controls more complicated and difficult for users to relate to what they are controlling. Another issue is that the diversity of controls on the market makes it difficult for users to carry over knowledge from one home to another, and this in itself may discourage replacement of controls. Any new control device inherently adds to this problem unless it is modelled on a common current device or sets a standard that others will want to follow.

One barrier to overcome is that users may overestimate their ability to use the controls (BRE Trust 2011) and to define an effective strategy (e.g. controlling temperature with windows rather than a thermostat, using a thermostat as an on-off switch, heating the home while it is unoccupied, and heating water constantly). So an SES needs to start with what householders want to achieve, and their understanding of how to achieve it, before redesign of controls. However, SES characteristics for controls may be recommended as follows (Bordass & Leaman 2012, Caird *et al* 2007, Karjalainen 2010, Meier *et al* 2010, Rathouse & Young 2004).

- Controls should be easy to use in terms of the required dexterity: buttons that are not too small or difficult to press, or have to be held down, dials that are easy to grip and not too stiff, and no tappet adjustments.[28]
- Printed or on-screen information should be easy to read (not too small, with good contrast) with clear meaning of (and distinction between) words and symbols.
- The logic of the controls should be intuitive, using terms that most people understand and avoiding technical jargon, with logical sequences of programming, and clearly distinguishing easily confusable information (e.g. actual vs set point temperature). Feedback should confirm to users what they have done or changed, especially if the response of the heating or hot water system itself is not immediate.
- The design should be consistent with the function (e.g. dial thermostats can reinforce the misconception that they are power controls) and suggest optimum settings (e.g. heating thermostats having a default range of 16-22°C plus frost protection).
- Control locations should be: logical in relation to what they control (close to the device controlled and, in the case of room thermostats, in a representative location for the room); easy to see and access (in good light, without bending and stretching); and in keeping with the household's aesthetic expectations. These three criteria might not always be compatible but wireless controls should make it easier.

An alternative is that the controls themselves should become more "intelligent" and reduce the need for user interaction. This would include controls that compensate automatically for windows being opened, or the current or projected outdoor temperature or heat demand, with minimal user awareness. A step up from this is for controls to advise users on certain actions, with the user still making the decisions, or to revert to default settings at some point after users have overridden them. Fully intelligent controls can learn users' habits, detect whether they are at home and where they are in the home, and adjust heating accordingly. In such cases, the opportunity for user override is important although it may not often be used.

[28] The issue with tappet adjustments is that people find them difficult to manipulate. Compared with some more sophisticated controls, they can make it easier to understand when the system is going to come on or go off but on/off times can be controlled and displayed in other ways.

Instructions should ideally be given verbally, to demonstrate rather than just describe, and to show users how to achieve what they personally want to achieve. But it may not be practical to do this for every new occupant of a home, so written instructions are important, backed up by access to the instructions and demonstrations online. The instructions should:

- be in common language, avoiding jargon and supported by clear diagrams;
- relate to the specific installed device, explaining functions, procedures and purposes of the controls;
- have a short, simple, basic guide, backed up by greater detail and explanation;
- be available in formats for people who have visual disability (e.g. large print or Braille).

6.8. Integrated feedback and control

Feedback is intended to affect actions, so there is a logic to enhancing the impact of feedback by linking it with the means of action, such as a switch or control device, or specific sockets or appliances. This could link *means*, *motive* and *opportunity* into a single intervention. It might also sustain interest in the feedback for a longer period. Where integration relates specifically to time of use incentives, this is discussed in Section 6.9 Ehrhardt-Martinez *et al* (2010) characterise four types of approach to integration, based on high or low automation (conversely, low or high need for user intervention); and many vs few options for control settings (i.e. high or low device complexity).

A complete home network could include integrated wired and wireless sensors, display/feedback devices and communication with the energy supplier. It could provide anything up to and including complete home energy management by some combination of automation and supplier control, guided by consumer needs. Systems can integrate not only energy use but also other applications such as energy storage, security, communication and entertainment. User operation can be within the home or remote (e.g. through a PC or mobile phone). More complex components and networks are more likely to require professional installation.

There is relatively little direct evidence on consumer response but the potential for enhanced control is clear. For example, a majority of householders do not use their heating controls as intended, and/or fail to realise the energy-saving potential of programmable controls. As described above, trials of IHDs found unwillingness to use buttons to change screens, and some preferences for a particular model because everything was on one screen. This reflects a widespread caution about using controls, related to concern about malfunction or loss of useful information. Hormazabal *et al* (2009) identified that consumer acceptance of new control systems depended on their ease of use and their perceived necessity: where they were perceived to be both difficult and unnecessary, they tended to also be unsuccessful.

One EDRP trial integrated a standard form of controller for gas heating and hot water with an IHD showing both electricity and gas consumption. There was no reduction in electricity consumption, and data issues limited the analysis of gas consumption, but a customer survey found a positive response to the intervention. The authors suggest that users valued the device as a heating controller but did not use it so much as an IHD. RAND Europe (2012) cites evidence that the dispersed physical location of energy-using devices within the home can create barriers to reducing consumption. They suggest that technologies that help to centralise the control of devices could reduce such barriers.

SES characteristics are likely to need to aim at easy data-sharing, inter-operability of components and standardisation of communication systems and protocols, together with the ability to build up a system over time, rather than have complete installation/replacement for each change in requirements. The roll-out of smart meters in the UK provides an opportunity for this.

6.9. Time of use tariffs/incentives

6.9.1. Introduction

There is evidence on various interventions focused on when energy is used, by providing a direct financial incentive to shift energy use away from a period of peak demand. This SES element is focused on *motive* – mainly financial but potentially environmental if users grasp the relative environmental impact of peak time power generation. The main two examples are time of use (ToU) tariffs (i.e. varying the unit price with time of day, and sometimes also by season, according to a fixed schedule) and critical peak pricing (CPP), i.e. setting much higher unit prices on a limited number of occasions, usually for short periods, when energy suppliers experience excessive demand and signal this to the consumer.

While the aim is normally to shift consumption away from periods of peak demand, total consumption might also be reduced, because consumers either become more aware generally of their energy use and savings options, or because they take more care to eliminate energy wastage when the price is higher without compensating by increasing usage at other times. The opposite effect is also possible, if consumers take less care of energy wastage during cheaper off-peak periods; the tariff levels and ratios may be important in this respect but it is difficult to disentangle evidence on these from other aspects of tariff schemes and research designs.

6.9.2. Consumer response

Research in the UK (Owen & Ward 2010, Raw & Ross 2011) and Ireland (CER 2012) shows a number of issues with the design of ToU tariffs that have limited their potential impact:

- tariff structures not understood or perceived as too complex (especially if combined with other financial incentives) or the tariff simply being forgotten about;
- consumers generally reacting negatively to ToU tariffs and having a limited understanding of their purpose, feeling that the changes required of them involve too much effort;
- either not seeing sufficient motivation in the differences in rates or seeing the peak rate as too high to make overall cost savings possible;
- uncertainty over how to shift demand, together with lack of feedback on whether demand-shifting and/or cost-saving efforts have been successful;
- concerns about safety, convenience and noise if appliances are run at night;
- trying to shift but giving up when the bill seemed to be the same (the most common reason given).

Some demand response trials give an insight into the time period over which households are responsive to ToU tariffs, by using different lengths of peak periods. A focus group from a demand response trial in Connecticut found that a peak period from 12 noon - 8 p.m. was too long, suggesting that demand shifting is more likely to occur over a shorter period of time (Connecticut Light & Power 2009).

A European survey on consumer willingness to accept load shifting via smart appliances (Mert *et al* 2008) reports concerns around shifting demand over longer periods, including laundry becoming mouldy, noise from appliances working during the night, and food safety. A consumer survey in the USA (Goldman *et al* 2009) also revealed perceptions that demand response programmes: have uncertain consumer benefits, are mainly for suppliers' benefit, and may result in unacceptable reduction of energy services.

Some of these responses may not be the effect of the ToU tariff as such but rather the design of trials. It is common for trials to aim at tariffs being cost-neutral if consumers do not change and ensuring that trial participants cannot pay more overall as a result of their participation. Therefore the trials did not represent a realistic real-world ToU tariff, with which consumers might pay more if they do not sufficiently reduce consumption in the peak period.

There is some evidence on the appliances or applications that consumers are willing to use flexibly, though the evidence base is limited. Trials have in general not broken down load shifting results to the appliance level. Where appliance-level data have been collected, this is often from surveys and so may not reflect actual behaviour but a wide range of changes in appliance use have been reported in response to load shifting incentives, including changing timing of laundry, adjusting thermostats, and switching off lights (Frontier Economics & Sustainability First 2012).

However, there is some evidence on how consumers shift their use of air conditioning and storage heating, as these represent large individual loads and have been directly controlled or automated in a number of demand-side response (DSR) trials and through Economy 7. A meta-study of DSR trials found that reductions in peak demand were 60-200% larger with automation/direct control than without, in trials of ToU and CPP (Stromback *et al* 2011).

Platchkov *et al* (2011) surveyed UK consumers about their willingness to delay appliance use to after 9 p.m. in return for a discount. They found that willingness was low for some appliances (17% for watching TV and 1% for cooking) but higher for washing machines and dishwashers. The same survey found evidence on attitudes to automation of household appliances (specifically kitchen white goods such as washing machines, dishwashers, fridges, freezers or cookers) to shift use away from peak periods: when offered only a small economic incentive, some consumers said they would accept changes to how their appliances operated. More than 20% agreed to interruption to their fridge or freezer's energy use, and 11% agreed to a cap on the use of their cooker at peak times in return for a 1% discount on their bill.

Different attitudes, depending on the type of appliance, could relate to quality of life needs. For example, households may be unwilling to accept automation where they do not have confidence in the technology – this was one of the concerns raised around smart fridges/freezers. Similarly, appliances used for entertainment could be less appropriate for smart use during peak periods than appliances such as washing machines, as the end demand is time-specific. Any application to heating or cooling would face the same issue that people would not want to be limited as to when they can be comfortable.

The alternative proposition of allowing energy companies or network operators some control of domestic appliances, to manage peak demand, is not widely accepted (Demski *et al* 2013) although acceptance varies with type of appliance. This is in a context where there has been little public discussion of how this would work and, in particular, the practical safeguards and the level of choice that consumers would have and perhaps whether the proposition is presented as outside parties taking control or offering help to reduce bills. A variant of this is community projects in which demand is locally managed to smooth out peaks and deliver heat to the coldest homes first (Oostra & Jablonska 2013).

Most evidence on load-shifting incentives is not from the UK – the aim is usually to shift electrical loads from daytime peaks, generally associated with air-conditioning in warm climates (mostly in the USA). Other studies also have limited relevance because they were aimed at peaks in demand from electric heating in very cold winter climates. A prepayment tariff used in Northern Ireland with a real-time feedback device delivered 10-11% peak-time savings and 1% overall energy saving. In the EDRP trials, ToU tariffs resulted in load shifts from the peak period of up to 10% with stronger effects in smaller households, but no overall load reduction.

Early findings from another UK study (British Gas 2013, Wardle *et al* 2013) provide further insight into the effect of ToU tariffs and the role of solar PV systems in shifting loads. This study compares four groups of households (all trial groups and a control group already had smart meters).[29]

- *Control*. This group shows a single evening peak in winter, at around 18:00. In the two months before and after winter, the peak shifts about an hour later and is lower. In the warmest period, the peak is reduced and splits, with an earlier peak again at around 18:00 and a variable later peak at around 21:00.
- *ToU tariff*. The tariff was adopted as part of the trial and this group used less energy in the early evening, but the later evening peak was accentuated: demand is deferred rather than anticipated.
- *Solar PV*. PV was already installed before the trial and there was no other intervention. This group tended to use more energy during the day than the control group, which may marginally offset consumption in the early evening peak in a way that is complementary to a ToU tariff, because demand is shifted forward rather than back.
- *Automating load switching*. Customers who already had PV were given automating switching to use PV for water heating by electric immersion when sufficient solar power was available. This group moved even more consumption into the day from the early evening peak, even in winter. On the assumption that this group normally heats water by electric immersion, they could already have been shifting load into the daytime without the automatic help, and they might have been doing it only when they actually needed hot water, thus freeing up power to the Grid.
- *Manual load switching*. Customers who already had PV were given a display to show when the PV was making power available, so that they could shift consumption manually. This group had a similar energy use profile to the PV group. It is possible that this group already tried to use power during the day or specifically when the sun was shining and that the display could add little to this strategy; sunshine itself

[29] Only the load shifting findings are reviewed here, not total energy use, because the control and trial groups were not matched and analysis did not take into account simultaneously the control group and baseline consumption.

is a useful signal that solar power is available and it can be detected from all over the house – not just where the display happens to be positioned.

A tendency to defer demand, rather than anticipate it, was also seen in ISMeT. In the electricity trial, no single tariff was significantly more effective than the others although there was a trend for peak time savings to increase with tariff ratios. There was also a trend for the combination of bi-monthly bill, energy usage statement and IHD to be more effective than other feedback interventions in reducing peak usage.

Internationally, the largest peak reductions (20-40%) are achieved through CPP, linked to enabling technology such as tariff-sensitive thermostats (with CPP itself also having significant effects). ToU tariffs deliver smaller reductions in peak loads of 2-10% with overall energy savings of 0-8% (average 4%). Overall savings may be slightly higher for ToU tariffs because the percentage savings are sustained for a shorter period with CPP. Also, ToU applies routinely whereas CPP applies only on certain days, hence being less likely to prompt development of new habits. Hence there may be a trade-off between CPP and ToU, with CPP better managing peaks in demand but ToU having a greater likelihood of reducing overall demand in addition to suppressing peaks. The overall savings achieved by ToU tariffs are generally less than for programmes focused on overall energy savings.

The results on peak shifting give an indication of the degree to which demand shifting could be expected with different incentives in place. In general, this rises with the extent to which demand response is automated or directly controlled. There have been a range of estimates on the proportion of domestic demand that is flexible; Owen *et al* (2012) report that:

- Ofgem assumed a 5-15% shift in peak demand for DSR modelling in 2010;
- Sustainability First estimated in 2010 that, excluding heating and most water heating, 20-25% of household electricity demand was potentially price-responsive or discretionary; and
- National Grid modelling of domestic wet appliance and refrigeration use implied that 5% of total demand between 4 p.m. and 8 p.m. could be discretionary.

6.9.3. SES characteristics

Focus groups in the ISMeT electricity trial saw the following as important for the design of ToU tariffs and this insight fits well with other findings.

- Usage knowledge – provision of tailored information to help consumers understand how much energy is used during the different tariff periods (e.g. with IHDs and/or historic feedback).
- Applicability – consumers may overestimate the significance of the peak period and underestimate the significance of the winter period. Communications devices, such as stickers or fridge magnet should aim to correct any misunderstanding and clearly define terminology.
- Justifiability – the rationale for pricing levels must be explained in clear language.
- Acceptability – the initial reaction to the tariff can lead to attrition or disengagement and this risk recurs if the first bill is higher than expected, even if later savings should compensate for it. Communications should explain expectations clearly at the outset.
- Rewarding achievable change – claims of potential savings were assumed to require unachievable behaviour changes, such as using electricity only at night. The consumer must be guided to identify how to save money and shown that these savings are possible through achievable behaviour change.
- Incremental benefit – the tariff can be interpreted as an extra burden on those who had already made an effort to reduce usage. Communication must stress that this is an additional way to save money over and above the existing ways and that the incremental nature of changes will provide even more benefits.
- Calculation of impact – consumers typically overstated the scale of impact of tariff prices on bill size. Communications should provide examples of the likely impact, ideally based on personalised usage.

Another factor that may assist ToU load-shifting is a householder commitment to shift. When using an IHD to access information, only the first or second screens in the access sequence tend to be used, so the most useful information should be put on those screens. Bills should show the effect of load-shifting on cost, and tariffs should not be complex and should be designed first and foremost to make sense to customers.

6.10. Target-setting

Some studies have set a target for energy savings, sometimes based on a commitment (to the trial organiser) from consumers to achieve the target, but with no reward for meeting the target (other than lower energy bills). This would probably act mainly by reinforcing existing motives to save, and possibly introducing a social motive through the relationship to the supplier. Financial incentives to reduce consumption are discussed in Section 6.11.

Evidence is limited as target-setting has usually been combined with other interventions but short-term trials with realistic, stretching targets have delivered energy savings, especially when combined with feedback. In EDRP, SSE randomly allocated its sample into customers who were not aware they were in a trial, those who were aware and those who were aware and additionally made a commitment to reduce consumption. Across all trial groups there was a significant effect of awareness on electricity demand reduction, this being higher for the Aware and Committed groups than the Unaware group. Commitment did not have an effect in addition to the effect of being aware of the trial. The effects of other trial interventions did not vary with awareness.

Target-setting, if used in an SES, should be combined with regular feedback. Challenging targets are more likely to motivate behaviour change than trivial, easy-to-achieve targets. As with benchmarking consumption, targets may work best in groups with a common interest who self-select to reduce energy use.

6.11. Financial incentives to reduce consumption

Incentives to reduce consumption give the consumer a direct financial reward for reducing overall consumption (in addition to any financial benefit from using less energy). The emphasis here is clearly on the financial motive although sometimes the reward is in the form of vouchers to spend on energy-saving products, thus turning motive into opportunity. It is not unreasonable to suppose that, if the reward is great enough, consumers will reduce energy use – indeed this was seen in early small-scale studies of how to achieve energy conservation, which were of relatively short duration. The practical issue is whether it is economically feasible to offer a reward that is high enough, and sustained for long enough, to have a lasting effect. It is perhaps because of such doubts that there is little direct research evidence.

The limited evidence, and the evidence from other fields, suggests that any effect from a financial incentive to reduce consumption is lost when the incentive is removed. The effect is also confounded by the necessary target-setting, which may be enough in itself to trigger a change in behaviour. The EDRP trials confirmed this general negative finding, with financial incentives to save energy producing no lasting effects. There is also concern that financial incentives can be counterproductive in the longer term by focusing attention on the financial motive, to the detriment of other motives that the consumer might have had prior to the intervention. Not only could this make it more difficult to sustain energy savings, it would render more probable the indirect rebound effect whereby energy savings are spent on other goods, services or benefits that might themselves be energy-intensive (e.g. a bigger TV or a holiday flight).

There is, however, some evidence that community peer support can be used to sustain energy-saving behaviour that has been initiated by financial incentives. It may also be safer to target households that are already motivated to save energy but lack the resources to invest in their goal, i.e. to use financial support to provide *opportunity* rather than *motive*. A possibility that has not been explored in research is that smart meters (and associated feedback) could make consumers generally more aware of energy prices and hence more responsive to price changes or offers, making financial incentives (or the negative equivalent – price rises) more effective in reducing demand.

The ISMeT electricity trial included an incentive to reduce consumption and this could have contributed to energy savings but its independent effect cannot be stated. In the gas trial a tariff varied with season, increasing in colder seasons. Most use of gas is tied to when it is needed: it cannot be shifted between seasons in the way that electricity can be shifted between times of day. Therefore, the tariff intervention is perhaps best seen as a financial incentive to reduce consumption in winter. Again, the effect of the tariff cannot be separated from the effect of accompanying interventions but any savings due to the tariff arose in winter. The diurnal pattern of reduction suggested that householders are able to adjust consumption selectively by time of day, without the stimulus of a ToU tariff.

Financial incentives to reduce consumption are of limited value in changing energy-related behaviour. If included as part of an SES, the following guidance on characteristics should be followed.

- Design the incentive so that the basis of receiving the financial benefit is clear to consumers but they cannot obtain it by increasing their consumption during a baseline period.
- Ensure that consumers are able to track their progress (using feedback) against a realistic trajectory to receive the incentive.
- Maintain the incentive for no longer than necessary to achieve impact and use it to put in place persistent change, through either investment (e.g. in efficient appliances or insulation), development of new habits or transition to another intervention.

6.12. Heat, renewable energy and insulation technologies

6.12.1. Introduction

A range of alternative technologies can be deployed as part of SES but there is surprisingly little evidence on the specifics of user response. In Sweden, Mahapatra & Gustavsson (2008) identified that decisions generally about replacing heating systems were guided by households' level of satisfaction with their current systems, and that annual heating costs, investment costs and functional reliability were particularly important in the decision-making process. Surveys by Herring *et al* (undated) identify barriers to uptake as: high upfront costs, perceived costs outweighing energy savings and technologies being unlikely to last long enough to pay back the initial cost. In the UK, Junemann & Raslan (2012) identified a number of barriers to retrofit, in particular: a lack of knowledge, skills and incentives for retrofit; a lack of consumer trust in energy companies and the building trades; confusing advice streams; and fragmented policy, delivery and funding for retrofit.

6.12.2. In-home heat technology and renewable energy

Butler *et al* (2013) point out that any human response to change does not happen in isolation but rather has to find a place within people's existing knowledge, understanding and values. One consequence of this was that participants in their qualitative research associated new technology with the nearest equivalent old technology that they were familiar with. So electric heating tended to be perceived negatively because of its association with electric storage heaters, even though electric heating could permit more precise control in space and time and might be thought of as aesthetically better by eliminating combustion appliances. This revealed certain key requirements of heating: controllability, speed with which a warm temperature can be achieved, cleanliness, and cost. In a related survey (Demski *et al* 2013), only 36% felt positively towards electric heating and 42% were "willing to use" it. When the survey proposed improvements to match the performance of existing systems, acceptance increased to 61% (85% if electric options were made cheaper). The fact that these figures were not 100% suggests that respondents did not entirely believe that such changes were possible.

These findings are supported by research commissioned by DECC into homeowners' willingness to take up more efficient heating systems, which found that gas boilers were a clear favourite for future installation, with 90% of respondents who were on the gas grid choosing gas boilers (and 71% combination gas boilers) unprompted. When further information about alternatives was provided, approval ratings for these alternatives were much lower; second favourite was micro-combined heat and power (46% approval), with respondents citing the familiar, proven and trusted aspects of the technology that they recognised from gas boilers as reasons for this approval. In contrast, air source heat pumps lacked credibility with many respondents, particularly those living in colder parts of the UK, who did not believe that the technology would work effectively at low temperatures (DECC 2013).

A survey by Caird *et al* (2007) found that 15% of respondents had considered micro-CHP but decided against it; the paper concluded that this was mainly because of the cost, the uncertainties associated with new technology and issues of connecting with existing heating and electricity systems. Even for the relatively well established condensing boiler, cost and reliability were barriers to installation. Despite the clear financial benefits, perceived complexity around the standard process for selling electricity from micro-generation back to the grid was one of the reasons found for households deciding not to adopt renewable technologies such as solar PV (Caird *et al* 2008).

Faiers & Neame (2006) examined attitudes towards domestic solar power systems using a Diffusion of Innovations approach. Those who were either early adopters of technology or assumed to be 'early majority' adopters had positive perceptions of the technology, but financial, economic and aesthetic characterisations of the technology limited their take-up. For 'early majority' householders, a negative opinion of the simple payback period was the single most important limiting factor overall. If solar power does not bring additional value for the property, then adoption will not be considered by householders who may move out before the payback period ends. They were also unlikely to adopt solar if they perceived it to affect the visual landscape and to be intrusive.

Heat pumps can appear more complex than more common technology and they deliver heat in a way that will be different to most householders' experience and expectations, particularly (a) heat sources such as radiators being cooler but larger and (b) continuous operation generally being recommended. Some heat pumps can also be used for cooling, so overall consumer response needs to take this into account too: heat pumps should not be considered purely as heating technology but also as cooling technology, with all the potential risks and benefits associated with air conditioning (see Section 4.6). Although uncommon at present, development of industry standards, and promotion by Government, could accelerate uptake. Most research has addressed the performance of the heat pump itself, rather than user interaction but the following can be concluded from the principal research carried out in the UK (EST 2008, 2010, Caird *et al* 2012, Stafford & Lilley 2012).

- Heat pump performance depends on user behaviour (in operating the equipment and through behaviour that affects building heat loss, such as opening windows) in addition to the design, installation and commissioning to ensure the device is working properly, controls are set up appropriately and everything is tuned to the particular dwelling.
- The majority of users are satisfied with the heat pump for space heating and (where applicable) hot water.
- Householders are in general pleased with having constant warmth as a result of the design intention for heat pumps to work continuously, but not all users understand that this is the preferred mode of operation or believe it is not safe to leave the heating on when they are away from the home.
- Users like the freedom from the re-fuelling, de-ashing and cleaning coal or wood dust residues required with solid fuel systems (this would apply to most new heat sources).
- Operational costs such as the electricity required to run the heat pumps and the cost of maintenance of systems greatly affect user satisfaction, particularly for social housing tenants who felt they had little understanding of heat pumps and had received little advice. More generally, many householders expressed difficulty in understanding the displays, controls and operating instructions in order to achieve high efficiency and lower costs.
- Noise can be a problem, especially with air source heat pumps. The evidence relates to the household with the system although neighbours might also be affected.
- The installation of a heat pump can potentially lead to either a more conservative use of energy (due to energy awareness) or to more energy consumption (due to the 'rebound effect').
- Additional heating sources are often used if heat pumps do not provide sufficient heat input at all times, which would increase energy use. However, this needs to be balanced against the additional energy use that would result from heat pumps that are oversized for demand through most of the year.
- Some occupants either heat rooms to higher temperatures than needed or complain that temperatures feel low in comparison to the temperatures they were used to.
- Only few of the heat pumps installed had a cooling function but even those that had were not used for cooling during the studies (it is not clear why not).

Thus, it is important that manufacturers, installers and housing managers offer insights on the comparative benefits of heat pumps before installation and advice and continuous support after. Heat pump manufacturers in particular could assist in householders' understanding by designing more user-friendly manuals, control systems and displays that provide users with real-time feedback.

6.12.3. Community heat

District heating refers here to a system where heat is generated outside the individual dwelling and then supplied to the dwelling (e.g. in the form of hot water to radiators or warm air). Such systems could be entirely within a block of flats or serve a neighbourhood, including non-residential premises. In fact, one source of heat can be “waste” heat from non-residential buildings. There are also systems whereby heating is centrally controlled but generated within individual dwellings (e.g. by electric heating). In an EcoTeams trial in Sweden, many of the participants were living in apartments where temperature settings were controlled centrally (Carlsson-Kanyama & Lindén 2007). This necessitated individual adjustment of each radiator if an occupant wished to make temperature adjustments; householders saw this as too time-consuming. The physical layout of the energy-using technology in the home, combined with lack of a single control point, therefore acted as a barrier to reducing consumption.

Key SES characteristic issues for district heating are likely to be: disruption during installation; reliability (given that the householder is relinquishing control of the technology); usability of in-home control devices; the responsiveness of the system to changes in demand temperature; consumers’ control over the seasons when heat is supplied; energy costs and consumers’ ability to control costs by controlling how much heat they use.

Some other community aspects of energy use are potentially of interest but evidence on actual practice (or how this might affect response to propositions about district heating) is lacking. For example:

- how people come together to make energy decisions (e.g. on sharing oil in rural areas);
- what might determine whether neighbours might wish to collaborate (e.g. to share a heat supply or have insulation fitted at the same time);
- whether broader community benefits (e.g. local jobs) act to encourage individual household action (e.g. insulating homes) and if so, when and why (see also Section 3.2)?

However, notions of ‘community’ and ‘local’ could improve the perception of retrofit measures, through benefits to the community (such as local jobs), the relevance of the measures to the community, and issues of trust: Junemann (2012) concludes that local delivery from local tradespeople, trust networks of friends and family, and policies and strategies designed to meet local needs that were relevant to local communities were important for the acceptance of retrofit for energy efficiency.

6.12.4. Insulation

Insulation is one of the main technologies used in thermal retrofit, and is discussed as a current behaviour in Chapter 4. However, insulation is also needed alongside many of the technologies discussed in this chapter. While other SES can make energy use and the patterns of its use visible, with a view to reducing that usage, insulation is needed to maximise the benefit of the energy that is used. As it does not have the appeal of novelty, response to the user, or status-enhancing properties of some other SES technologies, it can be seen as a less interesting technology by consumers, which can reduce the priority it is given when home renovations are considered.

6.13. Water efficiency initiatives

6.13.1. Introduction

While this report deals primarily with smart energy systems, interventions aimed primarily at water savings have energy implications for the householder (in the case of hot water) and wider implications for cold water (e.g. energy for purification and pumping). Most water efficiency initiatives entail direct approaches to householders; there have also been attempts to engage plumbers and plumbers’ merchants as intermediaries but with little success (Bowden *et al* 2012).

There has been an implicit reliance on three means of change: free or discounted installation of devices believed to reduce water demand; raising awareness of the need to save water; and providing information on how to use less water. Devices that have been deployed include tap inserts, replacement shower heads, shower regulators and timers, replacement washers, leak repairs, leakage alarms and water-efficient washing machines. Each of these three approaches faces problems.

- The evidence on what (if any) water savings are achieved by each device (and the persistence of any savings) is thin, largely because they tend to be installed in combination, and even the effect of combinations of devices lacks rigorous evaluation.
- While some devices might save water without the active assistance of the householder (e.g. replacement shower heads), others require the householder to choose to use them (e.g. shower timers). It is also clearly true that the available behaviours depend on the available devices (e.g. a shower being present).
- Raising awareness in itself is not a proven way of inducing behaviour change and information will have no effect unless that knowledge relates to something the recipients want to do and have the resources to do.

6.13.2. Consumer response

Water efficiency devices have been a mix of those installed by professionals and those provided for self-installation by the householder. For devices that are simple to fit, householders prefer to do it themselves, whereas professional fitting is preferred for anything that appears at all complicated. In this sense, the householder's knowledge and skills are a key element in the means of action. Professional installations should save more per household because more devices are available, more get installed, they are more likely to be fitted properly and the installer has the chance to talk to the householder about using the device. But self-installers may be more motivated to reduce water use and engage in additional behaviours to do so.

Householders give various reasons for not fitting a device: being unable to fit it (e.g. incompatible with existing taps), no time to fit, irrelevance (e.g. already have the device), and water pressure being too low for the device to function (Jordan 2012). The same paper reports that over 30% of householders have removed devices for reasons of poor function, device failure, not wishing to shower in under four minutes, inconvenience (e.g. slower to shower or fill a basin), lower flow rates, or the device not being used. Greater effort to match devices to homes and households could reduce wastage and avoid devices being discredited through inappropriate attempts to install.

Apart from this evidence on installation and removal, there is an implicit assumption that the effect of the device depends solely on it being in place. In fact, water savings will depend on subsequent householder behaviour. There are four elements to this: disuse, misuse, compensation and rebound.

- Disuse means simply that the householder opts not to use the device, without actually removing it.
- Misuse means that the householder – deliberately, carelessly or through lack of understanding – does not use the device as intended.
- Compensation refers to users adjusting their behaviour to compensate for an aspect of the device's function. For example, someone might take a longer shower to compensate for a lower flow rate.
- Rebound (e.g. being less careful to turn the tap off when brushing teeth if the water flow rate is reduced).

Consequently, water efficiency interventions that simply focus on replacing technology or reducing shower duration have limited impact (Browne *et al*, in press 2013). These issues have been recognised in relation to assumed water-saving improvements required for higher grades under the Code for Sustainable Homes (Green Building Magazine 2008). The result is disillusionment of occupiers and a tendency to replace low-flow products with higher flow-rate models. In the case of showers, the risk of replacement can be reduced by efficient shower head design, rather than simple flow restriction (Critchley & Phipps 2007).

Jordan (2012) provides evidence on specific barriers to effectiveness, which closely parallel those that apply directly to energy savings. Barriers related to *means* include: not understanding the rationale for the device or behaviour; not knowing how to use the device or not believing it will save water (in general or for the particular household); and tenants not being allowed to install anything (or believing they are not allowed). Barriers related to *motive* were saving water being seen as someone else's problem or decision, and believing they were already water-efficient. Mention of environmental benefits can provoke negative reactions about perceived high rainfall, planning controls, building on flood plains and not having enough reservoirs.

Barriers related to *opportunity* are more complicated. Cost is a barrier if measures are not free of charge but householders may think there is a catch because of a free offer (this emphasises the need for trust in the product and the person or organisation fronting the project). Time may be a more important barrier, expressed in words such as “hassle” and “commitment” (even though the first contact may require only a few minutes, this may be too much if the householder is busy or not sufficiently interested). Installing, and/or being at home to accommodate installation, are greater time considerations and projects therefore need to make the required time as short and as conveniently scheduled as possible. Space should not generally be an issue, with water-efficient alternatives typically taking up similar space to what they replace.

6.13.3. SES characteristics

The true performance of each device (individually and, where appropriate, in combination) needs to be established for each relevant context (e.g. different demographic groups or existing fittings) so that it can be offered with confidence that it will work. A key issue is showers: customers want showers to provide good water flow, at the right temperature, in order to wash, keep warm and enjoy the experience of showering (Critchley & Phipps 2007) and these need to be provided in ways that do not require or encourage excessive water consumption. Taps with ceramic washers (which allow taps to be quickly opened or closed) may do more to change behaviour than flow restrictors.

Confident deployment also depends on having an understanding of how consumers are likely to react to different devices and financial arrangements (free offers by trusted parties will help but there are obvious financial implications for the programme organiser).

Householders also have knowledge gaps, which could be filled to help motivate consumers (Myers 2010). This would include knowledge of how much water they consume daily, where their water comes from, and the environmental impact of water use (particularly if this is related to local rivers drying up). Action does not necessarily have to target only water technology (e.g. more efficient washing machines or showers). Alternatives are dirt-repelling or deodorising fabrics, and soaps and shampoos that rinse off more quickly.

6.14. The rebound effect following thermal retrofit

In many cases, consumer choices relate to the heating (or hot water) strategy following retrofit rather than the retrofit itself. This is worth exploring in detail because purely physical models underestimate heating demand following interventions that improve a dwelling’s energy efficiency by an estimated 15-30% (Sanders & Philipson 2006, Sorrell 2007, Sorrell *et al* 2009, DECC 2010a, 2011). In extreme cases, there could be no energy savings or even increased energy use (“backfire”). This “direct rebound effect” (also called “take-back” or “comfort taking”) is well known but poorly understood in terms of what householders actually do, or why, but a key mechanism is that some of the potential energy savings are exchanged (consciously or not) for higher room temperatures or heating in more rooms.[30] There is also a potentially even more complex “indirect rebound effect” where savings on energy costs enable more income to be spent on other products and services, including those that use energy.

Two assumptions are often implicitly made about the rebound effect following thermal retrofit, i.e. that higher temperatures equate to greater comfort, and that consumers actively seek to use some of the potential savings in energy/money to achieve higher temperatures (hence the achieved or set point temperature is referred to as “demand temperature”). These are reasonable hypotheses but not the whole story. Hamilton *et al* (2011), for example, show that room temperatures increase when building fabric quality improves, until it reaches a certain level of efficiency, with a combination of effects of the fabric itself, interaction between intermittent heating and the changing dynamic behaviour of an insulated dwelling, and the changing balance between heated and unheated part of partially heated dwellings.

To develop an appropriate and effective response to rebound, it is essential to have a proper understanding of the underlying behaviours and motives. It is a reasonable observation that rebound is associated with a reduction in the unit cost of warmth (perhaps expressed in units of £/K.m^3) but it should not be assumed that this is the sole or dominant causal factor. Some combination of the following scenarios can be envisaged.

- Warmth is cheaper, therefore householders actively acquire more of it.

[30] The discrepancy between predicted and actual energy savings is also due to two other major effects (the retrofit falling short of design expectations and error in modelling) but the main interest here is in behavioural response to the retrofit.

- The dwelling becomes warmer without householders doing anything differently (e.g. because there is a heat source in more rooms or the heating system has become capable of reaching the thermostat set-point temperature against colder outdoor temperatures) but they willingly accept the higher temperatures (e.g. in order to be warmer, or as warm with less clothing, or more welcoming to guests).
- The dwelling becomes warmer without householders doing anything differently; they would prefer (or be content) to be cooler but do not know how to achieve this or do not have the time to work it out.
- The dwelling would become warmer without householders doing anything differently but they take action to limit the temperature rise – either by reducing energy use (e.g. lowering the thermostat setting or reducing use of supplementary heating) or by increasing heat loss (e.g. by opening windows).

Any value judgement on these scenarios should be cautious. In any one of them, the achieved temperatures might be too low or too high for health and comfort (from the householder's perspective or from an outside view). And opening windows might appear to waste energy but could avoid adverse health effects or moisture damage to the dwelling. More generally, it should not be assumed that saving energy is the sole aim of thermal retrofit. In social housing in particular, the other aim (sometimes the driving aim) is that people should be healthier and happier (often expressed as "reducing fuel poverty"). Higher indoor temperatures are likely to contribute to this aim while also potentially contributing to saving money and/or energy in other arenas (e.g. the NHS, counselling services, crime and policing). In this sense, rebound may sometimes be the aim, without which there would have been no energy savings at all, rather than an unfortunate side-effect.

So the mechanisms are potentially complex and the evidence, particularly longitudinal evidence, is limited.

- Hong (2009) found that central heating resulted in the greater rebound effect (probably due largely to more rooms being heated), with draughtproofing and insulation appearing to mitigate the effect.
- Love (Pers. Comm. 2013) found that most of the rise in temperature following refurbishment for low-income households occurred while the heating was off, due to some combination of slower temperature decay after the heating is switched off and greater impact of incidental gains. The reasons why people got warmer homes were more to do with the limitations of control and the effort it would take to avoid the home getting warmer (even if this was their aim), given their limited ability to predict how much money would be gained by making the effort. Neither was there an increase in the number of rooms heated.
- In a small sample (10 households) Weihl & Gladhart (1990) found a more active involvement of householders, with small increases in thermostat setting following retrofit.

Cross-sectional data do not prove what happens when someone acquires a new device or appliance (the effect will depend on what they were doing before, as noted in Section 4.2) but can indicate potential unexpected effects. For example, Shipworth *et al* (2010) found a significant difference between thermostat settings in fully double glazed and draughtproofed homes and those that had lower levels of such measures (or none). They also report differences in heating period with respect to certain fabric efficiency levels.

There is a general expectation that use of rooms within the home will vary with thermal conditions and that this is related to rooms being heated (although it is not entirely clear when rooms are used because they are heated, and when they are heated because they are used). There is evidence of this from more extreme climates (Sawashimi & Matsubara 2004, Merghani 2001) but little from the UK. A specific example concerns conservatories. These are potentially useful as passive solar spaces to reduce heating bills, if they are occupied only in the warmer months and closed off to the rest of the house during colder months. But conservatories tend to be used all year, and heated on a daily basis (Chu 1990, Mumovic & Santamouris 2009, Oreszczyn 1993). Again, functional and aesthetic considerations outweigh energy.

Deliberate rebound (increases in temperature and number of rooms heated) has been reported following installation of heat pumps in Norway, where electricity is relatively inexpensive and almost entirely from renewable sources (Heidenstrøm *et al* 2013). In fact, increasing comfort was sometimes the purpose of installing the heat pump. A lesser effect was seen in Denmark (where electricity is more expensive and less is from renewables), and related mainly to room temperatures. The air-to-air heat pumps used in Denmark were also perceived as improving indoor air quality and this could account for some of the additional use of them. It is also notable that rebound seems more deliberate for lighting (using brighter bulbs and taking less care to switch lights off when not needed), where the control is more obvious and direct (Dütschke *et al* 2013).

6.15. Power generation

The central generation of power for the grid is largely outside the scope of this report but it merits some mention in terms of how it might affect the availability and uptake of new electricity-using technology. Behind the general assumption of progressive decarbonisation of electricity, and electrification of heat and other services in homes (DECC 2010b), there are public concerns about how that electricity will be generated. This spills over into the intention that diversity, security and continuity of energy generation should involve more generation at local level (DECC 2013).

The subject is too large for comprehensive treatment here but some general issues are noted. Confidence in energy technology – or perception of risk – can extend to the systems that sit behind the technology installed in the home. For example, while a heat pump might be perceived as “clean” at point of use, consumers may take into account that the electricity generation required burning of fossil fuel or a nuclear power station.

Butler *et al* (2013) offer some useful insights on this point. Nuclear power has a unique “dread” related to the consequences of a major nuclear incident, but some people are prepared to live with this (perhaps at a distance) because of the low likelihood of an incident. Carbon capture and storage (CCS) shares some characteristics with nuclear power, since both involve a waste product that needs to be transported and stored indefinitely. Also, CCS addresses carbon but not energy security and it is the latter that appears more salient to consumers. Biofuels are recognised as different from (and preferable to) fossil fuels but with the similarity that both are burned to obtain energy and both entail a vulnerability to other countries that supply the fuel. They are therefore seen as stopgaps rather than a long-term replacement for fossil fuel. There is some awareness of conflicts over alternative uses of land, e.g. for energy generation or growing energy crops, rather than producing food.

In quantitative terms, a linked survey (Demski *et al* 2013) provides the following indications of response to different means of power generation, which fit well with the qualitative findings.

- A large majority favoured renewable energy and agreed that the UK should reduce use of fossil fuels. Wind energy specifically was seen as clean, safe and good for the economy, with no significant risks, although there were mixed views on aesthetics. Offshore wind farms attracted more support than onshore but with low opposition to both and, surprisingly, 57% would support a wind farm in their area.
- Fewer respondents favoured biomass, consistent with it being associated more with fossil fuel than with renewable energy. It was also less likely to have been heard of than other renewable energy sources. Coal and oil were the least favourable forms of electricity generation but gas was judged more favourable than unfavourable.
- Although associated with dangerous waste, hazards to health, risks to wildlife, and spoiling the landscape, nuclear power was seen as a reliable electricity supply. Context is important: respondents were split on their attitudes to nuclear power, although slightly more unfavourable (39%) than favourable (33%) but acceptance of nuclear power increased to 66% when it was positioned in terms of being developed alongside renewable energy resources.
- The majority knew little or nothing about CCS. When given a brief description and asked about the potential continued use of fossil fuels with CCS, more supported than opposed this idea. Given a choice of CCS or nuclear power, 30% opted for CCS and 22% for nuclear, leaving a large proportion undecided. CCS has also been subject to public protest (De Best-Waldhober *et al* 2009, Dütschke 2011).

So long as the consumer perceives a new technology as using less electricity than his or her current technology, the source of electricity should not be a barrier to uptake, and could even be an incentive (e.g. if reducing demand is more attractive when the electricity comes from burning coal than if it comes from renewable sources). But perception is not necessarily a copy of reality and so the electricity impact will need to be very clear. This is especially the case if a new technology uses less energy but more electricity (e.g. a heat pump replacing a gas boiler).

6.16. Overview

The following main points have emerged from the review, in relation to consumer response and SES characteristics.

- A particular response is not guaranteed simply by implementing a particular SES element: response depends on the detail of deployment: how the element is designed, delivered and combined with other elements. The design of an SES needs to consider means, motive and opportunity – for individual elements but more importantly for the combination of elements. The whole customer journey also needs to be considered, from first engaging with an intervention (e.g. reading advice or installing an IHD), to initial impact of the intervention and sustaining actions over a longer period.
- People and households are not all the same: the more closely an SES can be tailored to particular households or individuals, the more effective it is likely to be.
- Consumers need to feel able to act: that they can carry out the necessary actions, and that those actions will not be isolated or ineffective (Faiers *et al* 2007).
- Quality matters, in relation to the technology, the consumer offering and the information provided. Quantity also matters: a balance needs to be struck between information overload and providing sufficient options and information. Complexity in the technology or in the information it displays is likely to reduce the level of uptake (Faiers *et al* 2007, Peffer *et al* 2011).
- Price and payback periods influence uptake: many consumers are willing to install energy efficiency measures only if their return on the investment is relatively rapid or at least that the technology is likely to be effective and last long enough to pay back the initial cost (Caird *et al* 2008, Emmert *et al* 2010, Faiers *et al* 2007). It also matters *who* is paying (the consumer or some other party) and who the consumer thinks *should* be paying or really is paying (e.g. if a free offer is financed through energy bills).
- The acceptability and real cost of an installation depends on the plans a household has for the home and the phase of occupancy. When moving to a new home, or if there are plans for some kind of refurbishment, there can be greater openness to installing an SES (EST 2011). So there is potential for more to be achieved at these points through intermediaries such as estate agents, surveyors, lenders and those in construction and retail businesses. Householders indicate that acceptability of new installations is generally at a low point when a home is on the market.
- An SES can save householders time by helping to select the best options, thus reducing an initial hurdle of having to invest time in decisions. There are other key points at which the householder's time needs to be considered: at first contact, in further discussion and for the installation itself.
- The form of engagement that leads to an installation may affect the outcome. Carroll & Berger (2008) report that more CFLs and low-flow showerheads were installed in homes where those measures were installed for the household. But households that adopted these measures through on-to-one workshops had a higher rate of self-reported energy-saving actions. School projects can not only increase the knowledge and understanding of pupils but also provide a means of influencing parents.
- The effectiveness of an intervention can depend on the extent to which the originator is trusted (trusted to be reliable as to the facts, competent to deliver, honest in expression and transparent in motive). Hence, even the best designed SES could fail if the target audience does not trust the source. Trust in messages from public authorities can be supported by the authorities themselves being seen to act in a way that is consistent with the message: in areas such as planning restrictions on thermal retrofit, lighting and overheating in public buildings and the behaviour of individual politicians and officials (Butler *et al* (2013). If regulation requires that products are included in official labelling and accreditation, such as an Energy Performance Certificate (EPC), this can help to validate communications about them.
- Community engagement is not an SES as such but it can be an effective tool, making use of social networks and social capital, and changing social norms. It may, however, require a higher initial investment and will not necessarily work in all localities. Local support from a combination of experts and peers can help consumers to understand what to do, appreciate reasons for taking action (reasons that make sense to them personally) and provide the resources (time, space and money). This is discussed further in Appendix D.
- Another effective tool for the delivery of a range of types of interventions is the web. Receiving web-based information is a more active process for consumers, and can be tailored and linked to options for action. Additionally, web-based information can be less resource-intensive than other media. However, the

design and content of the web pages need to be carefully considered, and may not be a good vehicle for real-time feedback on energy use. Web-based interventions are discussed further in Appendix E.

This chapter has reviewed possible elements of an SES. These elements could be combined in various ways, in different chronological orders, to create a coherent whole. While consumer response to the whole may not be completely predictable from response to elements, this is a fair starting point. It is also possible to start from research into response to change in whole energy systems although the subject of such research is difficult to define and, perhaps for this reason, relatively little research is available on the subject.

Butler *et al* (2013) report findings from workshops on whole energy system change. A key finding is that participants readily assumed that change itself is inevitable: the issue is the form and pace of change. Furthermore, while the possible form of change naturally raised concerns, there was also concern about doing nothing. Nevertheless, there were clear issues about the location of change in time and space. Some participants saw the change as being in the distant future, for others to deal with. In discussing the suitability of particular locations for change (e.g. construction of power generation facilities), the suitable location was generally seen as “somewhere else”.

While the latter response may be seen as “NIMBYism”, it was generally backed up by defensible reasoning, such as the proximity of housing to wind farms and inadvisability of remote control of appliances such as washing machines in flats, where noise overnight could disturb neighbours’ sleep. This is consistent with public support for renewable energy, contrasted with objection to local renewable energy schemes (Bell *et al* 2005, DECC 2009, Demski 2011, Devine-Wright 2010, McGowan & Sauter 2005, Spence *et al* 2010).

Two examples of needs

Needs related to quality of life → Well-being → Being relaxed and comfortable at home

The need for comfort may be met differently once SES are implemented. At a basic level, improvements in the fabric of the building (e.g. insulation) may result in increased room temperatures: where someone heated one room and used blankets on the sofa to keep warm, improvements that allowed more rooms to be heated or rooms to reach temperatures that made blankets unnecessary might result in changes to the way the home is used, with more activities taking place in other rooms or away from the cosiness of the sofa. Visible feedback showing when and how much energy is being used would help the householder to balance cost with comfort. Changes to control systems could give greater flexibility over when and where heat energy is used, allowing it to be more effectively targeted to when it is really needed.

Social needs → Social interaction → Being a good host to visitors

This flexibility would be particularly important for social needs: patterns of heating use could easily be adapted according to the needs of visitors to the home. SES could also add to the self-image of the householders, particularly if they are early adopters of the technology and its presence is seen as something desirable or aspirational that visitors to the home might admire.

7. Evidence gaps

RQ10: What are the barriers, risks and gaps in our knowledge at the end of the project?

RQ10 logically cannot be answered until the end of the project but this chapter summarises the most important gaps in evidence, based on the literature review. As the CRaB project progresses, the gaps will be revisited to identify those that remain at the end of the project. This process will also feed into other CRaB Work Packages to address the barriers to (or risks arising from) consumer response to smart energy solutions, particularly through the second stage fieldwork (WP5.7) and work directly on solutions (WP5.5) and their ideal characteristics (WP5.8).

The gaps in evidence can be characterised as gaps in our detailed knowledge, or as gaps in our understanding of the complexity of interactions between the aspects that have been identified. From this arise many of the barriers and risks associated with this research. It is important to identify the missing detail, but at the same time that detail's value lies in the interactions between the different elements that surround it, and the specific applications envisaged by ETI.

1. The literature provides a reasonably good guide to what the key needs are but based largely on self-report rather than observational or experimental evidence.

2. While some relationships among needs are obvious, logical or evidenced, there is not a complete picture of the relationships in consumers' minds, rather than how they have been grouped by researchers. It is also unclear how these relationships vary with the characteristics of persons or dwellings, or how needs (individually or in clusters) determine behaviour now or expected response to SES. In some cases, the needs will be obscured by habit and approaches to such cases need to be defined.

3. Many energy-related behaviours have been described, even quantified or subjected to detailed research into why they occur. Nevertheless, there is an incomplete understanding of how the various behaviours originated, what sustains them, or how interchangeable are different behaviours that appear to address the same needs. Apparently simple behaviours can have multiple connections to needs and the purposes of home, and simple responses to SES should not be assumed; individual behaviours are important but they should not be viewed in isolation. Rather, they should be seen as something that shapes and is shaped by needs, purposes, and the physical and technological contexts within which behaviours occur.

4. Some energy-related behaviours have not been investigated in as much detail as others within the existing literature, or have not been fully investigated from the viewpoint of occupant behaviour and response to the particular technology. There are a number of specific issues that are not yet fully understood, such as:

- the acceptance of new heating technology and insulation, and behaviour following installations;
- motivations for and experience of energy efficiency renovations and retrofit;
- practices around the use of hot water or drying clothes;
- response to overheating;
- the meanings and aesthetics of the home and their implications for decisions to renovate;
- the "social dynamics" of how energy-related decisions are made in households;
- the implications of community interactions and collaborations for broader sharing of energy resources.

While these have been identified as particular gaps in the literature, they will not necessarily be addressed by the SSH research, but their existence as gaps will inform the design of the next stages of the research.

5. Critically for the SSH programme, it is generally unclear whether a behaviour would easily be adapted to an SES or whether the SES should be designed around the behaviour. The answer may be found in the extent to which the behaviour is an integral part of a lifestyle, meeting multiple needs (e.g. taking a shower to feel clean and fresh, sooth aches, wake up in the morning and feel confident to face the day) or more specific and functional (e.g. running a dishwasher).

6. There has been a focus on individuals' needs, behaviours and choices but much energy-related behaviour is decided at a household level (or at least with reference to persons other than the individual actor). This approach is likely to have limited our understanding of the true dynamics of energy-related behaviour, particularly in relation to "social interaction" needs and how actions within the household are negotiated between different members of the household. Similarly, our understanding of variation in the population has most likely been distorted by a focus in the literature on variables that are easy to measure or observe, rather than the underlying needs, knowledge, values or constraints. Understanding such variations across the population can illuminate design or implementation issues for SES. Where those variations may obscure design or implementation issues, this would also be important for CRaB and for SSH as a whole to understand.

7. The extent of actual energy wastage is unknown, for example as a result of rooms being heated when they do not need to be (which is not the same as being heated when they are empty), or heated more than is necessary for the occupants' comfort. The converse is also unknown: the extent to which spaces are used but not heated to the extent the occupants wish.

8. Social change can be expected to change energy-related behaviour but the details of this are lacking – e.g. the impact of working from home, displacement of energy use outside the home, multigenerational households or immigration.

9. It is clear that the details of SES design matter but we have an incomplete understanding of the precise details that matter most. There is reasonable evidence, for example, about the design of controls and IHDs but relatively little on some technologies for heat or power, such as heat pumps or district heating, that are set to become more prevalent and could be a key part of the SSH programme. The true effectiveness of some technologies (especially those for reducing water consumption) is also uncertain, particularly because of direct and indirect rebound effects.

10. In general terms, we know that the messenger (and trust in the messenger) matters, and that consistent messages from different parties are therefore important. But the precise combinations that will work best have not been determined. For example, while peers may be most trusted in the sense of offering genuine advice, they may be least reliable as to the accuracy of their advice.

11. Community-level action can be effective in encouraging uptake of energy-saving technology and behaviour but the key characteristics of this approach – to make it cost-effective – have not been determined. Additionally, the relationships between benefits seen for the wider community from such action and how these relate to actions performed within the home are not yet fully understood. More generally, the evidence probably does not allow the full potential to be realised of connections beyond the household (neighbourhoods, localities) and the shift towards local policy responsibility.

12. More generally, the evidence on response to SES is built up largely from response to individual elements in short-term trials, with limited combinations having been studies in detail. This leaves uncertainty, therefore risk, in relation to predicting response to whole systems (especially response that involves purchase or persistent behaviour change).

13. The evidence relating to domestic buildings, while incomplete, is substantial. The evidence relating to non-domestic buildings offers a much less complete or coherent picture of consumer behaviour. This is partly because there are many different building types and a range of consumers (e.g. building owners, tenant organisations, building/energy managers, visitors to the building, students, staff managers and other employees). Perhaps also, because non-domestic buildings tend to be managed differently, there is less tendency to see consumer behaviour as important. Specific gaps of relevance to the SSH programme are as follows.
    - Much of the literature on non-domestic buildings reviews environmental performance at an aggregate, organisational level of analysis, rather than the behaviour of individual building occupants.

- There is limited understanding of the relationships between the ownership or management of non-domestic buildings, the policies and strategies of the organisation occupying the building, the culture of the organisation and its shared environments, and the behaviours enacted by individual building occupants.
- The literature tends to focus on particular types of buildings, such as universities, large office buildings and corporate headquarters, rather than on other types of buildings such as factories and workshops, community buildings, or shopping or leisure facilities.
- Similarly, the literature tends to focus on large organisations, rather than on SMEs or community organisations which are prevalent in residential areas.
- Little research has been conducted into the displacement of energy use from the domestic setting to non-domestic settings, for example when people shower at work or at the gym, eat out, or go to public buildings to avoid needing to heat their home.

8. Conclusion

Future energy systems will deploy new technologies and business models, potentially with greater consumer involvement. This review contributes to a consumer perspective, aiming to understand the energy-related lifestyle services that consumers require (such as comfort or entertainment); the potential for changes to lifestyle; the preferred characteristics of their interactions with the energy system; the design features of successful consumer-focused energy products; and the likely barriers to changes in technology and products. The following key messages follow from the review.

1. Using energy in the home is not an aim in itself – it is part of how people meet a wide range of needs, all of which should be taken into account in the design of smart energy solutions (SES) to meet unmet needs or meet needs in a new way. The needs may be categorised broadly as follows.
   - *The wider implications of energy use*: consumers might feel a need to act in a way that protects or promotes interests that go beyond the household, at scales of the planet, country or neighbourhood (relating to climate change, pollution, depletion of natural resources, the consequences of environmental damage, and energy security).
   - *Resource-related* needs: saving (or making) money, being in control of expenditure, avoiding waste and achieving self-sufficiency.
   - *Quality of life*: well-being (comfort, relaxation, rest, health, safety, security, privacy, freedom from worries or fears), aesthetics, ease, simplicity, confidence, control, entertainment and happiness.
   - *Social* needs: self-image, recognition, conforming with social norms and aspirations, association with role models, social interaction and caring for others.
   - *Regulatory* needs, i.e. complying with laws and standards.
2. Needs are not all equal, not independent of each other and priorities are not fixed.
   - The wider implications of energy use drive much policy and social action but the needs that dominate consumers' actions appear to be those related to resources, quality of life and social factors, with wider implications having a supporting but background role, especially where the perceived impact relates to energy security or is more local. Regulatory needs have a constraining role. All the needs should be taken into account in the design and deployment of SES because needs that initially appear to be subordinate will rise to the top once dominant needs are met.
   - Different needs can be closely linked in people's minds or in their behaviours, so a theoretical framework does not entirely capture the "real life" complexity of needs and how they are reflected in overarching purposes of the home, such as having a healthy, comfortable life, maintaining cleanliness, or caring for a family. Needs and purposes are both relevant to the design of SES, along with their relationships to behaviours.
   - Needs, and priorities among them, vary: between individuals and households; over time as people or their circumstances change or new technology creates new possibilities; and between contexts (e.g. home and office). The dominant needs behind one behaviour will not necessarily apply to another, one need may be met in many ways and one behaviour may meet many needs.
3. Frequency is a key dimension for understanding consumer behaviour: whether the behaviour is frequent (more-or-less daily), occasional (perhaps only once during a person's occupation of a home) or infrequent (between these two). These affect the amount of time and thought that a consumer needs to give to the behaviour (e.g. whether it is a habit or an extensively researched investment), the resources necessary for the behaviour (e.g. a light switch or a new boiler) and who is in control of making the choices (e.g. an individual adjusting a thermostat or a household deciding to install microgeneration), and therefore the kind of interaction the consumer would need to have with an SES.
4. The key issues for SES depend on the domain of behaviour.
   - Space heating is driven principally by comfort and other aspects of well-being, with social needs also playing a role, but constrained by resources, regulations and (for some), wider implications of energy use. It is complicated by limited understanding of how heating works, how to control it and negotiation within households.

- Water heating supports a diverse range of behaviours (e.g. related to personal hygiene, washing dishes and laundry, eating and drinking) and therefore a complex mix of needs. As an area for action in relation to behavioural impacts on energy use, water heating may be (or become) more important than space heating because: it could be more open to interventions targeting peak power demand; as the efficiency of space heating improves, along with levels of insulation, the role of occupant behaviour in determining energy consumption is diminishing; major water-using appliances are replaced more often than heating systems; and water use is more individually decided rather than requiring negotiation in a household.
- Insulation of a home is an important one-off behaviour but it is also important to support insulation (or heating) of individual persons with technological and social developments.
- Passive cooling must be addressed in SES, in order to avoid increasing demand for air conditioning in homes. Window-opening, in particular, is complicated since it depends on the indoor thermal environment but also indoor air quality, condensation and mould, communication with the outside world, external noise or air pollution/odours, the weather, security, safety, privacy, keeping pets in (or animals/insects/pests out) and practical/ergonomic difficulties in opening the window.
- Heating and cooling are affected, directly or indirectly by various behaviours that householders would not necessarily count as heating, from background incidental gains to major effects from cooking, tumble-drying and personal heating/cooling with baths and showers.

5. Sociodemographic variation in needs and behaviour is important but difficult to apply; it is more important to understand the needs and behaviour themselves. Energy-related behaviours and needs vary with a range of demographic factors, at individual, household and community level. But the relationships are not sufficiently clear or strong that sociodemographic segmentation would indicate the appropriate SES for a particular person or household: this would more likely start from the dwelling characteristics. Groups defined by clusters of needs could guide the development and deployment of SES, without necessarily assigning each person or household to a group in advance.

6. In a research context, demographically based stratification could nevertheless be useful in ensuring that a wide range of relevant characteristics, needs and behaviours are represented in a sample.

7. Over time, response to SES could change in response to changes in external factors, i.e. factors outside the direct influence of programmes to implement smart energy system. These factors could be:
    - political, e.g. EU or national policies addressing consumer attitudes;
    - economic, e.g. fuel prices, or the cost structure of personal energy generation;
    - social, e.g. demographic changes or changes in societal and individual attitudes and roles;
    - technological, e.g. the rate of technology obsolescence and shifting to new technologies;
    - legal, e.g. changes in regulation or Government policy;
    - environmental, e.g. changing weather patterns.

8. Options for SES should not be considered generically or individually. The details of design and deployment matter and need to be judged against the available research evidence and practical experience. The combinations of elements also matter, to create coherent overall packages that offer households the means, motive and opportunity to manage energy better.

9. SES do not have to be completely smart or targeted directly on energy. The basics of insulation and simple instructions are critical, and “lateral” solutions should also be considered, such as dirt-repellent and deodorising clothes, and soaps and shampoos that are easy to rinse off.

10. People understand that change is necessary and inevitable but they need to be persuaded about particular changes. Critical non-technical factors will be:
    - timing in relation to household events such as moving home, major repair or refurbishment, extending or having a family;
    - trust in those proposing or offering change;
    - clear presentation of benefits and value, especially if there are barriers such as a large capital cost, long payback period, inconvenience or aesthetic objection.

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Appendix C: Review of the Literature: http://www.ofgem.gov.uk/Sustainability/EDRP/Documents1/EDRP%20Appendix%20C%20Review%20of%20the%20literature%20of%20interventions%20used%20in%20EDRP.pdf

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Abbreviations

Key to abbreviations used in the text.

ACEEE	American Council for an Energy-Efficient Economy
CCS	Carbon capture and storage
CFL	Compact fluorescent lamp
CHP	Combined heat and power
CPP	Critical peak pricing
CRaB	Consumer Response and Behaviour
DCLG	Department for Communities and Local Government
DECC	Department of Energy and Climate Change
Defra	Department for Environment, Food and Rural Affairs
DfT	Department for Transport
DSR	Demand-side response
ECEEE	European Council for an Energy-Efficient Economy
EDRP	Energy Demand Reduction Project, published in a report on the trials plus a literature review (Raw & Ross 2011)
EST	Energy Saving Trust
ETI	Energy Technologies Institute
IAQ	Indoor air quality
ICT	Information and communication technology
IEA	International Energy Agency
IHD	In-home display (also sometimes referred to as “real-time display”)
ISMeT	Irish Smart Meter Trials, published in a set of reports by the Irish Commission for Energy Regulation (CER 2012)
MV	Mechanical ventilation
ONS	Office for National Statistics
PV	Photovoltaic
RQ	Research Question
SES	Smart energy solution(s)
SSH	Smart Systems and Heat
ToU	Time of use

Appendix A. The research questions

Introduction

The relevant Research Questions (RQs) agreed for the Consumer Response & Behaviour (CRaB) project as a whole, were as follows.

RQ1. What needs do consumers want to meet, that involve energy use?

RQ2. What do people currently do that uses energy?

RQ3. Why do consumers exhibit particular energy-using behaviours?

RQ4. How do consumer needs, behaviour, motivation and rationale vary across the population?

RQ5. What external factors, that could affect consumer needs, behaviour, motivation or rationale are likely to change over time?

RQ6. How would these factors be expected to impact consumer needs, behaviour, motivation or rationale?

RQ7. What is the likely consumer response to potential smart energy system solutions?

RQ8. How can smart systems meet current and future needs?

A workshop at the start of the CRaB project brought together the Consortium partners, ETI representatives and ETI advisors. This workshop refined our interpretation of the RQs to show what should be considered in relation to each question, when reviewing the literature or consulting experts. It is this interpretation that is described below and applied in the review.

RQ1. What needs do consumers want to meet, that involve energy use?

This refers to the needs that people have, for which they use energy, and the extent to which each need is currently being met. Fundamental needs can generally be related back to comfort, health, safety, productivity, security and happiness. Examples are:

- achieving thermal comfort (whether by heating or cooling), acceptable air quality and levels of lighting that promote certain moods or enable certain tasks to be carried out;
- having hot/cooked food and drink; being clean and having clean (and dry, mould-free) clothes, homes and cooking/dining items;
- entertainment.

Within these fundamental needs, there may be evidence on more specific needs, such as how much of the home is heated or the specific temperatures required.

The definition of "need" is intentionally broad, ranging from objectively "essential for life" to preferences based on individual perceived needs or values. A need exists whether or not a person is aware of either the need itself or the contingent energy use. In some cases, the role of energy may be distant in people's minds from the need itself; this might be true, for example, where the need for social acceptance leads to maintaining a temperature higher than necessary for thermal comfort, or where light is used for aesthetic effect rather than to see things. Needs might relate to a person's own individual needs, social norms and expectations, or standards set by regulators or professional bodies.

Whether the need is personal, social or standard-based, there may be a priority order of needs, although this may be observable only when there is a limit on the resources available to meet the needs (e.g. in cases of fuel poverty). The definition of priority order is complex, since it might be:

- either perceived or objectively defined;
- either observed or reported;
- either fixed or flexible for a given person or household;

- dependent on relationships between needs, where one behaviour addresses more than one need (e.g. a fire may offer both heat and light, a bath may provide washing, comfort and relaxation);
- related to whether or not each need is currently met.

Needs may be directly those of the person taking the decision that results in energy use (e.g. I want to read, so I put the light on), decided by negotiation (e.g. I'm OK but my partner wants the light on, so I put the light on) or decided on behalf of someone else (e.g. my toddler needs to see his toys, so I put the light on). Hence, the definition of needs and priorities is socially complex, depending on who is dominant in the decision-making, the needs of a range of persons, and care responsibilities (e.g. foregoing a hot meal so that children can be kept warm).

RQ2. What do people currently do that uses energy?

This refers to the range of behaviours that people currently exhibit that result in use of energy in the building they are occupying; it includes behaviours that result in *less* energy use. The person might or might not be aware of the energy implications of the behaviour. For example, switching on an electric fire might obviously use energy but opening a window (on a cold day, if the heating is controlled by a thermostat) will indirectly use energy. Similarly, people may not be aware of the role of energy in a sedentary lifestyle (e.g. watching a lot of TV), which may require higher room temperatures but less frequent washing of clothes.

Behaviour is broadly defined, including: one-off major installations (e.g. insulation or a new boiler); routine purchases (e.g. light bulbs); and day-to-day behaviour with whatever "technology" is available (e.g. turning lights on or off).

There is always some combination of behaviour and technology, even if the technology is a warm sweater, hence the two should be considered together. In particular, the possible behaviours will depend on the technology that is available. Furthermore, one piece of technology may meet several needs and one need may be met by the interaction of several technologies, hence there may be complex interactions. The review should therefore include what technologies (systems, products, services, programmes) people interact with when they use energy.

Descriptions of behaviour may be expressed at a range of levels, from the generic (e.g. heating, cooling, ventilating, lighting, cooking, washing) to specific (e.g. heating the whole home by using a gas boiler and radiators, to a living room air temperature of 21°C from 07:00-09:00 and from 17:00-22:00 each day from October to April). Behaviours may vary in time – during the day, week or year, or over a lifetime.

The scope is energy delivered to homes. Energy delivered outside the home that has an impact on domestic energy use (e.g. eating out or showering at a gym instead of at home) is included in the review but not quantified. Embodied energy and lifecycle analysis are out of scope.

RQ3. Why do consumers exhibit particular energy-using behaviours?

While RQ2 refers to *what* people do, RQ3 refers to the reasons *why* they do it: why do people adopt (or change) particular behaviours (and the associated technologies) to meet their needs as defined in RQ1? The question applies, whether or not the behaviour is a conscious choice or the person is aware of the energy impact or energy is an issue in the decision to act (e.g. renovation may be carried out for other reasons but have an impact on energy use).

Potential ways of explaining behaviour include various aspects of motivation and rationale in addition to the specific need being met, such as awareness, knowledge, personal drivers (e.g. environmental concern, family dynamics, desire to socialise, achieve social status or personal control over costs), people's beliefs about how much energy they use (and whether this is high or low), experience of different thermal climates (in other countries or in different buildings or means of transport), habits, barriers and constraints. For example, someone may use gas central heating because it is "normal", trusted, affordable and understood.

Choices related to energy supply and billing are also relevant here, e.g. the attention given to energy bills, switching providers or changing tariffs.

The review considers the constraints and trade-offs relating to finance (including the role of energy costs and incentives to reduce or shift energy use), awareness of the energy implications of particular behaviours (e.g. how energy is used by putting on a heater or opening a window) understanding of the technology (e.g. how the heating system works), lifestyle (e.g. eating out, taking part in sports) and the actual level of choice or control (e.g. whether the heating system has central or room-by-room thermostatic or timing controls, and being able to understand and manipulate those controls).

This question includes understanding whether (and why) the same individuals exhibit different needs, behaviours or motivations in different settings, e.g. home vs office.

RQ4. How do consumer needs, behaviour, motivation and rationale vary across the population?

This refers to consumer segmentation to assist understanding of the take-up and use of smart energy solutions (as defined in RQ7) across the whole UK population. For example, one segment may need warmth less and want to be less wasteful, and therefore could be more likely to use heating timing controls; another segment may want to be warm all the time and distrust technology, and therefore prefer to switch heating on manually whenever they are (or might be) at home.

The final segmentation will need to relate to consumer requirements and behaviour (particularly space heating) related to energy use but the practical basis of the segmentation needs to be informed by the review and consultation. The basis of segmentation could include:

- individual consumer or household demographics – either direct (e.g. age, sex, income) or indirect (e.g. Mosaic, ACORN);
- dwelling demographics – the fabric of the building and its services;
- location factors – climate, urban/rural;
- potential to install or connect to smart energy systems;
- consumption patterns (e.g. exceptionally high or low energy use).

RQ5. What external factors, that could affect consumer needs, behaviour, motivation or rationale are likely to change over time?

This refers to external factors that could change (according to realistic scenarios) up to 2050, and that have some potential to change people’s needs, behaviour, motivation or rationale. Relevant factors may be categorised using the PESTLE (Political, Economic, Social, Technological, Legal and Environmental) framework. The external factors are outside the obvious energy-related needs, behaviour, motivation and rationale. Examples of external factors are:

- political, e.g. EU or national policies addressing consumer attitudes;
- economic, e.g. fuel prices, or the cost structure of personal energy generation;
- social, e.g. demographic changes (older population, multiple generations living in one home), or lifestyle changes (home working, growing food at home), or changes in societal and individual attitudes and roles (shift from consumer to prosumer);
- technological, e.g. the rate of technology obsolescence and shifting to new technologies;
- legal, e.g. the regulatory landscape (Feed-in Tariff, Renewable Heat Incentive, Green Deal, carbon reporting/recording, etc.);
- environmental, e.g. changing weather patterns impacting on energy generation and consumer awareness.

Evidence on the direction of change is included, plus any quantification of the magnitude, timing or pace of change.

RQ6. How would these factors be expected to impact consumer needs, behaviour, motivation or rationale?[31]

This refers to analysis of how the factors identified in the context of RQ5 would affect specific consumer energy-related needs, behaviour, motivation or rationale, or consumer acceptance of smart energy systems. While core needs (e.g. wanting to keep warm) will probably not change, the details (e.g. the means by which needs are met) probably will.

A full quantification was not intended but the direction of effect, and whether it is likely to be major or minor, is indicated (along with the general trajectory, e.g. whether it is likely to be a step change or a smooth transition, whether the change may be persistent or transitory). For example, a marked increase in gas prices should tend to make people more receptive to smart energy solutions that use electricity for heating.

Evidence on how external factors (or their effects) are distributed across consumer segments is also relevant. This includes segments of residential consumers and differences between residential and non-residential consumers. Conversely, the question could be which household or individual characteristics intervene between changes in external factors and behavioural changes in energy use.

While the evidence may be based largely on what has affected consumers in the past, future scenario studies are also relevant.

RQ7. What is the likely consumer response to potential smart energy system solutions?

This refers to prediction of how consumers would respond to particular smart energy system solutions – solutions aimed at meeting unmet needs or meeting needs in a different way. It includes both the uptake of solutions and their use after take-up. There is an overlap with RQ6 to the extent that external factors may affect consumer response. Also of interest is evidence on differential targeting and response between consumer segments, based on RQ4.

A solution scenario is in essence a system of technologies combined with social interaction. The technologies might include general renovation measures in addition to the smart element, and solutions for the provision of comfort that are part of a larger smart control system (e.g. providing communication or security systems).

The social interaction elements of a scenario relate to how the solutions might be presented and facilitated: whatever is put in place to either promote or support the smart system and the service that it aims to provide. This would include, for example:

- general and personalised consumer engagement strategies, communications and education;
- logistics, implementation strategies and delivery processes;
- removal of barriers;
- financial mechanisms and policy instruments.

The role of personal and household social networks should also be considered.

The functionality of the smart systems will be focused primarily on heat/cooling provision, but may also include peak demand management and energy efficiency (making the same amount of energy deliver greater benefit to consumers).

Evidence for the answer to RQ7 may come from experience of consumer response related to smart systems, energy-related interventions (e.g. Green Deal), both or neither. Evidence might concern:

- existing technology adoption models;

[31] The numbering of RQ5 and RQ6 does not imply that one should be fully answered before consideration of the other. In practice, understanding what external factors are most likely to affect energy issues (RQ6) should guide how much effort to put into investigating each external factor (RQ5).

- what motivates customers' response to energy innovation;
- the relative importance of socio-demographic, attitudinal or behavioural characteristics, price and billing, brand in determining adoption decisions;
- who people trust in relation to energy in general and smart energy systems in particular;
- the dynamics of consumer response within individual households;
- potential barriers and adverse trends, either technical or related to the process of adoption (data security and privacy, health concerns, cost, payback, hassle, etc.);
- how these barriers might be overcome (e.g. through communications or direct support or advice).

RQ8. How can smart systems meet current and future needs?

This refers not to specific technological or social solutions but to the solution characteristics, i.e. the characteristics that solutions will need to have if they are likely to be successful (now and in the future). This will need to take into account the answers to RQs 1-7 but extend them to identify specific key characteristics, ideally with an order of priority. These characteristics might, for example, relate to:

- core functions;
- simplicity/ease of installation or use;
- engagement;
- cost;
- disruption;
- technological complexity and attractiveness;
- reliability and performance;
- service model;
- variation across consumer segments.

Appendix B. Literature review summary template

This template is to guide your review if you are not connected to Zotero, away from a computer or just prefer to record on paper first.

If you are using a computer, please replace the relevant non-bold text with your review.

If you are recording on paper, you can use the reference numbers on the left to relate your review to the template.

Review details

Reviewer name: Text

Date of review: Text

Source ID: XX.nn

Document title: Text

Existing Zotero Ref? Yes / No / Don't know

Source details (If no Zotero Ref)

Author(s): Text

Date of publication: Text

Source [Title of source]: Text

Publisher [Including "commissioned by" if applicable]: Text

Source Category: Select from Zotero categories, e.g. Academic Journal / Review / Book / Discussion / Report / Media Article / Other (specify)

Confidentiality/Rights [Is it embargoed, commercially sensitive, licensed or subject to other limitations?]:

Text

Abstract to be obtained through Zotero? Yes / No If not, write a brief summary.

Text

Source content

Reviewer's overall comments

Text

Author's Research Question(s) [If applicable]

Text

Key words to characterise source [Select from current list in separate document]

Text

Method category: Telephone survey / Postal survey / Online survey / Face to face interviews / Questionnaire / Interview script / Focus groups / Ethnography / Economic modelling / Energy monitoring / Environmental monitoring / Scenario development / Technology development or testing / Other (specify: text)

Research tool available?

Text

Summary of research design/method

Text

Relevant technologies

Text (if not adequately covered by keywords)

Relevant focus characteristics, if applicable [E.g. does the study focus on a particular time, location or otherwise? What does the sample look like in terms of size, demographics, etc.?]

Text

Key conclusions by author(s)

Text

Relevant to WPs: WP5.1b / WP5.2 / WP5.3 / WP5.5 / WP5.6 / WP5.7 / WP5.8 / WP5.9

Quality Rating: No value / poor / medium / good / excellent

Quality Comments [Do you believe the findings? Why/why not? Has specific evidence been presented to back up the conclusions? Are some findings or conclusions valid but not others?]

Text

Any key references for follow-up

Text

<u>**Answers to the research questions**</u>

RQ1. What needs do consumers want to meet, that involve energy use?

Text

RQ2. What do people currently do that uses energy?

Text

RQ3. Why do consumers exhibit particular energy-using behaviours?

Text

RQ4. How do consumer needs, behaviour, motivation and rationale vary across the population?

Text

RQ5. What external factors that could affect consumer needs, behaviour, motivation or rationale are likely to change over time?

Text

RQ6. How would these factors be expected to impact consumer needs, behaviour, motivation or rationale?

Text

RQ7. What is the likely consumer response to potential smart energy system solutions?

Text

RQ8. How can smart systems meet current and future needs?

Text

RQ9. What characteristics would the ideal field trial location have?

Text

RQ10. What are the barriers, risks and gaps in our knowledge at the end of the project?

Text

ETI CRaB: Reviewer guidance

Each review should be recorded in Zotero, even if you conclude that the document is irrelevant or of such poor quality that it should not be used.

By using the Zotero set-up to guide your recording of the review, you should be able to record what the project requires. The heart of the review is the answers to the 10 Research Questions (RQs), so please put most of your effort into these.

The RQs are listed and explained in a separate document.

It is important to respect the confidentiality of any documents that are not in the public domain, and to avoid any risk of being accused of plagiarism.

Remember to review the research methods used, not just the findings and conclusions of the documents reviewed. In particular, please be careful to note methods and research instruments that could be adopted or adapted for CRaB.

Assessment of the quality of each report is largely down to you but should focus on the way the report helps us to answer each RQ, rather than the quality of the report as a whole. For example, a report might give you little confidence in relation to explaining householders' behaviour, but be reliable as a simple description or quantification of the observed behaviours.

Please use the keywords listed overleaf. Please note:

- the bold headings just to organise the key words – they are not themselves key words;
- these are keywords for recording your reviews, not search terms to use in database searches, although there will be some overlap;
- if you wish to add a key word, please contact one of the Zotero administrators.

ETI CRaB: Keyword index

1. Basic needs
- thermal comfort
- air quality
- light
- hot food/drink
- cleanliness
- entertainment
- health
- wellbeing
- other basic need

2. Basic inputs
- heating
- cooling
- ventilation
- lighting
- cooking
- washing
- power
- other basic input

3. Settings
- domestic
- offices
- retail
- schools
- transport
- manufacturing/industrial

4. Meeting needs (buildings & systems)
- building fabric measures
  - energy efficiency
  - insulation
  - airtightness
  - passive solar
- in-building control systems
  - central heating controls
  - thermostatic radiator valves
  - energy displays
  - smart technology
  - BEMS
- in-building energy storage
  - thermal mass
  - thermal stores
  - phase change materials
- in-building power generation
- in-building heat generation
  - boiler
  - heat pump
  - solar thermal
  - micro-CHP
- in-building cooling
  - air-conditioning
  - comfort cooling
- in-building ventilation
  - uncontrolled ventilation
  - heat recovery
  - mechanical ventilation
  - passive ventilation
- in-building system installation
  - new build
  - retrofit/renovation
  - home improvement
  - installation
  - repairs/servicing
  - replacement
- centralised generation
  - district heating
  - distributed generation

5. Physical indicators
- energy consumption
- temperature
- air movement / draughts
- air flow / air changes
- humidity
- heating degree days

6. Consumer characteristics
- demand for energy
- knowledge
- awareness
- attitudes
- expectations
- behaviour
- motivation
- income status
- fuel poverty status

7. Consumer behaviour
- adaptive approaches to meeting needs
- energy use behaviour
- indirect energy use behaviour
- energy controls/systems behaviour
- vehicle charging patterns
- technology adoption
- drivers & barriers of behaviour change
- behaviour modelling
- trends in consumer behaviour

8. Demand side response
- dynamic pricing
- time of use tariffs
- energy feedback

9. External drivers/barriers
- political
- economic
- social
- technological
- legal
- environmental

10. Scenarios / trends / projections
- energy demand
- energy prices
- transport demand
- technology innovation/ adoption
- population/demography
- 2050
- low carbon

11. Segmentation/sampling
- population
- demographic profile
- income
- energy use
- fuel poverty status
- household composition
- building type
- attitudes
- behaviour

Appendix C. Identification of external factors

Using a combination of collaborative workshops and external consultation with experts on various PESTLE (political, economic, social, technological, legal and environmental) factors, a wide range of external factors have been explored that had the potential to impact consumer needs and behaviour. In order to evaluate the significance of these factors and select the key factors to be considered further, we focused on the following criteria.

- A high and direct impact on consumer needs and behaviour for energy use. A number of external factors were discounted because they did not have a direct enough impact, or were secondary rather than root factors.
- Strongly expected to change out to 2050, highly uncertain out to 2050, or have a changing relationship with energy needs and behaviour to 2050.
- Sufficiently well defined, to allow desk research to be carried out.

Based on this assessment, we narrowed down the initial list of external factors drawn up in a brain-storm exercise to the 18 key external factors shown in Table B1. Six of the group (income, age, education, technological progress, energy performance labels and Building Regulations) have a low uncertainty of change, meaning the evidence surrounding the expected change to 2050 is the most robust.

Table B1: Key external factors

PESTLE factor	Key External Factors
Political	• *EU policy* – influence on UK energy policy and consumer attitudes • *National policy* – provision of support, guidance and direction to the public • *Local Policy* – impact of localisation on climate change policy implementation
Economic	• *Income* – average consumer income, income distribution and disposable income • *Cost of low carbon technologies* – absolute and relative costs, relationship between upfront and running costs • *Housing tenure* – changes in levels of home ownership • *Fuel and electricity prices* – domestic gas and oil prices, grid electricity prices
Social	• *Ageing population* – increase in elderly population • *Education* – rising levels of education • *Household size* – changing household sizes, rise of single person households
Technological	• *Energy efficiency* – advances in smart technologies, improved efficiencies for appliances, retrofit products and microgeneration • *Diversity of energy generation* – role of low carbon technologies • *Electrification* – impact of mass market electrification, increase in electricity demand
Legal	• *Building Regulations* – stricter standards for emissions reduction • *Energy sector regulation* – market controls, maintaining security of supply, reducing carbon emissions • *Energy performance labels* – impact on consumer decision-making and product availability
Environmental	• *External temperatures* – projected temperature increases, changes in heating and cooling demand • *Extreme weather events* – changing weather patterns and consequences, impact on energy generation and consumer awareness of climate change

Appendix D. Team and community action

Community- and team-based approaches use peer support (and, indirectly, social pressure) through group briefings, meetings, shared action and commitments. They thus combine elements of technology with advice, feedback, benchmarking, target-setting, etc. with the addition of direct social interaction and engagement. A community does not have to be geographically defined – it could be members of a group defined by a sports team, church, mosque or school. Action at this level tends to be flexible and interactive, depending on the households, not just a researcher. Therefore is it is inherently difficult to describe the solution or specify why an action has succeeded or failed in terms of the observable measures taken.

The point is not so much to try to relate outcomes to specific measures, either installations or behaviours: that would be to miss the main point of community trials. The energy savings from specific measures can be estimated a trial but the estimate will be wrong because the major unknown is whether the measure will be taken at all. In any case, it may not be possible to attribute impact to specific energy-saving measures. The point of community trials is that the community decides what actions to take: it is not driven by an energy savings formula. The magnitude of potential savings is relevant and there has to be a sense of proportion, but this leaves many sensible actions for communities to choose from. The sense of engagement comes from making that choice in a way that fits with the particular community.

Consumer response may appear to be a misnomer in this case, because the community may be the initiator rather than the responder and community-led initiatives are often more successful at encouraging participation than initiatives led externally (Southerton *et al* 2011), e.g. by Government or energy companies. But being part of a local community can introduce contradictions in an individual's attitudes or motivations towards energy use. Changing energy use behaviours may be a source of personal inconvenience, discomfort and ambivalence, at the same time as being subject to considerable social and personal moral approval through its links to topics such as environmental risk, climate change mitigation or the promotion of sustainable energy futures (Harwood 2012).

RAND Europe (2012) reviewed studies that employed this approach; they conclude that team-based interventions can achieve behaviour change, resulting in persistent energy savings of the order of 10% without major installations. Widening the approach to whole communities can also bring about substantive savings, particularly where there is a financial incentive to save energy or to take particular actions, or if installation grants are available. Examples are Transition Streets (Ward *et al* 2011), Green Streets (Lockwood & Platt 2009) and the EDRP Community Trials (Raw & Ross 2011). However, wider implementation of such programmes may be limited by cost and the requirement for highly tailored instructions and coaching.

Where the action takes the form of a competition, RAND Europe (2012) concludes that the initial savings can be higher but are less likely to be persistent. Hence competitions should aim to achieve structural changes that will bring about persistent energy savings without persistent behaviour change.

This evidence represents a context, common in the UK, in which communities respond to an external initiative. This may be compared with an alternative (common in the Netherlands, for example) in which communities take the initiative and seek external support (Oostra & Jablonska 2013). These projects tend to start with a significant, highly visible investment (e.g. a large PV array) and develop household-level action from this starting point.

Raw & Ross (2011) make the following suggestions about the process of community-level interventions.

- *Baseline*: each community has a different starting point, in terms of: actions already taken; understanding of what else could be done, and why; motives and resources – money, time, space and intellectual and social capital. This is partly dependent on the extent to which the community is truly a community, not just people who happen to live in the same area: whether there is an existing sense of belonging, common culture or a community focal point. All these factors need to be considered in community-level action.
- *Leadership*: local leadership is essential so that it is seen as part of the community rather than externally from outside. It is generally easier to find local leaders among people who are already involved in energy issues (and their involvement is important) but leadership focused on energy alone finds it difficult to a the community, especially if it is newly formed for the trial and has no existing identity in the community. There will be people of local influence and reputation, whether in official positions or not; it is easier to

give them an understanding of energy issues than to give energy enthusiasts a local network. Much can also be achieved through a loose collective of local groups, each with a focused aim.

- *Support*: while leadership should be local, it is also important to have access to high quality advice and guidance, to make the most of the available resources. External financial support can also be a significant factor in gaining local interest, so long as there do not appear to be strings attached or ulterior motives.
- *Relevance*: many actions can be taken but not all will be relevant to a given community. Some actions will physically make more sense, or be aesthetically or socially more acceptable, than others. The motives that a particular community can relate to are also relevant (e.g. the environment, saving money, or taking pride in having the latest technology). Actions also need to be tied to the resources available, including the time that people can offer, the space available and local expertise in designing, procuring or installing measures. These can be complex choices and it is essential to have a fair and open way of people expressing their views and get involved in delivery. One or two high profile public measured will give a clear reminder of the overall project and engender a wider sense of ownership. Where a target has been set, the recommended actions also need to be based on their actual contribution to meeting the target.
- *Promotion and communication*: not just the actions but also the promotional activities need to be relevant and attractive. Activities can benefit from being part of some wider event that people would be attending for other reasons (e.g. local fairs). Websites and newsletters are tools for coordinating and supporting activities but they are passive means of engaging people. The biggest risk is a promotional activity that backfires because its message or style creates antagonism, embarrassment or confusion.
- *Targets and rewards*: It should not be assumed that either a target or a financial reward is essential or that each requires the other. A fixed target can provide motivation but so can a judged competition, or just community pride in what is being achieved. A key factor is that any target or competition should be widely viewed as fair – at the start and throughout the project. Also, the smaller the defined community, the more difficult it will be for free-riders to go unchallenged. The nature of any reward should balance relevance to the community, scale and affordability. Financial rewards can gain greater substance by deciding collectively what to do with them, at the start of the project. The counter-argument is that some people will disagree with the chosen use, and therefore be disinclined to support the endeavour. However, if the use is well chosen, it should retain interest from more people than an entirely unspecified use.
- Feedback on progress – at household, business and community level – is essential. This should be reliable, easy to access and digest, and regular (but at long enough intervals to create a sense of anticipation and show movement from one period to the next).

Appendix E. Web-based interventions

The web is not an intervention as such but is a rapidly developing medium for delivery of a range of types of intervention. The important differences between paper- and web-based information are probably that the latter is (a) a more active process for consumers than passively receiving printed material, (b) more able to provide tailored information and advice to the individual user, to support response to feedback and (c) more easily and immediately linked to options for action to reduce consumption and the resources for carrying out those actions. Certainly the web offers opportunities to bring together *means*, *motive* and *opportunity* in a way that would be hugely more resource-intensive through other media. The key point is not so much whether the web has greater impact for a given intervention but rather that it creates new possibilities.

Studies have used the web as part of a package of interventions delivered to households, variously including feedback, advice, targets, ToU tariffs, incentives and IHDs. These studies tend to show significant energy-saving effects but they do not provide evidence of the particular contribution, if any, of the use of the web. In the EDRP trials, web-based interventions (including a TV-based web page) did not have any sustained effect on energy consumption. It was not tested directly but surveys suggested that the online provision of feedback would have been more effective if real-time data had been provided. Web-based feedback was perceived as being less convenient than IHDs because of the extra time involved in accessing PCs but this evidence was largely from before the era of tablets, smart phones, etc.

More direct evidence comes from two studies reviewed by RAND Europe (2012), in which online participants achieved greater savings than those participating by post. The review questions whether the higher impact of online information provision is due to the media through which the information is communicated (online being more immediate and delivered via an electronic device rather than a letter) or the self-selected sample that chose to receive the online communication and engaged more actively.

The varied and complex contents and delivery options of web-based services make it difficult to discern what the essential “active ingredients” are or what the optimum web-based feedback would look like. In addition to generic principles of good web design, the following are general pointers for SES characteristics.

As far as possible, web interventions should be independent of the specific existing ICT in the home, to maximise accessibility and flexibility of delivery. Information should focus on what users most want to see, and with better linkage between consumption data (real-time and historic), advice and access to external financial and technical support. It is also important to pitch information at an appropriate level: making the sites simple and attractive for newcomers to energy issues but with easy access to detail and tools for people who are actively researching (and seeking to reduce) their usage. Only the first or second screens in access sequences tend to be used, so the most useful information should be put on those screens.

User feedback suggests that the web is not a good substitute for IHDs in relation to their prime function of real-time feedback: using a PC for this takes extra time and trouble and relies on a good internet connection. IHDs are also more portable and more convenient to leave in rooms such as kitchens and utility rooms. There is a case for combining web-based feedback with an IHD (and allowing users to download data from the IHD to a web page). The IHD is then used for immediate information, while the web page can supply graphics, a long view of consumption patterns, and the opportunity for detailed exploration of the data.

For web-based interventions – perhaps more than for other media – the right question might not be whether they work, but rather for whom they work. The most promising uses of the utility-based websites seem to be with particular subsets of the population and/or specific, focused programmes. Some people would not use web-based service at all, some would make limited use (e.g. to check consumption, but with no intention of reducing it) while others would make effective use of websites to reduce consumption. Alternatively, it may be that most people would use a web-based service but only at certain times (e.g. when moving to a new home or when there is a rise in energy prices) or in certain contexts (e.g. where a more complex energy management demand, such as ToU tariffs, benefits from additional information).

Data privacy may be a consideration for some people; for others, this will seem insignificant in relation to the information that they already exchange online.