# How occupants behave and interact with their homes

## The impact on energy use, comfort, control and satisfaction

NHBC Foundation
Housing research in partnership with BRE Trust

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# FOREWORD

Consumers are becoming increasingly aware of the benefits of energy efficient homes, and how purchasing a new home can deliver substantial financial savings on energy by contrast with an older property. However, the energy-efficiency of new homes is reliant on human interaction and behaviour as well as design and technology.

This publication reviews current and previous research carried out with users of low and zero carbon homes. It summarises how the energy use of buildings is significantly affected by the actions of homeowners, considers their perceptions of microrenewable technologies, and assesses the relationship between occupant behaviour and energy efficiency. It also helps to throw light on the extent to which new homes in use (in some cases) fail to deliver the anticipated energy efficiency.

Homeowners need to understand how renewable technologies can play a part in achieving optimum comfort levels as well as energy savings, through guidance that not only shows how they operate, but how owners and occupiers can make the best use of them. The use of new, low carbon and renewable technology in homes is increasing and is expected to grow further through incentives such as the Feed-in Tariff and the proposed Green Deal, so it is essential that the gap between expected and actual energy performance of the home is bridged.

While moving towards zero carbon for new homes, and overcoming the challenges of reduced domestic energy consumption, it is vital to demystify renewable technologies and ensure homeowners gain full advantage and satisfaction from the innovations in design.

I hope that you will find the evidence in this publication useful and informative.

**Rt. Hon. Nick Raynsford MP**
Chairman, NHBC Foundation

# ABOUT THE NHBC FOUNDATION

The NHBC Foundation was established in 2006 by the NHBC in partnership with the BRE Trust. Its purpose is to deliver high-quality research and practical guidance to help the industry meet its considerable challenges.

Since its inception, the NHBC Foundation's work has focused primarily on the sustainability agenda and the challenges of the government's 2016 zero carbon homes target. Research has included a review of microgeneration and renewable energy techniques and the groundbreaking research on zero carbon and what it means to homeowners and housebuilders.

The NHBC Foundation is also involved in a programme of positive engagement with government, development agencies, academics and other key stakeholders, focusing on current and pressing issues relevant to the industry.

Further details on the latest output from the NHBC Foundation can be found at www.nhbcfoundation.org.

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# CONTENTS

# EXECUTIVE SUMMARY

The NHBC Foundation believes that there is a pressing need for more information on how end users interact with new homes and what impact this has on energy use and occupant comfort and satisfaction. This review was therefore commissioned to examine a broad spectrum of research areas including: research on controls and user interfaces, domestic user guides and product manuals, occupant behaviour and behaviour change, occupant feedback on low energy homes and consumer perceptions of micro-renewable technologies. The review examines current and previous research and aims to identify any gaps in knowledge and specifically where further work is needed. It details the findings from a comprehensive literature review and contributions from BRE social science experts.

The findings of the research indicate that further research will be required to examine:

- **Occupant behaviour**: How occupants use their homes and energy-dependent systems. How best to change occupant behaviour. How new homes and technologies can be designed to encourage behaviours and habits that reduce energy use.
- **Feedback to occupants**: Looking at what information should be provided through smart meters, and other feedback devices, and in what format this information should be provided.
- **Designing controls and interfaces**: How to design intuitive, simple controls and user interfaces. Examine what impact automated controls have on domestic energy use and what occupants think of them.
- **Educating and informing occupants**: How best to inform users how to make the most efficient use of their homes and the systems in them, not just how to operate them. Understanding what information should be provided in user guides, at what level of detail and in what format should this information be provided.
- **Post-occupancy evaluations**: Collecting occupant feedback and monitoring data from the latest low energy homes to better understand how these homes are used and how they perform in practice.
- **Microrenewable technologies**: How these technologies actually perform in the 'real world'. What the future maintenance issues are likely to be. How well occupants understand the systems and how to control them. The impact of occupant behaviour on the performance of the systems and what influence the systems have on how occupants behave.

# 1 Introduction

## 1.1 Background

The energy efficiency of buildings is significantly affected by the presence, actions and attitudes of building occupants. Unoccupied houses require little or no energy, however a great deal of energy is used to ensure the environmental conditions in the home (temperature, lighting, ventilation etc) are 'comfortable' for the occupants. Thus, the way the occupants behave and interact with the building can have a massive impact on the energy used and the comfort levels achieved. The NHBC Foundation believes that there is a pressing need for more information on how end users interact with new homes and what impact this has on energy use and occupant comfort and satisfaction. This review was prepared by the Social Research Team at BRE for the NHBC Foundation. It was commissioned to examine current and previous research in this area and to identify any gaps in knowledge and specifically where further work is needed.

The aim of this review is to provide an overview of research into occupant behaviour in domestic buildings. It will summarise and assess the relationship between occupant behaviour and the energy efficiency of domestic dwellings. It will also look at occupant feedback on new homes and their perceptions of micro-domestic energy systems.

The objectives are to:

- review research into end users of new homes
- assess the current and potential issues and problems
- identify gaps in knowledge and where further research is needed.

This review examines five main areas:

- **Designing for the end user**: An examination of research on controls and user interfaces and the importance of getting them right as technology and control systems become ever more complicated.

- **Informing the end user**: The role of domestic user guides. What research has been done in this area? What should they contain? In what format should the information be presented?
- **The impact of the end user**: How occupants interact with their homes and the impact of their behaviour on energy use, comfort and satisfaction.
- **Feedback from end users**: What occupants are saying about the latest homes on the market and what the latest examples of low energy homes are like to live in.
- **Perception of microrenewable systems**: Drivers and barriers to investing in these technologies and an examination of how these systems are performing in the real world and how consumers perceive them.

This review outlines the main findings from an extensive literature review and input from experts at BRE.

## 1.2 Energy use in households

Energy use in domestic buildings is determined by physical factors, such as building characteristics and local climate; and socio-demographic factors such as household composition and human behaviour. Approximately 27% of British carbon dioxide emissions come from the energy used in homes (Energy Saving Trust, 2010b). The typical household wastes approximately one-third of that energy each year (POST, 2005). Although POST does not specify where this waste comes from, an Energy Saving Trust report (*The Habits of a Lifetime*) found that the most prolific habits that lead to wasted electrical energy were: 71% of consumers left appliances on standby, 67% boiled more water than needed in the kettle, 65% left electrical chargers plugged in and 63% forgot to turn lights off in unoccupied rooms.

In UK homes, energy use is split between heating and hot water (approximately 77%) and powering appliances/lights (approximately 23%) (POST, 2005). Domestic energy consumption has fallen in recent years, after a peak in 2004. Reasons for this reduction include high fuel prices, relatively warm weather, actions by consumers, such as making improvements to their homes (for example, insulation) and changes in behaviour, for example, turning electrical equipment off instead of leaving it on standby (Ofgem, 2010). British Gas figures show a 22% drop in household demand for gas as energy efficiency measures take effect (Centre for Economics and Business Research Limited, 2011). According to POST (2005), the two main barriers to energy efficiency are technology and behaviour.

The Climate Change Act (2008) requires cuts in UK emissions of 80% by 2050 from 1990 levels (779.9 Mt $CO_2$ e). More than an 80% reduction is expected to come from the housing sector to compensate for other sectors which would have difficulties making the cuts. This significant change means that it is vital to understand householders' attitudes, perspectives, behaviours and the barriers to the take-up of the necessary actions.

> *'Detailed analysis shows there is a path to achieving the necessary reductions and that, by 2050, energy savings in buildings can equal the total energy consumed in today's transportation. It is clear that financial, behavioural and knowledge barriers must be overcome for individuals, governments and businesses to aggressively adopt energy saving options.'* (WBCSD, 2010)

The house-building industry needs to move fast to make the necessary changes to improve energy efficiency. A culture change is needed and this will require an improved understanding of how buildings are used by occupants. New technologies, controls and innovative house designs can lead to occupants becoming bewildered and confused and so not gaining full advantage from the innovations. It is important that occupants understand new technologies as the way occupants interact with buildings, and in particular, the building controls, can have a significant impact on the energy used and the comfort levels achieved. There is little evidence on how well some of the new technologies perform in real life or how they affect behaviour. The lack of information can lead to people becoming reluctant to invest in new technologies (Energy Saving

Trust, 2010b). In addition, there is concern that many new homes are untried and untested within the context of mainstream housing in the UK. Many do not go through thorough monitoring and evaluation to check whether they achieve their designed performance targets (Bell, Wingfield, Miles-Shenton and Seavers, 2010).

Post-occupancy evaluations are important to gain an increased understanding of occupant behaviour in new homes. During post-occupancy, problems can be detected and feedback obtained to ensure that energy saving measures are fully optimised. Bell *et al* (2010) suggest that post-occupancy evaluations should become routine and the results fed back into the design process. Weaknesses in design could be overcome and it would allow greater opportunities for improved interaction and understanding between building providers and occupants. This would result in improvements in processes and products and allow innovations to really make a difference.

## 1.3 Occupant behaviour

It is the occupants who determine how energy efficient a dwelling will be – even if the building is well insulated and the dwelling has an efficient energy source (Stevenson and Leaman, 2010). There are often large gaps between occupant and design expectations and the final energy performance of buildings. Some reasons for this are that many designers do not take into account how occupants use buildings, and solutions that look good at the design stage are often too complicated to be used effectively by building occupants (Pett and Guertler, 2004). Innovations in the design of buildings necessitate behaviour changes because people need to understand them and use them in appropriate ways.

A report by BRE for the BRE Trust (Prior, Hadi and Brown, due for publication end of 2011), looks at attitudes to low flow taps in the light of the drive to low flow appliances, eg in the *Code for Sustainable Homes: Technical Guide* (Department for Communities and Local Government, 2010b). They found that consumers would not accept the lowest flow rates and in fact said that they would have these fittings changed if they found them in their new homes. BRE also found similar issues in post-occupancy evaluations on new homes, for example, for the Home Group 2009 (unpublished). A number of occupants were unhappy with their low energy light fittings after moving in and were having them replaced. This suggests that new low energy/low water appliances need to be perceived as acceptable by occupants, otherwise they will simply be ripped out and replaced.

Reducing energy use depends upon not only improving building performance, but also understanding the relationship between how occupants use the property and their particular personal circumstances. Personal circumstances can have many effects on the building's energy use, for example, a single person out at work all day will have different energy needs to a family with young children who spend a large portion of their time in the house.

Human behaviour is varied and complex. There is considerable uncertainty about what motivates people to behave in an environmentally responsible way. Research has shown that there is no single general construct that predicts environmentally friendly behaviour (Oskamp *et al*, 1991, cited in McMakin, Malone, and Lundgren, 2002) and studies have shown no connection between people reporting concern for the environment and their own energy use (McMakin *et al*, 2002). Steg and Vlek (2008) argue that promoting behaviour change is more effective if the behaviour to be changed is carefully selected, the factors that cause the behaviour are examined, well-tuned interventions are applied and the effects of the interventions are systematically evaluated.

Even if the public is concerned about the environment, there is a reluctance to make significant changes in lifestyles and practices. A Department for Environment, Food and Rural Affairs (DEFRA) research survey of public attitudes and behaviours towards the environment (DEFRA, 2007) found that, while 75% of respondents reported that they were prepared to change their behaviour, only 5% said that they had actually reduced their car usage due to environmental concerns. Psychologists would argue that changing attitudes does not necessarily change behaviour, rather the opposite is often true (Abrahamse, Steg, Vlek and Rothengatter, 2005).

## 1.4 The psychology of occupant behaviour

It is widely recognised that social factors influence energy use in the home (McMichael, 2007). Several studies have indicated that, although everyday energy consumption is usually regarded as an individual act and while energy consumption may be undertaken by individuals, it is actually a social phenomenon (McMichael, 2007). According to McMakin *et al* (2002), householders are constantly striving to use the same (or better) goods and services as friends, neighbours, etc. McMakin *et al* evaluated the social-psychological model of energy use, including Social Comparison Theory. This suggests that comparison, and even competition, with other people increases motivation to achieve something seen as possible, reduces uncertainty and helps determine standards of personal behaviour. Social Identity Theory proposes that people constantly strive for a positive self-image and being a member of a group is perceived as part of their identity. These theories suggest that emphasising a group identity can result in more cooperative behaviour and improved performance. They also indicate that a tailored approach should be taken to energy-reducing strategies with certain demographic variables (such as type of housing) and psychographic variables (such as constraints of occupants) being identified and targeted. They also suggest that changing people's behaviour (in this case, to reduce energy use) might best be achieved by targeting groups of people rather than individually.

The social-psychological model of behaviour integrates societal, group and individual-level processes. It provides support systems to assist behavioural change. Supporters of this model suggest that people are more likely to make permanent changes in their energy behaviours:

- if the new behaviours are easy and convenient to perform
- if they have the necessary skills and resources to change behaviours
- when their friends and neighbours are changing in similar ways
- when they make commitments to change in public settings.

More specifically, there is an increased likelihood of people adopting energy efficiency behaviours if:

- they view energy efficiency as being a benefit to themselves rather than a curtailment; this is particularly true in terms of increased thermal comfort and health
- energy use and savings are visible and so provide goals and motives
- if others around them are engaged in similar behaviours or trying to meet similar goals
- information is provided in a vivid, salient and personal manner (McMakin *et al*, 2002).

These principles are important because they can usefully be applied to a range of behaviours outlined further in this review to increase the likelihood of occupants behaving in more energy-efficient ways, such as ways of informing end users how to operate systems and the use of smart meters to make energy use more visible. Changing an individual's behaviour will be easier if others around them are also changing their behaviour in similar ways. The same may also be true of investing in low energy technologies, microrenewable, insulation, etc.

# 2 Designing for the end user

Controls are important; their usability affects how well many aspects of a building perform, such as energy efficiency, speed of response, avoiding discomfort and user satisfaction. According to Stevenson and Leaman (2010), overly complex interfaces are a contributory factor in a decrease in the level of energy savings. If controls are not used in the intended way, this can lead to equipment being left on, not being used as it should and systems not being used effectively or efficiently. It is therefore vital that designers develop controls that are intuitive and simple to manage.

Research by Bell *et al* (2010) included interviews with occupants about their use of heating and hot water controls in new low carbon homes. They found that the complexity of the heating and hot water systems resulted in householders feeling bewildered by an array of controls which included a main heating controller, hot water controller, immersion timers, room thermostats and solar controller. Resident feedback indicated that the controls for the heating and hot water were very confusing. The main heating controls all had different displays and approaches to operation. This caused confusion and led to residents not being able to use their homes effectively or efficiently. The designers expected that some controls would need little or no adjustment once set, however, it was found that this information was not effectively communicated to the residents.

Research suggests that end users' level of understanding over how their appliances and controls work is often overestimated. There is often a disconnection between consumer responses to an expert or in a questionnaire (where socially desirable responses are given or there is a gap in understanding between the consumer and the 'expert') and those derived in a focus group or interview. BRE post-occupancy evaluation studies on homes, for example, Home Group (BRE, 2009, unpublished report), found that consumers reported in a survey that they had a 'good understanding' of how to use their heating controls but when questioned in-depth, many were not actually using their timers or controls as designed, but instead using other more intuitive ways of controlling the temperature such as using their thermostats as an on/off switch. Consumers often understand the controls well enough to make the systems do what they need it to do. However, they often do not control the systems in the most efficient and effective ways.

Research for the Department for Communities and Local Government (2010a) used an expert workshop to examine behaviours in housing, including use of heating controls. The authors suggested that:

> *'Buildings would be more energy efficient if the occupants had, and made adaptive use of, heating controls such as thermostats and timers to supply heat only where and when it is needed.'*

They estimate that good building controls can save approximately 17% of heating energy; more complicated controls can deliver greater savings, but only if the instructions are clear and the occupants can understand them and have the time to make the best use of them. It is important that controls allow occupants to easily achieve an optimal heating pattern and that all heating controls are provided with guidance on how to make the best use of them, not just how to operate them.

In a study by the Energy Saving Trust (2010b) into people's views of heat pumps, wide-ranging performance values were partly attributed to occupants' use of controls. Control systems were commonly found to be too complicated for householders to understand and some householders found it difficult to control the ambient room temperature.

Research at the BedZED eco-village (Peabody, 2004) found that some occupants did not know how to operate their internal services: 45% did not fully understand how their heating system worked and about two-thirds felt they could not control the temperature of the heating adequately.

A well-regarded piece of literature in this area is the *Controls for End Users* report by Bordass, Leaman and Bunn, 2007. Although this is not specifically concerned with controls in a domestic setting and it does not ascertain the views of housing occupants, many of the findings are nevertheless relevant. The research focuses on controls for heating, cooling and ventilation devices. It emphasises the importance of achieving good environmental conditions with minimum energy use, particularly through good integration of natural and mechanical systems and ways of avoiding the unnecessary running of equipment. They found that many environmental controls do not work as well as they should; electronic controls can be too complex and occupants tend to ignore features that they do not understand or find complicated. Effective user controls can be simple and unobtrusive and have usually received careful attention to detail in briefing, design, specification, installation, commissioning and handover and in the user interfaces.

> *'If user controls are ambiguous in intent, poorly labelled, or fail to show whether anything has changed when they are operated, then the systems that lie behind them are unlikely to operate effectively or efficiently'*
> (Bordass et al, 2007).

Typical problems that arise include:

- a lack of understanding of users and their needs; the authors suggest that this requires more knowledge-gathering by designers and controls specialists
- lack of design integration
- lack of clarity of design intent
- cost-saving pressures
- poor dialogue between controls specialists, designers, clients and users
- lack of communication of the design intent of the control devices to users.

If controls are to be operated as intended and if they are designed to suit the end user, control devices should:

- be easy to understand and use and preferably intuitively obvious
- work effectively, with sufficient fine control to allow the required level of adjustment
- provide instant, tangible feedback to indicate to the user that the device has operated

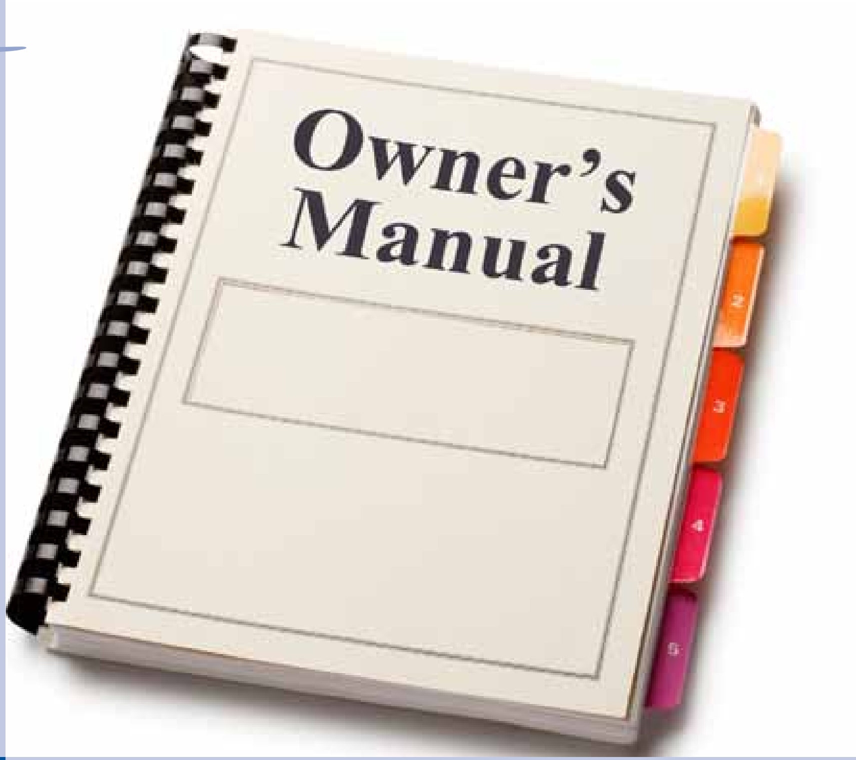
- provide rapid feedback to show that the intended effect has occurred
- not need to be used too often
- require little intervention for users
- be located as close to the point of need as possible.

Bordass *et al* end the report with a list of recommended iconography for user controls and checklists for building designers, controls manufacturers and suppliers, and controls installers.

Hadi and Halfhide (2010) found that if users are uncomfortable, they will adapt a building to meet their needs, even if this increases energy wastage and compromises safety. They also reported that controls, in particular, lighting controls, were often poorly designed, complex and counter-intuitive leading to wasteful behaviour by occupants. Control designs did not take into account principles of user-centred design such as feedback, affordance and mapping advocated since the 1970s.

Several manufacturers have begun to develop domestic automated control systems. These systems control some or all of the environmental conditions in the house with minimal or no input from the occupants. Research into the use of automated controls in non-domestic buildings has shown that these types of controls rarely provide the desired energy saving or occupant comfort level (Hadi and Halfhide, 2010). It is unclear how these automated control systems will perform in domestic buildings and how satisfied the occupants will be with these types of controls. Research on the latest types of control systems will be vital over the next few years.

The research suggests that if energy-efficient new homes are to operate effectively, user controls need to be simple, easy to understand, intuitive and provide instant feedback. Iconography should also be simple and easy to understand with standardised universally-recognised icons.




# 3 Informing the end user – domestic user guides

*'The nature of information provided about ventilation, heating or managing energy within a home affects how people understand their home. This, in turn, will affect their understanding of how to go about reducing their carbon footprint.'* (Bell et al, 2010)

User guides are recommended in the *Code for Sustainable Homes* (Department for Communities and Local Government, 2010b) and are included in Category 8: Management. The aim of including user guides in the Code is to promote the provision of guidance enabling occupants to understand and operate their home efficiently and make the best use of local facilities. The assessment criteria against this item are two credits for the 'Provision of a Home User Guide, compiled in accordance with Checklist Man 1, Part 1, together with confirmation that the guide is available in alternative formats', and one additional credit 'Where the guide includes additional information relating to the site and its surrounding and is compiled in accordance with Checklist Man 1, Part 2'.

The information required to demonstrate compliance is:

- **At the design stage***:* A home user guide should be supplied covering operational issues only: confirmation in the form of a letter from the developer or in the specification that the guide will be supplied to all dwellings within the development and be developed to the required standards.
- **At the post-construction stage***:* The provision of a sample copy of the home user guide covering all of the issues required and confirmation that the home user guide has been supplied to all homes.

The information recommended for inclusion in user guides in the Code covers a wide range of issues ranging from environmental strategy/design and features, energy and water use, to recycling and waste, and local amenities. If paper copies are not supplied to householders, a hard copy of the contents page should be provided to all dwellings where the guide is provided in an alternative medium, eg via the internet or on CD.

However, despite inclusion of a home user guide in the Code for Sustainable Homes criteria and the extensive research that outlines the importance of occupants fully understanding how to use their homes and the systems in it, relatively little research has been conducted on what the user guides should cover, how the information should be presented, etc. A small amount of information was found in some reports, for example:

- The Energy Saving Trust (2010b) found that many householders reported difficulties understanding the instructions for operating their heat pumps. The Energy Saving Trust recommended that clearer and simpler customer advice was needed.
- Research by Bell *et al* (2010) suggests that information provided in home user manuals is likely to be much less effective than a well-designed thermostat dial.
- Research by the Stewart Milne Group on the Sigma low energy, carbon-neutral home concluded that manuals need simplistic diagrams, illustrations and descriptions which are bespoke to the home.

BRE consultants have noted that manuals and user guides are often lost or misplaced over time and that they are not always passed on when properties are sold. Therefore, occupants often have to manage the systems without the manuals or guides. In recent years, manufacturers have begun to make more and more manuals and guides available online, however, this information is not always available for products no longer being manufactured. Therefore, manuals and user guides are not always available for the entire lifespan of the products. For new homes, practical demonstrations and inductions are often offered, but these are not available for homes that have been previously owned.

Recent (unpublished) research by BRE into occupants' views of manuals found that some occupants complained that the manuals were too complicated and detailed and many preferred 'quick start' guides. Several occupants felt that user manuals should not be on paper but in video format and available online. Some found that the guides used acronyms in places which were confusing as they had not been introduced or referenced. Occupants reported that they would not read long manuals; instead they would put them in a drawer and forget about them. They felt that 'quick start' guides should cover the core features and user interfaces. These guides should provide sufficient information to get started and understand the majority of the system capabilities.

BRE research for the Department for Communities and Local Government in 2008 (Hadi and Rathouse, unpublished) investigated the type and efficacy of information provided to homeowners and tenants when they move into a new home. The research team visited householders in their homes and carried out face-to-face interviews covering their knowledge of how to operate their homes (for example, heating and hot water, installing fixtures and fittings, etc) and the usefulness of the information provided when they moved into their home. Although all of the householders had received comprehensive information packs, and some even had videos, few people had looked at them. Correct operation of their home was, therefore, a 'hit and miss affair', with subsequent impacts on energy and water efficiency and health and safety. Often the manuals were generic rather than home-specific. Social housing tenants reported a better experience than private homeowners, as they could approach their tenant liaison officer for help.

Research by the Stewart Milne Group on the Sigma low energy, carbon-neutral home found that occupants need greater time and simpler instructions at handover and induction stages to understand the systems. The complexity of the technologies installed in these types of homes requires a full review of how developers induct new homeowners. This will require the introduction of a whole new skill set and process. The research suggests that a series of reminder sessions and/or helpline services will be necessary to ensure occupants feel supported, comfortable and confident in the use of the technology.

Social Comparison Theory, outlined in Section 1.4 of this review is particularly useful when considering the most effective way to inform end users. This theory suggests that it may be better for housebuilders to hold regular 'group' induction sessions that cover how to use the technologies efficiently rather than individual sessions. Occupants can then share their experiences, learn from each other and learn together how to use the homes efficiently. If they are encouraged to make commitments to try to use the systems more efficiently in this public setting, the research suggests they are more likely to stick to these commitments. These could be induction sessions or 'how to improve the efficiency of your home' sessions.

The lack of research found on user manuals suggests that more research is needed, in particular on:

- What information should be provided?
  - How much?
  - User guides or manuals?
  - Day-to-day usage guide, maintenance, what to do in an emergency
  - Contact details for more information/questions.
- In what format?
  - Paper
  - Electronic
  - Video
  - Words versus diagrams
  - Practical demonstrations/inductions
  - Individual inductions or group inductions?
- When should this information be provided?
  - As soon as they move in?
  - Reminder sessions
  - Help lines.

# 4 The impact of the end user

According to McMichael (2007), the two main ways that households can become more energy efficient are:

- Use less energy, for example, by turning down heating, switching off lights, turning off electrical items when in standby etc, and avoiding energy loss, for example, by shutting windows in colder weather and putting heat reflectors behind radiators.
- Use or buy more efficient energy services or energy-efficient technology, for example, change energy supply, buy products that have high-energy efficiency ratings, insulate cavity walls, draught-proof doors and windows.

Since the 1990s, there has been a change to buying more energy-efficient appliances but there has also been a rise in the amount of appliances people are buying, such as dishwashers and extra televisions, etc. According to Vale and Vale (2010), although UK houses are becoming smaller, households are using more and more energy-consuming equipment. Even though the amount of energy consumed by the building for heating space is lowered, occupants can still use as much energy as they want for appliances.

In the WBCSD (2007) summary report, it is suggested that the behaviour of occupants in a building can have the same impact on energy consumption as the efficiency savings of the equipment. A report for the Department for Communities and Local Government (2010a) examined specific behaviours concerning energy use. The types of behaviours that reduced energy consumption ranged from expensive, complex one-off investments, such as installing a solar thermal hot water system, to simple everyday behaviours and habits, such as switching off appliances when not in use, and occasional behaviours such as heating system maintenance. They found that some of the behaviours, such as using energy-efficient lighting can change quickly whilst others, such as adaptive use of clothing, may need progressive changes in social norms.

According to McMichael (2007), changes in social norms of comfort, cleanliness and convenience can lead to changes in energy use. An example is provided by Shove (2004, quoted in McMichael, 2007) who points out that the number of times householders do laundry has significantly increased in the Western world because of changes in what is 'normal' in relation to wearing clean clothes.

A related issue is the change in personal washing habits. A study by Waterwise (2009) focused on showering and bathing and reported great changes in personal washing habits over the past 40 years, due mainly to rapid growth in shower ownership. Showers have become part of daily routine whilst baths are becoming a leisure activity associated with relaxation and indulgence. Many households now have more than one shower.

The transition to using energy efficiently is difficult because significant changes in habits are required, such as switching off appliances when not in use. The Energy Saving Trust (2010a) examined 'small behaviours' that occupants carry out on a daily basis, such as only filling the kettle with as much water as needed and switching off lights and appliances when not in use. The Energy Saving Trust estimates that if everyone took up these measures, it would reduce household emissions by 3.4% and save approximately £1 billion per year off consumer bills. From the survey findings, the Energy Saving Trust found that 84% of people in the survey said they only filled their kettle with as much water as they needed and 67% reported that they switched off lights in unoccupied areas. However, these results may be due, at least in part, to increases in energy prices and the economic downturn. In addition, participants may have overestimated these energy saving behaviours when responding to the survey due to socially desirable responding (ie trying to give what they think is the right answer to the question, or an answer they think they should give, rather than responding with the honest answer).

An interesting study by McMakin *et al* (2002) investigated the motivations of occupants to conserve energy without financial incentives. The research took place at US military bases where occupants did not pay their own utility bills. Occupants were surveyed about their end-use behaviours and reported being motivated by the desire to 'do the right thing', set a good example for their children and have a comfortable house. Researchers recommend continued awareness and education, disincentives and incentives to promote sustained change. This study has implications for other situations where occupants do not pay for their electricity use, for example, university dormitories and master-metered apartments. The findings show support for some aspects of the social-psychological model of energy saving, with emphasis on altruistic as well as egoistic motives for behavioural change.

According to the WBCSD (2007), barriers to energy efficiency include: 36% of people felt they would be less comfortable if they reduced their energy use, 25% believed their actions would just be a drop in the ocean, 25% said they could not afford it and 22% said it would be too much effort.

WBCSD suggested three key issues influencing these reported barriers to energy efficiency:

1. Lack of awareness and information: People do not know how much energy costs and are often not aware that they are wasting energy.
2. Habit: People are in the habit of not adjusting heating and leaving lights on.
3. The rebound effect: Energy savings lead to additional activity through either increased use or for another action that increases energy use.

Research by BRE into the impact of domestic water meters on water efficient behaviours (Market Transformation Programme, 2008) found that affluence also has an impact. In more affluent areas, consumers felt that, if they could afford it, they could spend their money as they chose; and if they chose to spend it using more water or energy, that was up to them. In less affluent areas, there was much more interest and incentive for those with water meters to reduce their consumption.

## 4.1 The rebound effect

This is an important issue in energy use that needs to be considered in more detail. The rebound effect is the reduction of the potential energy savings caused by the user offsetting some of the savings through changed behaviour. For example, the energy saving could lead to additional activity through either an increased use of the same product or another energy-using action. Typical examples of the rebound effect include justifying leaving lights on for longer because they are energy-efficient bulbs or heating the house to a higher temperature after insulating the walls and loft.

> *'The rebound effect limits potential energy savings by substituting new consumption for some of the energy saved'* (WBCSD, 2007)

It is not only the energy use in the home that can be affected; the savings can affect energy use in other ways. For example, people saving money on energy bills may decide to spend the savings on an overseas flight.

Some research (eg POST, 2005) suggests that demand reductions will only be possible if energy efficiency is coupled with measures that encourage consumers to reduce their energy use. This suggests that it is changes in human behaviour that are vital to reducing energy use.

> *'Changes in human behaviour are believed to be needed because technical efficiency gains resulting from, for example, energy-efficient appliances, home insulation and water-saving devices tend to be overtaken by consumption growth.'* (Midden et al, 2007, cited in Steg and Vlek, 2008)

A report for the UKERC (2007) suggests that economy-wide rebound effects amount to at least 10% of the expected savings, although often higher, and that rebound effects should be taken into account when developing and targeting energy-efficiency policy.

The magnitude of the rebound effect varies depending on the particular type of energy use (WBCSD, 2007). For example:

- Space heating: 10–30%
- Space cooling: 0–50%
- Lighting: 5–20%
- Water heating: 10–40%
- Automobile: 10–30%.

More research is needed into rebound effects in new homes and how they are affecting energy efficiency.

The rebound effect raises the important question of the distinction between energy efficiency and energy conservation. The Edison Electric Institute (1997, cited in Moezzi, 1998) states that:

> *'Energy conservation means doing without to save money or energy. Electric energy efficiency means getting the most from every kilowatt-hour of electricity you pay for'*. Edison Electric Institute.

> *'Narrow application of the idea of energy efficiency focuses on technological aspects of energy use and overlooks the human behaviours that drive energy consumption.'* Moezzi (1998).

Moezzi suggests that energy efficiency does not necessarily save energy, but instead it can act as permission to consume energy. So, for example, an electric toothbrush may be labelled as energy efficient but a manual toothbrush will not be, yet the electric toothbrush obviously uses energy whereas the manual one does not.

## 4.2 Thermal comfort

People want to be comfortable in their homes. The most commonly used indicator of thermal comfort is air temperature, but air temperature alone is neither a valid nor an accurate indicator of thermal comfort and it should always be considered in relation to other environmental and personal factors.

According to the Health and Safety Executive, there are six factors that affect thermal comfort: air temperature, radiant temperature, air velocity and humidity and the personal factors, clothing, insulation and metabolic heat. These factors may be independent of each other, but together contribute to thermal comfort. According to Darby and White (2005), there is no definite standard of thermal comfort – people can, and do, live in a range of climates. In the adaptive approach to thermal comfort, people are tolerant of temperature changes and both consciously and unconsciously act to influence the heat balance of the body. They can become more active where possible, or adapt their clothing or thermal envelope, for example, open/shut windows, doors, or use fans, etc. So comfort can be achieved in a wider range of temperatures when it is something that individuals achieve for themselves.

Adaptive variables are very important in 'free-running' buildings (those with no active heating or cooling systems). Occupants of these buildings need to have the ability to control their immediate environment by opening and closing windows, using shades and dressing in such a way as to maximise comfort. Research into the comfort levels of sedentary people shows that 'simply being "at home" in an environment that is familiar and under control is conductive to comfort and makes people less sensitive to temperature' (Oseland, 1995, cited in Darby and White, 2005). Darby and White argue that householders' ability to achieve comfort easily needs to be seen as a vital objective. This means windows that can be easily opened, very straightforward heating controls and ventilation systems that are easy to control.

If climate change leads to a trend in higher temperatures in the UK, this could have an effect on thermal comfort, particularly in the summer. Cooling needs should be taken into account in design, construction and refurbishment to avoid high-energy demand for cooling in the future. Sales of air conditioners are increasing in the UK, especially during heat waves, and seem likely to increase even more if temperatures rise due to climate change. According to Boardman, Darby, Killip, Hinnells, Jardine, Palmer and Sinden (2005), cooling is likely to become an increasingly important issue in the future. Consumer focus group research carried out in 2006 by BRE for the Department for Communities and Local Government, *The impact of societal change on the building regulations* (Department for Communities and Local Government, 2007), identified that householders were increasingly viewing air conditioning in their homes as an aspiration and even a necessity in the future, in spite of its potential environmental impact.

Other issues that may need consideration are future trends in immigration and changing expectations with a migrant population.

Research into thermal comfort suggests that occupants want to have control of their homes. According to Darby and White (2005), policy should be geared towards design for high thermal mass, high insulation values and the use of shading and natural ventilation wherever possible. Darby and White also advocate better controls and the use of feedback as a way of improving occupant control over their own comfort while reducing energy consumption. Educating occupants on alternative methods of controlling thermal comfort may prove to be an effective way of reducing energy use, for example, wearing extra clothes instead of turning up the heating or opening windows rather than using air conditioning.

## 4.3 Feedback

Darby (2006) argues that most domestic energy use is invisible to the user and that the majority of people only have a vague idea of the amount of energy they are using for different purposes. Research by the Energy Saving Trust (2008) found that around one-third of people did not find their energy bill easy to understand and 82% did not even know what energy tariff they were on.

*'One of the fundamental barriers stopping individuals from saving energy is that they don't understand how the energy they use at home relates to their gas and electricity bill'.* (Energy Saving Trust, 2008)

Research in the USA (Houwelingen and Raaij, 1989) supports these claims and suggests that many people do not know the costs of their energy use or how to save energy. Householders have no way of knowing how much energy is being used when the heating is on, hot water is used and appliances are being run. Energy bills are not specific, they arrive too late to make users aware of their energy-using behaviour and so have a limited feedback function.

Feedback is of particular importance in making energy more visible and easier to understand and control. Several studies suggest that household consumption feedback can be an effective tool in reducing energy use. Direct feedback is provided instantaneously, such as in-home displays. Darby (2006) found that direct feedback led to consumption savings of between 5% and 15%. Instantaneous, easily accessible displays are particularly effective because they can show the surge of consumption when an electrical item is switched on or the relative consumption of different appliances, such as the television, computer or toaster. Research suggests that savings are more likely to be persistent when feedback has helped occupants develop new habits and when it has led to them investing in efficiency measures. Feedback used together with incentives to save energy may change behaviour but the changes greatly reduce when the incentive ceases. Generally, a new type of behaviour formed over a 3-month period or longer appears to be likely to endure, although continued feedback is required to help maintain the change.

Smart meters can help householders have more control over their energy use and spending. Ofgem (2010) report that direct feedback through smart meters reduces energy use by between 5% and 15%, and the majority of this is achieved by consumers seeing the direct impacts of their behaviour at home. They estimate that smart meters will save consumers approximately £5.98 billion over 20 years. Smart meters provide the opportunity to raise people's awareness of their energy use and to help their changes in behaviour become permanent habits.

The EPRI (2009) developed a criteria for effective feedback based on a review of research in this area. The report suggests that feedback is more effective when it is:

- provided frequently, as soon as possible after a completed behaviour
- presented clearly and simply
- customised to the household's specific circumstances
- provided relative to a meaningful standard of comparison (for example, $kWh/m^2$)
- provided over an extended period of time.

The Energy Saving Trust (2008) found that the key benefits of smart meters for the consumer and energy supplier include:

- frequent data on energy consumption (both gas and electric)
- time of use and historical data
- differential tariffs based on time of use
- greater control over peak demand
- ability for consumer to receive communications from supplier, for example, energy saving tips
- accurate and timely billing
- net metering for microgeneration
- improved security of supply
- ability to switch between credit and pre-payment functions.

However, not all research on smart meters is positive. Stevenson and Leaman (2010) question whether mass-produced 'one-size-fits-all' energy monitors and technological solutions are achieving energy savings and they suggest that a clearer understanding of the relationship between the occupier and these systems is needed. Further doubt is raised on the effectiveness of feedback to occupants in a study by Darby (2006) who found that feedback may have a bigger impact on high-energy users than low energy users; feedback did not motivate households with low consumption to reduce their energy use and may even have caused them to increase consumption.

## 4.4 Occupant views of smart meters

Energy Saving Trust (2008) research measured consumer attitudes to smart meters and found that consumers viewed the main benefits as:

- providing more accurate billing (54%)
- there was no need for the existing meter to be read (35%)
- the energy supplier could give accurate advice by analysing exact usage (32%)
- providing ways of visually tracking usage trends, for example, weekly, monthly, or on the internet (26%).

An in-depth review by Ofgem (2010) used focus groups and family groups to examine consumers' views of smart meters. Nearly one-third of participants had heard of smart meters and perceptions of them were typically positive. Some were enthusiastic and only a small minority were sceptical and/or slightly nervous. Ofgem suggested that there might be particular potential for using in-home displays for helping householders whose usage was higher than they felt it should be and who were unsure of the best way to reduce usage. They also found that some householders did not have the will or motivation to make cut-backs in their lifestyles to save money.

Feedback to occupants via smart meters has received considerable interest in the last few years. The findings indicate that smart meters can give control over energy use to the occupant and they ensure that energy use is visible and easier to understand. The best results for energy reduction appear to be found with occupants who use high amounts of energy and those who have no idea of how much energy they are using.

# 5 Feedback from end users

Research by Bell *et al* (2010) on the Elm Tree Mews low carbon housing scheme included post-occupancy interviews with occupants to investigate their views on the new homes. This was an in-depth study of users' views, but on a small scale which only examined the views of occupants of five dwellings. Findings included:

- There were discrepancies between the design of the dwelling and the needs of the occupants; these included:
  - The loft space was designed to provide additional living space but it was found that, in practice, it reduced valuable storage space.
  - The indoor 'winter garden' (similar to a conservatory) was too cold to use in the winter and a waste of potential garden space. One occupant was considering heating this space which is against the ideal of a low energy home.
  - The lack of suitable indoor space to dry clothes on wet days was made worse by the lack of radiators. Some occupants had bought, or were considering buying, a tumble dryer, which would obviously increase appliance energy consumption and carbon emissions.
  - Occupants' level of understanding of the heating systems appeared to affect how confidently they used the systems and also how effectively they used them.
  - Several residents were unaware of the trickle vents on the windows and how they worked and so had not used them; windows were opened instead.
  - An example of a problem that gave rise to a lack of confidence was the shower cubicles which were designed for those with a disability but caused bewilderment and frustration to the occupants. All of the householders reported that the shower doors leaked and needed replacing but it took a number of visits by maintenance staff for the problem to be resolved.

Low carbon housing needs to be clear what energy savings can be made and provide explanations on how to run the systems so that efficiency can be maximised. This is particularly important for low income households. The ability of occupants to use the systems will be affected if they are uncertain how to use them. Occupants in the Elm Tree Mews housing scheme reported relatively low bills for space and water heating. However, occupants did express concerns about electricity bills. The relatively high electricity bills were generally the result of a higher than expected use of lighting and appliances in the homes. This is a good example of how living in a 'low energy house' does not mean electricity bills will automatically be less. Occupants need to reduce energy use by changing their behaviour to see a reduction.

BRE carried out a post-occupancy evaluation for Home Group on their Smartlife developments in 2009 (BRE, 2009, unpublished report). The 130 homes were built to EcoHomes standards using four different construction methods including off-site construction. Feedback was generally very positive. There were some issues, however, with the layout of some of the homes, for example, number and position of windows restricted possible locations of furniture such as wardrobes in the bedrooms. There were also some gaps in occupants' understanding of the operation of the heating and hot water systems, although feedback from users was that energy bills were generally lower than in their former homes.

BRE has also carried out a number of consumer research projects with householders, for example, *Perceived quality of kitchens in social housing: Does it encourage tenant responsibility?* (Rathouse, Hadi and Gemmell, 2009). This longitudinal study by BRE for BRE Trust and the Guinness Trust investigated the factors that influence the perception of quality of kitchens, and the relationship between perceived quality and how well tenants look after them – factors that impact on durability and replacement frequency. The first part of the project used consumer focus group research to ascertain what attributes of kitchens are seen as good and which as poor quality. This was followed by a longitudinal questionnaire study of housing association tenants over two years to find out any associations between choice, perception of quality and subsequent treatment of their new kitchens.

The Stewart Milne Group carried out a post-occupancy evaluation of the Sigma low energy, carbon-neutral home, a low energy carbon-neutral home (Stewart Milne Group). This small-scale study was based on a family of four who occupied the home for four 2-week periods at different times of the year. Methodology included using video diaries, interviews, log sheets and thermal comfort surveys. They found that:

- solar gain from large areas of glazing conflicted with the need for privacy for the occupants
- there was a conflict between the mechanical ventilation heat recovery (MVHR) system and openable windows in terms of occupant behaviours, preferences and functionality
- there was a need for additional drying facilities to lessen the need for a tumble drier
- the artificial lighting was excellent, although sophisticated remote controls were too complicated.

BedZED (the Beddington Zero Energy Development), is an eco-village and is flagged as one of the most coherent examples of sustainable living in the UK. It comprises 100 homes, community facilities and workspace for 100 people. The aim of the development was to have a zero carbon strategy to reduce energy demand in the buildings, for example, through insulation, fitting homes with low energy appliances and trying to influence occupants' energy use behaviour by having meters on show. Post-occupancy research by Peabody (2004) included a questionnaire sent to residents examining occupants' views on issues such as overall likes, overall dislikes, overall design, fixtures and fittings, internal services and renewable energy. Occupants were enthusiastic about the design and layout of their homes, although there was a problem with inadequate storage space. About 50% reported a reduction in fuel bills but some residents could not operate their internal services, for example, 26% said they did not know how to turn off their electricity supply in an emergency, 50% could not switch off their water supply and 21% said there was not always enough hot water.

In summary, the main findings from research on feedback from occupants in new low carbon homes suggest that:

- occupants were not saving as much energy as expected (especially electricity use)
- occupants adapt their homes to suit their needs, even though this conflicts with energy saving ideals, for example, heating conservatories
- there was often insufficient storage and drying space
- controls were too complicated
- there was a low level of understanding of how the systems operated, leading to them being operated ineffectively.

# 6 Perception of microrenewable systems

Low and zero carbon (LZC) technologies are key features of the UK Government's energy and climate strategy to reduce the carbon footprint of homes. Microgeneration is 'a small scale production of heat and/or electricity from a low carbon source' (Caird, Roy, Potter and Herring, 2007). The technologies include domestic renewable systems such as solar thermal water heating, microwind turbines, and low carbon technologies, such as heat pumps and micro-combined heat and power systems. They have the potential to make 'a significant contribution to the UK's energy efficiency as well as reducing fuel bills' (Energy Saving Trust, 2010a). In 2010, there were just over 100,000 domestic microgeneration installations in the UK (Energy Saving Trust, 2010a). According to Caird *et al* (2007), the three main barriers to the widespread consumer adoption of microgeneration technologies were:

- high costs and low value of exported electricity and lack of targets and incentives for renewable heat
- legislation, particularly planning permission
- low levels of awareness.

The cost of renewable technologies is likely to be the biggest single barrier to take-up. Costs can be thousands of pounds, but the Energy Saving Trust (2010a) found that 30% of people would only be willing to spend up to £500, 21% up to £1000, 7% would spend up to £2000 and only 3% up to £5000. People's willingness to pay is strongly influenced by their socio-economic circumstances. The Energy Saving Trust suggests that the high upfront costs will be a significant barrier for many consumers and that it is important to find ways to incentivise people to buy them. Their research found that many people do not believe they should have to pay commercial levels of interest when borrowing money to undertake such work and there is a strong preference for some kind of Government subsidy so that costs are either interest free or kept low.

The recent introduction of new Feed-In Tariffs and the proposed 'Green Deal' begin to address some of the barriers highlighted by Caird *et al* (2007) and Energy Saving

Trust (2010). Consumer reaction to these incentives and the subsequent uptake of microrenewable domestic energy technologies will need to be carefully monitored.

Research at the BedZED eco-village (Peabody, 2004) found that about two-thirds of occupants said it was very important to them to use renewable energy. However, the other third said the cost of electricity was more important. Leaseholders were more likely than tenants to say that it was important to them to use renewable energy.

According to the Energy Saving Trust (2010a), understanding of microgeneration technologies is generally low among householders in the UK and very few have heard of newer technologies, such as heat pumps. However, they also found that interest is quite high, particularly in solar technologies and wind turbines, and many people are attracted to the idea of generating their own energy, for example, 48% of people would like to know if their home is suitable for generating renewable energy.

Some research suggests that the systems are not being used as expected. Caird *et al* (2007) examined consumer adoption and use of household renewable energy technologies and found that households which have adopted renewable systems may not understand the systems, experience problems in controlling them or find it difficult to make changes to their lifestyle. The Energy Saving Trust (2010a) found that consumers know little about the maintenance required for the systems and they can have unrealistic expectations about performance. Rebound effects also need to be taken into consideration when looking at renewable systems; these include heating rooms with wood-burning stoves to higher temperatures or using more solar heated water. Caird *et al* found that 60% of wood-burning stove users said their stove heated one or more rooms to a higher temperature than before and others admitted heating more of the house (17%) and/or heating rooms for longer periods (13%). However, controlling outputs of wood-burning stoves can be difficult and increased outputs may not be a result of rebound effects.

The study on the Elm Tree Mews low carbon homes scheme by Bell *et al* (2010) included an examination of occupant views of heat pumps. It was found that occupants generally viewed heat pumps as beneficial:

> *'it made a huge difference to know that I could have the heating on and not worry about the effects it was having on my carbon footprint.'*

This quote is another good example of rebound effects in that heat pumps do draw electricity but it appears that the occupant is unaware of this and not concerned about their usage.

Further research on heat pumps by the Energy Saving Trust (2010b) examined how heat pumps perform in real-life situations. It monitored customer behaviour and found that:

- householders reported good levels of satisfaction with both space heating and hot water provision
- occupant behaviour was shown to impact on performance
- many householders said that they experienced difficulties understanding the instructions for operating and using their heat pump, thus highlighting a need for clearer and simpler customer advice.

Research on solar photovoltaics by Darby (2006) found that most households with solar photovoltaics expect a fair payment for their own-generated electricity and would like to be able to see the amounts of electricity they are importing and exporting. Where this information is visually displayed, it has led to increased awareness and thus to a conserving behavioural effect; this has resulted in a reduction of total electricity consumption by as much as 20% from pre-microgeneration levels (Keirstead and Boardman, 2005, cited in Darby, 2006). Solar water heating installations with display units that show water temperature and/or the amount of energy absorbed by the sun have a significant effect in increasing awareness of the potential for reducing carbon emissions and saving energy.

*'Beyond the sheer excitement and pleasure of DIY energy generation, the impact is seen in householders' shifting attitudes to energy conservation and consumption… there starts to develop a strong sense of which behaviours are free and self-provided, versus ones that cost money and are supplier-dependent.'* (Dobby and Thomas, 2005, cited in Darby, 2006)

Research on the Sigma low-energy, carbon-neutral home by the Stewart Milne Group included an evaluation of the microrenewable technologies used (Stewart Milne Group). Some difficulties were experienced with the solar thermal and microwind technologies. The solar thermal system had been removed from the market which led to concern over future repair and obtaining spare parts. The outputs generated did not always synchronise with the occupants' needs. This resulted in output during sunny days, with little immediate use, as heating demand was required or desired during early morning or in the evening. The researchers concluded that effective heat storage is needed; although this adds complexity, it is vital to capturing and using the benefit gained. The microwind technology generated little effective electricity; the systems underperformed and were not suitable for a city centre low rise location. In addition, the turbines experienced several problems relating to repair, noise and certification. The research concluded that it is highly questionable whether new homes should be individually provided with these types of renewable systems.

The research on microrenewable systems suggests that occupants generally have low levels of awareness of these systems. They often do not understand how they operate or know the maintenance required and they experience difficulties understanding the controls. All this suggests that the systems are not being used effectively and again highlights the need for clear, simple customer advice on how to operate systems. Current research commissioned by the Energy Technologies Institute (ETI) on microrenewable domestic energy systems will shed more light on how these systems are performing 'in the real world' and how occupants interact with and understand their systems.

# 7 Summary and conclusions

This review examines the current and previous research surrounding the end users of domestic buildings. It covers a broad spectrum of research areas including controls and user interfaces, domestic user guides and product manuals, occupant behaviour and behaviour change, occupant feedback on low energy homes, and consumer perceptions of microrenewable technologies. This section highlights the key findings and key areas for future research.

## 7.1 Occupant behaviour and energy habits

The research suggests that improving the energy efficiency of homes, and the appliances in them, will not necessarily reduce the overall energy consumption. Rebound effects and the appetite for more and more energy consuming products in the home mean that overall energy savings are far less than anticipated. The research shows that changes in human behaviour are vital to reducing energy use, not just improving the efficiency of buildings and the products/appliances in them. It is human behaviour that drives energy consumption, therefore, we also need to target human behaviour when looking to reduce energy use.

The research shows that energy savings are more likely to be persistent as occupants develop new, less energy-consuming habits. More research is needed to see how new homes and products can be designed to encourage these new behaviours and energy-efficient habits. Smart meters have been found to be effective ways of influencing some occupants' behaviours and generating new energy-saving habits, however, more research is needed to understand what information should be provided and how different occupiers relate to and interpret these systems. Overall, the literature suggests that feedback ensures that a measure of energy use is visible to occupants and makes it easier for them to understand and control their energy consumption. However, the research has found differing levels of energy savings depending on a broad spectrum of factors relating to the feedback. More research is needed to understand how best to feedback to different occupiers, what factors influence the persistence of feedback effects, the value of different types of feedback, dynamic pricing interactions and distinguishing the effects of feedback among different demographic groups.

This review highlights a need for more research to improve our understanding of occupant behaviour and examine the behaviours that have a particularly detrimental effect on energy efficiency. There is also a need to identify potential interventions that will encourage more efficient energy use behaviours. There has been relatively little research into occupant perception, expectations, experiences and behaviour in relation to building performance in new housing. Often there are large gaps between the expected and the actual energy performance of new low energy buildings and homes. Many designers do not take into account how occupants use these buildings. More research is needed around how occupants actually use their homes and the appliances in them.

## 7.2 Designing controls

New technologies, controls and innovative house designs can lead to occupants becoming confused and unable to gain full advantage from the innovations. It is important that occupants understand new technologies as the way occupants interact with buildings, and in particular the building controls, can have a significant impact on the energy used and the comfort levels achieved. Different technologies need to be able to work together so that their controls are integrated. Controls should also be designed so that similar symbols or actions have similar meanings. Changing the settings with one controller should not have an adverse effect on another controller for a different technology. The findings of the research into user controls suggest that occupants often find controls overly complicated and difficult to understand and operate. The research clearly shows that overly complex interfaces on supposedly low energy systems result in smaller energy savings than expected. This is likely to be an even greater issue as more complex energy-saving technologies are installed in new homes. It is therefore vital that designers develop controls that are intuitive and simple to manage. Unless the design of controls is kept simple and intuitive for occupants, the full potential of the systems will not be achieved.

More research is needed into the design of intuitive user interfaces and how best to instruct the user on how to use the systems. The research suggests that if energy-efficient new homes are to operate effectively, user controls need to be simple, easy to understand, intuitive and provide instant feedback. Iconography should also be simple and easy to understand with standardised universally-recognised icons. Some controls manufacturers are beginning to develop automated control systems that require little or no input from the occupants. It is unclear how these automated control systems will perform in domestic buildings and how satisfied the occupants will be with these types of controls. Research on the latest types of control systems will be vital over the next few years.

## 7.3 User guides for homes and systems

Findings from new, low energy housing estates show that occupants need to be shown how to use such houses efficiently. Other research suggests the same is true of new low energy appliances and products. The research shows that having an energy-efficient home or appliance does not automatically result in less energy use, it all depends on how the appliances are used. It is important that innovative technologies are provided with guidance on how to make the *best* use of them, not just how to operate them. Research suggests occupants often have the bare minimum understanding of how to control their heating and other energy dependent systems. More research is needed on user guides (both for products and houses) to ascertain what information should be provided, how the information should be presented and in what level of detail. The study of the Sigma low energy, carbon-neutral home suggests that there needs to be an examination of what new aftercare processes are needed for new, energy-efficient homes. Training requirements for service providers also need to be considered.

Little research has been conducted on 'home user guides', despite them being included in the Code for Sustainable Homes guidance document (Department for Communities and Local Government, 2010b). As with the guides for individual appliances and technologies, research is urgently needed on what information should be passed on and in what format, to allow the occupants to make the most efficient use of these homes and the systems installed in them. The importance of clear and easy to use user guides and product manuals will become increasingly important as new low energy homes are fitted with new types of technologies. Current research suggests that occupants will need guidance on how to use these homes efficiently and effectively to minimise energy use and maximise their comfort.

## 7.4 Feedback from occupants

The views and experiences of occupants provide vital feedback on what does or does not work about a particular house design or installed technology. This information can be used to improve the technology and design of future housing. Bell *et al* (2010) recommend that post-occupancy evaluations should be carried out routinely and the results fed back into the design process. This would increase designers' understanding of occupants' needs and behaviours and assist them to improve any weaknesses in their designs. Bell *et al* (2010) also state that it is important to understand the relationship between occupants and their properties to ensure that energy-efficient new housing works for a range of households. Failure to attend to the resident-dwelling relationship is likely to lead to more dissatisfied occupants and higher than expected energy use.

Some notable examples of research into occupant views of new low energy homes were the Elm Tree Mews low carbon housing scheme, Sigma low-energy, carbon-neutral home and BedZED eco-village projects. These projects revealed, and clearly highlighted, several issues experienced by occupants. Occupants' views and experiences can be valuable tools in ensuring that mistakes are not repeated in future homes. These studies were in-depth but the first two were on a very small scale. More, larger-scale, research of this type is needed to provide more reliable data and to fully understand what these new low energy homes are like to live in and how expected energy use differs from the reality. Research suggests that the way occupants behave and use energy differs greatly from house-to-house. Larger scale, post-occupancy evaluation projects would enable a greater understanding, not just of the typical behaviours but also the range of behaviours and occupancy patterns designers of houses, technologies and controls need to consider.

## 7.5 Perception of microrenewable domestic energy technologies

The introduction of Feed-in Tariffs and the proposed Green Deal are likely to increase the uptake of these systems. However, little is known about the systems and how they will actually perform in the 'real world'. What will the maintenance issues be? How well will occupants understand the systems? How will their behaviour impact on the performance of the systems and what impact will the systems have on occupants' behaviour? BRE social scientists are currently looking to begin to answer these questions through a project funded by the Energy Technologies Institute (ETI), however, more research will be needed as investment in these technologies accelerates over the coming months and years.

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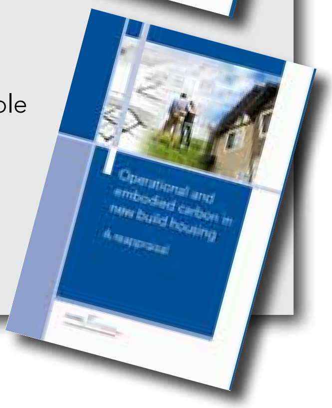
# NHBC Foundation recent publications


## Ground-related requirements for new housing

In 2010 the NHBC Foundation undertook workshops and a survey to look at the issues facing the housebuilding industry in potentially conflicting requirements for ground related works. This report provides the responses and draws together the common themes arising from the discussion at the seminars. ***NF32*** June 2011


## Low carbon cooking appliances

This report provides guidance to developers who wish to understand the role that low carbon cooking appliances can play in reducing $CO_2$ emissions within new dwellings.
***NF33*** October 2011




## Operational and embodied carbon in new build housing

This report covers the results of a study to investigate the percentage split between operational and embodied $CO_{2eq}$ in new build housing. It provides detailed results across multiple dwelling types, build weights and compliance levels, and includes a full account of the methodology used.
***NF34*** October 2011

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## NHBC Foundation publications in preparation

- Fire performance of residential buildings
- Building sustainable homes at speed: Risks and rewards
- International refurbishment compendium
- Lessons from the German Passivhaus experience
- Energy efficient fixed appliances and building control systems

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# How occupants behave and interact with their homes

This review was commissioned to examine current and previous research around domestic occupants (end users), to identify any gaps in knowledge and specifically where further work is needed. It details the findings from a comprehensive literature review and contributions from BRE social sciences experts.

The review covers a broad spectrum of research areas including research on controls and user interfaces, domestic user guides and product manuals, occupant behaviour and behaviour change, occupant feedback on low energy homes, and consumer perceptions of microrenewable technologies.

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The NHBC Foundation has been established by NHBC in partnership with the BRE Trust. It facilitates research and development, technology and knowledge sharing, and the capture of industry best practice. The NHBC Foundation promotes best practice to help builders, developers and the industry as it responds to the country's wider housing needs. The NHBC Foundation carries out practical, high quality research where it is needed most, particularly in areas such as building standards and processes. It also supports housebuilders in developing strong relationships with their customers.


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