The impact of occupant behaviour and use of controls on domestic energy use

NHBC Foundation

Housing research in partnership with BRE Trust

The impact of occupant behaviour and use of controls on domestic energy use

NHBC Foundation

Housing research in partnership with BRE Trust

March 2012

NHBC Foundation
NHBC House
Davy Avenue
Knowlhill
Milton Keynes
MK5 8FP
Tel: 0844 633 1000
Email: info@nhbcfoundation.org
Web: www.nhbcfoundation.org

Acknowledgements

This review was written by Sharon Monahan, Research Consultant and Andrew Gemmell, Social Research Business Coordinator, BRE

NF38
Published by IHS BRE Press on behalf of the NHBC Foundation
March 2012
ISBN 978-1-84806-245-0

FOREWORD

The impact of occupant behaviour on the energy efficiency of a home cannot be underestimated. How people use their home and its heating and ventilation systems can profoundly influence in either a positive or negative way their energy consumption, and therefore the running costs of a home.

In 2011, NHBC Foundation published *How Occupants Behave and Interact with their Homes* – the impact on energy use, comfort, control and satisfaction. It pulled together existing research on the subject of occupant behaviour, concluding that homeowners need to understand how renewable technologies can play a part in achieving energy savings and optimum comfort levels.

As a companion to that publication, this review brings together previous research and knowledge on occupant behaviour in low carbon homes with specific reference to controls, smart systems and user interfaces. It looks at how complex these systems are, levels of understanding, what features are liked or disliked and future trends.

The subject of how behaviour can affect a home's energy consumption is a vital part of the zero carbon homes agenda, and the findings suggest that there is still work to be done in both refining systems and educating users to ai d effective usage of the technologies.

While it is clear that further research is required, NHBC Foundation is pleased to bring together this knowledge that will help to shape and inform future debate.

I hope that you find this publication informative and interesting.

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.

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.

NHBC Foundation Advisory Board

The work of the NHBC Foundation is guided by the NHBC Foundation Advisory Board, which comprises:

Rt. Hon. Nick Raynsford MP, Chairman

Dr Peter Bonfield, Chief Executive of BRE

Professor John Burland CBE, BRE Trust

Imtiaz Farookhi, Chief Executive of NHBC

Richard Hill, Executive Director, Programmes and Deputy Chief Executive, Homes and Communities Agency

Neil Jefferson, Chief Executive of the Zero Carbon Hub

Rod MacEachrane, NHBC Director (retired)

Robin Nicholson, Senior Partner of Edward Cullinan Architects

Geoff Pearce, Group Director of Development and Asset Management, East Thames Group

David Pretty CBE, Former Chief Executive of Barratt Developments PLC

Professor Steve Wilcox, Centre for Housing Policy, University of York

CONTENTS

EXECUTIVE SUMMARY

This review was commissioned by the NHBC Foundation to examine previous research and knowledge on occupant behaviour and user interface design in homes. An extensive literature review was conducted and information was also gathered from experts at BRE.

The review examines how energy is used in the home and how the way people behave affects their energy consumption. It explores the factors that affect energy use in the home and looks at the ways in which energy consumption can be reduced. In particular, the review examines the importance of providing guidance, feedback and information to occupants, and the role of in-home displays such as smart meters. It investigates behavioural science theories for changing behaviour and how these have been applied to energy use behaviours. It also examines the differences between energy efficiency and energy conservation and asks if energy-efficiency measures go far enough to tackle energy reduction.

Occupants control the energy used in a home through controls and user interfaces. These controls and interfaces can influence occupant behaviour. The review, therefore, goes on to explore the influence of controls and user interfaces on domestic energy use. It explores findings from previous research into how occupants typically use controls, their level of understanding and the information provided with controls. The review also compares automated and manual control systems in dwellings and their advantages and disadvantages.

The review then explores future user interfaces and 'smart homes'. It examines how occupants will interact with future homes and what interfaces they are likely to use. It highlights where smart home systems might add value and possible barriers to the widespread roll-out of smart homes. It also examines recent consumer research on the latest low energy homes and outlines the concerns of consumer groups about the technologies and interfaces installed in these homes.

The findings and recommendations are summarised at the end of this review. The review recommends further research in the areas of:

- User interface design – the development of intuitive, user friendly controls.
- How to bring about long-term behaviour change through feedback, information, interventions and the design of controls.
- The impact of smart meters on long-term domestic energy use.
- The domestic energy use of different consumer groups, the strength of the rebound effect and targeted interventions for key consumer groups.
- Occupant feedback on the latest low carbon and smart homes.
- How to improve the user guides, manuals and training given to the occupants of new, low energy homes to ensure they can use the technologies installed in them efficiently and effectively.
- The impact of smart systems and automated controls on occupant energy use, comfort and satisfaction.
- The training, maintenance, supply chain, design and build implications of future control systems.

1 Introduction

This review was prepared by the Social Research Team at BRE for NHBC Foundation. The review was commissioned to examine previous research and knowledge on occupant behaviour and user interface design in low carbon homes.

In most countries in the world, buildings are responsible for at least 40% of energy use (WBCSD, 2007). This figure is rising fast as construction booms in countries such as China and India. In the UK, over 40% of energy consumption is building related. The energy used in homes alone is responsible for more than a quarter of CO_2 emissions (Energy Saving Trust, 2005). CO_2 is the main greenhouse gas and the most significant cause of climate change. Most of the energy used in homes is produced using processes that release CO_2 into the air.

1.1 Domestic energy consumption

The Department of Energy and Climate Change (DECC) provides a breakdown of domestic energy consumption in UK domestic dwellings (DECC, 2011). Total domestic energy consumption has risen from 36,884,000 tonnes of oil equivalent in 1970 to 43,590,000 tonnes of oil equivalent in 2009. Breaking this down into types of fuel, between 1970 and 2009 total domestic electricity consumption increased by 59%, use of coal, coke and other solid fuels decreased by 96% and natural gas consumption increased by more than 300% (Figure 1).

Space heating is responsible for the majority of domestic energy consumption, followed by lighting, appliances and water heating. Out of a total of over 43 million tonnes of oil equivalent in 2009, space heating was responsible for 61%; lighting and appliances for 18% and water heating for 18% (Figure 2).

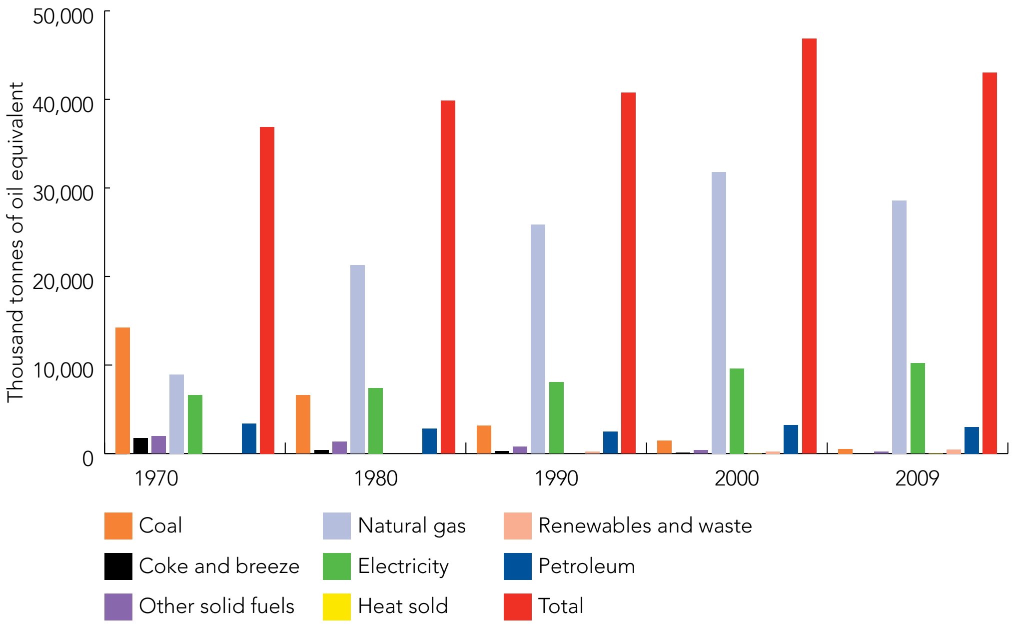


Figure 1 Domestic energy consumption by fuel, 1970 to 2009 (thousand tonnes of oil equivalent) (DECC, 2011)

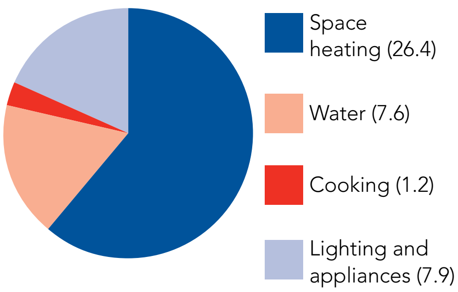


Figure 2 Proportion of domestic energy consumption by end use, 2009 (DECC, 2011) (million tonnes of oil equivalent)

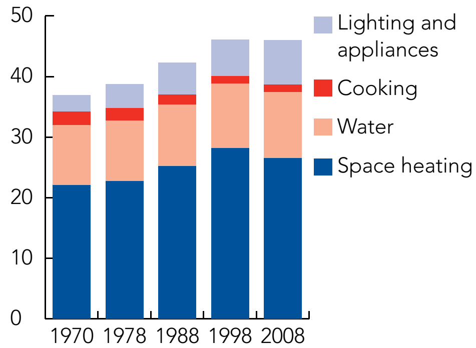


Figure 3 Domestic final energy consumption by end use, 1970 to 2008 (DECC, 2011) (million tonnes of oil equivalent)

Figure 3 shows that the energy consumed for space heating, lighting and appliances has increased between 1970 and 2008, while for cooking it has decreased. Reducing the energy used for space heating, lighting and appliances is vital if the Government is to hit its carbon targets.

1.2 New housing and occupant behaviour

In 2006 the UK Government set a target for all new housing to be zero carbon by 2016. This target included not only space heating, water heating and lighting (normally regulated through the Building Regulations) but also emissions from appliances such as televisions, washing machines and fridges. In April 2011, this target was amended and cooking and plug-in electrical devices are no longer included. This is still an ambitious target to achieve, although it should be possible, with the use of improved technologies, thermal efficiencies and the use of renewable energy sources. However, there is growing concern that variances in human behaviour will have a huge impact on our ability to reach the Government's target. If improvements in energy efficiency are to be achieved, then the attitudes and behaviour of occupants of domestic dwellings must also be targeted and altered.

Unoccupied houses use no energy; however, a great deal of energy is used to ensure that environmental conditions in the house (temperature, lighting, ventilation, etc) are comfortable for occupants. Thus, the way the occupant interacts with the building, and in particular the user controls, can a have a massive impact on the energy used and the comfort levels achieved. The performance of low-carbon buildings is very much dependent on occupant behaviour. From evidence, both anecdotal and empirical, it is suggested that the full benefits of low-carbon buildings are not being realised because occupants do not fully understand how to control the technologies efficiently. A major element of this is the inaccessibility of the user interfaces and the misuse and/or misunderstanding of the systems installed. There is a need to better understand occupant behaviour and how occupants interact with buildings (in particular, the user controls) as this can have a massive impact on the energy used and the comfort levels achieved.

In addition, there is growing concern that the zero carbon housing policy could be undermined by the fact that many low-carbon measures are untried and untested in mainstream housing production in the UK (Bell *et al*, 2010). Many schemes have not been comprehensively monitored and evaluated to check whether they have achieved their performance targets.

1.3 Aim of the review

The aim of this review is to provide an overview of previous and current research into occupant behaviour and user interface design in low carbon homes. It contains the main findings from an extensive literature review and input from experts at BRE. The main objectives are to examine:

Occupant behaviour in low carbon homes

- The influence of occupant behaviour on energy use.
- How users behave and interact with the latest low carbon homes.
- The psychology of energy saving.
- The principal drivers to user behaviour in homes.
- The concept of comfort and the expectations of different demographic groups.

User interface design

- The complexity of control systems and the impact on behaviour and interaction.
- What aspects of controls are liked and disliked by occupants.
- The debate surrounding the use of automated control systems and the arguments against them.
- Occupants' levels of understanding and misuse of systems.
- Future trends and technologies.

2 Occupant behaviour

2.1 Behaviour and energy use in the home

Research suggests that changing occupant behaviour will allow more energy to be saved than through architectural and technical strategies alone (Shama, 1983, cited in Janda, 2011). Differences in individual behaviour can produce large variations of more than three times the average in energy consumption (>300%), even when differences in housing, appliances, heating, ventilation, air conditioning and family size are controlled for (Janda, 2011). Further research on the effect of differences in behaviour comes from the World Business Council for Sustainable Development (WBCSD) (WBCSD, 2007) who carried out research on Passivhaus homes. The Passivhaus Standard began in Germany in 1991 and is an approach that claims to reduce the energy demands of a building to one-twentieth of a similar-sized home built to current Building Regulations. The energy consumed in Passivhaus homes is significantly lower than the lowest usage in average new buildings. However, research on the Passive House Standard (Passive House Institute) found that even if people live in identically constructed houses, different users will have very different energy consumptions. Deviations of ±50% from the average consumption value are not exceptional.

Research consistently shows that much of the energy consumed in domestic dwellings is wasted. According to a Parliamentary Office of Science and Technology (POST) report in 2005, the typical household wastes approximately one third of energy each year (POST, 2005). 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.

Producing successful low energy housing is not only about the performance of the properties, but also about understanding the relationship between people, their personal circumstances, lifestyles and the building itself. A home is more than bricks and mortar.

> 'The relationship between a dwelling and its occupants is highly complex and varies over time. Together a building and its occupants form an integrated system in which people live their lives and, in the process, use energy and emit carbon.' (Bell *et al*, 2010).

Martiskainen (2007) carried out a review of research on behaviour and energy use and found that behaviours are influenced by both societal and personal factors. Macro-level factors, such as technological developments, economic growth, demographic factors and cultural factors, influence behaviour at a broader level; whereas micro-level factors, such as motivation, ability and opportunity, influence behaviour at an individual level (Abrahamse *et al*, 2005, cited in Martiskainen, 2007). Behaviour is also influenced by habits and routines that people perform without thinking about them. Most people turn lights on and boil their kettles without even considering where the energy to power these actions comes from and how much energy they may be wasting. The factors that influence these actions can be divided into internal factors (attitudes, beliefs and norms) and external factors (regulations, institutions). To change people's environmental behaviour both internal and external factors need to be considered (Jackson, 2005).

2.2 Lifestyles

Bell *et al* (2010) suggest that the success of low carbon housing depends upon not only improving the fabric performance, but also understanding the relationship between how occupants use the property and their particular personal circumstances. Personal circumstances, household types and working status can affect a 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 proportion of their time in the home. In addition, socio-demographic trends, such as fewer people per household, an ageing population and more two-income households, coupled with an increase in working from home, will impact on future energy use. Increasingly, energy companies are recognising this and all the big UK energy suppliers are conducting research to look at the future energy needs of their customers. Scottish and Southern Energy have even gone as far as building 10 zero carbon homes and monitoring the occupants' energy use. They are keen to understand what the future energy demands are likely to be from different household types.

Other trends that influence energy use include a rise in household incomes and the purchase of more and bigger appliances in homes. In addition, people tend to keep their homes warmer in winter than they used to and there has also been an increase in the number of households, as the number of people who live alone has increased (DECC, 2011).

2.3 Time spent at home

The Office for National Statistics (ONS) (ONS, 2006) records that people in the UK spend 70% of their time at home and 27% of time away from home on primary activities. Lifestyle factors that may increase the length of time spent at home, and therefore increase the likelihood that heating duration and energy consumption will be higher, include home working, unemployment, permanent ill health, disability and retirement. During the winter months in particular, space heating may increase if occupants are at home for longer periods during the day.

The increase in the availability of technology in the home has contributed to an increase in the number of home workers, which has risen from 2.3 million in 1997 to 3.1 million in 2005 (Ruiz and Walling, 2005). Cairns *et al* (2004) suggest that if this growth continues there could be around 30% of the UK workforce home working for at least some of the time by 2014. This would lead to increases in energy consumption in domestic dwellings but needs to be offset against energy savings at the place of employment and reductions in travelling. The Department for Transport (2009) reports data from the 2008 National Transport Survey. It found that people in higher managerial and professional occupations and those on high incomes are more likely to be home workers; 21% of those in the highest income quintile surveyed were likely to be home workers.

As with home workers, stay-at-home parenting affects the amount of time spent in the home, which in turn is likely to affect the amount of energy used. The number of stay-at-home parents in the UK fell from 2.8 million in 1993 to 2.2 million in 2008 (uSwitch.com, 2008). This reduction in the amount of time spent in the home is likely to result in less energy being consumed. However, having children in the home leads to increased energy consumption, this may be partly explained by increased time spent at home and house size, but is mainly due to the number of occupants.

The ONS (2009) reports that 3.3 million households are occupied by people that are of working age but do not work. Retired people occupy 26% of households and 10% of households are occupied by other economically inactive groups such as the permanently sick and disabled, and students. Older people are living longer. On average, older people consume less energy, so an increasing older population could lead to a reduction in expected total energy consumption. However, older people are also more likely to live alone or in homes with low occupancy density. The Department for Communities and Local Government (DCLG, 2009) estimates that there will be a 60% increase in the number of one person households between 2006 and 2031, much of this increase will be among the older population, aged 55 years and above. This is likely to lead to an overall increase in energy consumption and therefore CO_2 emissions.

A trend highlighted by the ONS is that of young people returning to live with their parents, this may have an impact on energy use, such as increased use of appliances and changes to heating and water consumption (although some research indicates that these changes had very little effect). More research is needed into differences in energy consumption in each of these groups and the extent of their impact on overall CO_2 emissions over time.

2.4 Space heating

Heating and hot water account for around 84% of energy use in a typical home in the UK (Department for Business Enterprise and Regulatory Reform (BERR), cited in CIPHE, 2008). Improving the energy efficiency of heating systems, or reducing demand, by even a small amount, can have a far bigger effect on energy use than making changes to, for example, lighting. Research from BERR (cited in CIPHE, 2008) showed that turning a room's thermostat down by just 1°C can reduce heating bills by 10%.

People increasingly want to be comfortable in buildings. The average temperatures inside domestic dwellings are estimated by BRE to have increased from 15.5°C in 1991 to 19°C in 2002. The rise in temperatures has been helped by the increased use of central heating – central heating ownership increased from 79% of households in 1990 to 91% in 2002. Another factor is greater use of insulation in dwellings (DECC, 2011).

Temperature in a domestic dwelling is an important factor in energy consumption. According to Shorrock and Utley (2003) a comfortable living room temperature during occupancy hours is 21°C, in other parts of the house it is 2°C lower. The thermostat setting and length of time heating is on influence a dwelling's space heating energy use (Shipworth *et al*, 2009). A 1% increase in heating temperature is estimated to cause a 1.55% increase in CO_2 emissions. The same percentage increase in heating duration is likely to result in a 0.62% increase in CO_2 emissions (Firth *et al*, cited in Shipworth *et al*, 2009). So, increasing the temperature in a home results in more CO_2 emissions than having the heating on for a longer time period. However, these figures should be treated with caution as 1% of six hours is 3.6 minutes, which, if the temperature has been reached, is negligible.

Some suggest there is an urgent need to develop control systems that achieve effective zoning of the house, coupled with methods for persuading occupants to close doors in winter in order to avoid hot bedrooms and cool living rooms. Several manufacturers (for example Danfoss and Honeywell) have recently launched wireless controlled radiator valves that will support effective zoning. However, how these systems perform will still depend upon user behaviour, especially how good the occupants will be at closing doors.

The temperature that occupants set their thermostat to is affected by many different factors, such as social grade, type of dwelling, tenure and number of persons in the household. Statistics from the Department for Environment, Food and Rural Affairs (Defra) (Defra, 2009) show that higher social grades reported setting their thermostat to 21°C. People in lower social grades reported setting their thermostat at least 3°C higher (Defra, 2009). Defra (2009) found that two of the main factors that contribute to higher than average thermostat settings are whether a person lives in a flat or a maisonette and whether they live in the private rented sector. People living in flats reported setting their thermostats to as high as 28°C, 8°C higher than the self-reported thermostat setting for people living in detached houses (Defra, 2009). Private renters set their thermostat to 27°C on average, which is higher than other tenure groups.

Research by DCLG (2011) found that over a third of private renters live in flats so there may be a relation between these two groups. In addition, the type of homes that private renters occupy may have an impact on why their thermostat settings are high. For example, over 40% of private renters live in older dwellings built before 1919 and these houses have the lowest proportion of energy-efficiency measures, such as insulation (DCLG, 2011). Further findings on internal temperature suggest that people living on their own tend to live in colder homes (Yohanis and Mondol, 2010).

Meier and Rehdanz (2008) investigated residential space heating behaviour of British households. The analysis covered 15 years and included more than 64,000 households. The main findings were that socio-economic characteristics, such as household income, play an important role in explaining differences in heating expenditures. Heating expenditure increases with household size, average household age and number of children. Owners have higher expenditure than renters. The reasons for this may include housing type, with renters mainly living in flats and the majority of owners living in detached or semi-detached houses. In general flats are more energy efficient than houses.

2.5 Gas and electricity consumption

A Danish study carried out a very detailed analysis of the patterns of domestic electricity use (Gram-Hanssen *et al*, 2004). The first data set included over 50,000 households and coupled individual electricity use with economic data on household members, building size and type, etc. The second data set looked at 100 households and measured electricity consumption every 10 minutes during one month for each appliance and for most lamps. A detailed analysis was carried out on use of appliances coupled with socio-economic and building data from a questionnaire and with qualitative interviews on everyday life and electricity use in 10 households. They found that electricity usage was different depending on house type. The average electricity used by people in detached houses was 4189 kWh/yr, in semi-detached houses it was 3114 kWh/yr and in apartments it was 1720 kWh/yr.

Further analysis found that up to 40% of the variation in energy levels was accounted for by three variables: household occupancy, floor area and income. The number of people living in each household explained the majority of the variation for each house type. Electricity consumption per person reduced when there were more household occupants. The average electricity consumption per year per person in a detached house was 541 kWh, this increased to 556 kWh per person in a semi-detached house. The energy consumed in apartments was about half as much at 291 kWh per person per year. A strong correlation was also found between household income and floor area, which, when considered together, accounted for between 6.2% and 8.5% of the variation in energy consumption. Other variables such as age, education and ethnicity, only accounted for around 2% of the variance.

Gram-Hanssen *et al* (2004) cited previous research on lifestyle (for example Schipper *et al*, 1989, Bourdieu, 1998), which concluded that lifestyle and energy use correlate. But a later study by Gram-Hanssen (Gram-Hanssen, 2002, cited in Gram-Hanssen *et al*, 2004) found that if similar households are compared according to all relevant background variables, there is still considerable difference in energy use. This study, therefore, implies that lifestyle, occupancy and building type only partly account for the activities that are relevant for understanding energy use.

The findings by Gram-Hanssen *et al* (2004) show that the total electricity consumption in a household is highly dependent on income and the floor area of the dwelling, whereas age, education, gender and ethnicity appear to have very little influence. Furthermore, both income and age influence some, but not all, of the end uses; electricity use for refrigerators/freezers and televisions, for example, appears to be independent of both age and income; however, dishwashing, washing/drying, lighting and standby use depend both on age and income. Background variables only describe 30 to 40% of the variations in electricity consumption. Some of the variations can be further explained by whether the household is careful about saving energy, which may depend on a need to save money, on deep-rooted habits from childhood or on a conscious wish to act in an environmentally-friendly way.

The findings demonstrate that age, income and lifestyle affect relative energy use. However values, attitudes and unconscious habits are also relevant to the understanding of energy use. Gram-Hanssen *et al* (2004) suggest actual behaviour cannot be understood in a simple, rational model in which occupant's desire to save energy actually leads them to changing their behaviour. The final finding was that daily habits and routines in many cases are changed very slowly in spite of information and campaigns.

Another study into patterns of energy consumption was carried out by Summerfield *et al* (2009), who examined changes in energy demand in 36 low-energy UK dwellings in Milton Keynes, from 1990 to 2005. No significant changes were found in average gas and electricity consumption over time. However, dwellings were then classified into low, middle and high groups according to their energy use in 1990. Although no significant changes were found in low and mid-groups over time, there was a clear pattern of increase for the high use group, where electricity consumption had increased by 72% (Figure 4). This rise is possibly due to both an increase in appliances and some electric heating in house extensions. Although there were some limitations in this study, the authors support their findings with national data, which indicates a similar pattern. For example, the top 30% of households by income spend more on energy than all other households combined (Shorrock and Utley, 2003, cited in Summerfield *et al*, 2009). Furthermore, analysis of national expenditure on energy from 1999 to 2005 by income deciles showed that higher income households not only spend far more on energy in absolute terms than lower groups, but there had also been a greater increase in their energy expenditure (ONS, 2000, 2007, cited in Summerfield *et al*, 2009).

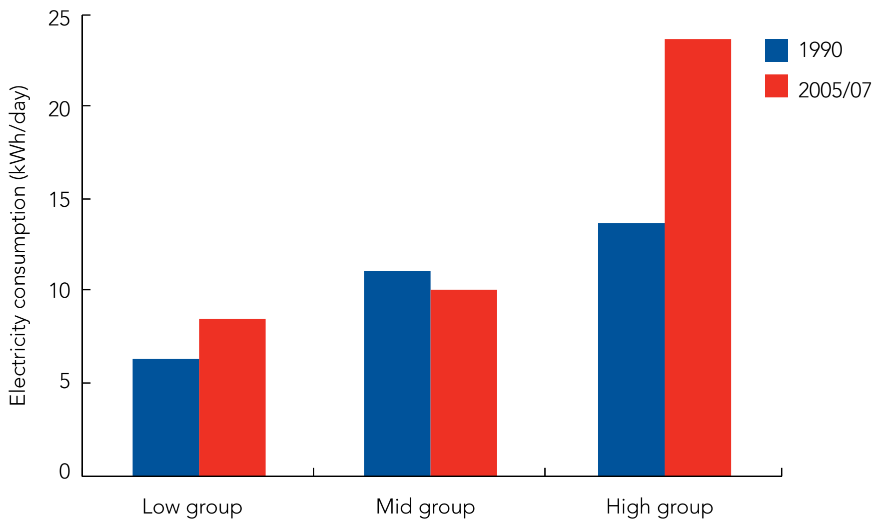


Figure 4 Electricity consumption (KWh/day) by group 1990 to 2005/07 (external T = 5°C)

According to Summerfield *et al* (2009), this study highlights the impact of the skewed energy distribution towards high energy users and the increasing skew in demand over time, particularly for electricity demand. The authors suggest that these results, together with the national data, question the reliance of using average values in examining energy statistics from the housing stock for policy development. They recommend that energy-related statistics in the domestic sector should be stratified by consumption, or dwelling size, or an indication of the interquartile range (ie the differences between the top and bottom quartiles).

These findings highlight the potential importance of focusing energy policy on those parts of the stock and population where consumption is highest and where it appears to be increasing the most.

In an earlier study on the Milton Keynes Energy Park (Summerfield *et al*, 2007) the authors highlighted a number of additional potentially significant issues:

- Higher initial energy use corresponds with greater increases in energy use and is related to dwelling area, extensions and occupant income.
- Occupant behaviour can counteract the internal temperature of even well insulated buildings by, for example, opening windows.
- Although dwellings may achieve specific standards, they may not stay at that standard, particularly when extensions have been added or occupant lifestyles have changed.

2.6 Appliances and lighting

Since the 1990s people have been buying more energy-efficient appliances but, at the same time, there has been an overall increase in the purchase of appliances, for example extra televisions and other consumer electronics. The increase in the purchase of appliances has been influenced by cheaper prices and increased personal wealth. In addition, increasing individualised lifestyles can lead to a household having multiple versions of the same appliance. For example, in 2003 over 60% of households owned two or more televisions. Other reasons for increased energy usage include use of appliance standby modes and increased use of rechargeable portable devices such as laptop computers. The use of standby on some electrical goods is responsible for around 1% of total domestic energy consumption and 6% of domestic electricity consumption (DECC, 2011). Changes in technology can also result in energy being used in a different way, for instance the popularity of mobile telephones and iPods have resulted in increased usage of chargers in the home. These are often left on when the device has been fully charged or even if the device has been unplugged.

Energy consumption for lighting has increased by around 1% per year since 1990, mainly due to the shift away from rooms lit by single ceiling bulbs towards multi-source lighting. So, although lighting is now more energy efficient, more lighting is being used. There has been an increase in the use of Halogen lighting in this time. Halogen light bulbs are more efficient than incandescent light bulbs but the efficiency is often cancelled out because people tend to use more of them. 'Down-lighter' halogen bulbs are recessed into ceilings and people often have many more of these than the traditional single light in the middle of the ceiling. Older people appear to use less lighting than younger people: households aged 20 to 64 years use 61% more energy for lighting than households aged 65 and over (Bladh and Krantz, 2008). This may be because older people are more likely to show cost-conscious behaviour than other age groups and switch off lights that are no longer needed. It is also likely that turning lights off in unoccupied rooms is a more ingrained habitual behaviour for this age group.

The presence of children in a household is also likely to affect the number of appliances per home and the resulting energy use. An example of use of energy by children is that 58% of children aged between 12 and 14 have electric appliances, such as televisions and games consoles, in their bedroom and 23% of young people reported being likely to fall asleep with appliances left on (Sleep Council, 2007). The use of appliances is changing, particularly with regard to teenagers who are using more than one device at the same time, possibly while leaving other devices paused in another room so that they can go straight back to where they left off. Recent research by the Kaiser Family Foundation found that young people are spending at least seven and a half hours a day with media (computers, cell phones, TV or music) (MSN News, 2011).

Although only a small-scale evaluation of lifestyles and energy consumption, these findings do indicate that lifestyles can have a significant impact. Energy consumption in a household is most likely to be related to income, number of occupants and presence of children in the household. Those on higher incomes and living in larger houses are likely to consume more energy. Some findings suggested those on low incomes tended to heat their houses to higher temperatures. However, if a home is three or four times larger, occupants are likely to spend three or four times the amount on heating to reach the same temperature. So a temperature of 21° in a big house is still consuming more energy than a temperature of 28° in a small house. Lifestyle factors, such as time spent at home, use of appliances and lighting, and the level of heating also have a significant impact. Potential trends, which may affect energy consumption, also need to be taken into consideration, such as the ageing population and changes in home working and home parenting. More research is needed into the effects of these different variables on energy consumption. This will allow more targeted interventions to be applied, for example targeting those on higher incomes with policy initiatives.

Box 1 Summary of findings

- Space heating and water heating account for the greatest proportion of energy use in the home. Reducing demand, by even a small amount, can have a far larger effect on energy consumption than reducing use of, for example, lighting.
- The highest energy use appears to be in behaviours related to time spent at home and control of the thermal environment. Lifestyle factors that increase the length of time spent at home include home working and unemployment.
- Income, size of house, number of occupants and the presence of children in the household are factors that relate to using more energy.
- The proportion of older people is predicted to rise. On average this group uses less energy compared to the average for the population, however, older people are also more likely to live alone or in homes with low occupancy density.

3 Reducing energy consumption

3.1 Background

It is clear from the previous section that energy-consuming behaviour has an impact on the amount of energy used. A key question, therefore, is whether energy consumption in the home can be influenced through behavioural change measures. Changing behaviour in energy consumption is an important and yet difficult issue. There are two separate aspects of changing energy behaviour to reduce energy consumption: buying efficient equipment and using energy efficiently (WBCSD, 2007). It is not sufficient just to improve the efficiency of housing and appliances; there is also a need to change occupant behaviour.

According to Jackson (2005), improving the energy efficiency of domestic products offers clear benefits. It both reduces energy consumed and the environmental impact per unit of service delivered and it often offers financial benefits to the consumer, such as lower electricity bills. However, people may not buy energy-efficient equipment if there:

- is not enough information on equipment performance
- is a lack of concern for energy efficiency. There is a tendency for consumers to be more interested in issues like comfort, aesthetics and technical performance
- are cost differences between standard and energy-efficient products (WBCSD, 2007).

Furthermore, there is an increasing recognition that energy-efficiency improvements may not significantly reduce environmental emissions. According to Jackson (2005) there can be low uptake of energy-efficient appliances and even when purchased consumers may use the financial savings from using energy-efficient appliances in two ways: they may keep their existing patterns of use and reduce their overall electricity consumption or they may choose to use the savings for increasing their energy use, for example by keeping lights or heating on longer. This issue of rebound effects is explored in more detail further on in this section.

3.2 Providing guidance and information

There has been substantial research on the effects of guidance and information on energy consumption. The information deficit model (cited in Martiskainen, 2007) proposes that providing occupants with more and better information will lead to more efficient energy use. Awareness and education are the main tools used to overcome information deficit and change people's behaviour (Janda, 2011).

Pyle *et al* (1996) suggest that the best way to educate occupants on how to use energy effectively and efficiently in a way that will not affect their levels of comfort is to:

- provide them with more information on how to save energy in the home
- raise awareness of the best ways to use heating systems efficiently
- increase awareness of how behaviour affects energy use.

Research clearly shows that the occupants of new low energy homes need clear guidance and information about how to use these homes efficiently and effectively to maximise comfort and minimise wasted energy use. Bell *et al* (2010) suggest that developers and landlords should provide more meaningful guidance on the use and operation of low carbon homes to occupants. Social landlords are in a particularly good position to lead the way in the provision of information. They could also provide feedback to designers and to developers on occupant views of the dwelling, particularly the design of systems and controls.

Further evidence for the need for improved training comes from research by DCLG (2010) which examined social housing that had been built to the Code for Sustainable Homes standards. The Code for Sustainable Homes was introduced in England in 2007. It is a national standard intended to improve the overall sustainability of new homes. It is now mandatory for social housing, homes built on ex-public land and where required by planning conditions. The research by DCLG examined four case studies of predominantly medium-scale sites of social housing units. The research included occupant feedback, which appears to have been based on information collected through the developer's normal customer service and support channels.

The low carbon and renewable features of these homes included high levels of insulation, low-energy lighting, passive solar energy such as photovoltaic cells, biomass boilers, combined heat and power systems, heat recovery systems and heat pumps. One of the key lessons identified from the case studies was that owner and resident training for new energy systems is vital to ensure their successful implementation and use. To ensure that systems are used effectively, there is a need for more information and training in the sustainability features of new homes, not just for the occupiers but also for housing managers, repair line operators and housing repair managers.

One important way of providing more information to occupants is in-home user guides. Effective user guides can help occupants to fully understand how to use their homes and the systems in them. Recent (unpublished) research by BRE examined occupants' views of user manuals. The main findings were that occupants found the manuals too complicated and detailed. Many occupants reported finding 'quick start' guides more useful. Also, some research (for example Hadi and Rathouse, 2008, unpublished) found that occupants do not tend to look at their manuals, so the operation of systems in the home was very much 'hit and miss', reducing the likelihood of the systems being used in an efficient way. Much more research is needed into the use of manuals and how they can be improved, including what information should be provided, in what format and when is the best time to provide this information.

Janda (2011) suggests that not only is there a need for more information to be provided to occupants, but also others involved in the housing process. Information should be flowing backwards and forwards between occupants and professionals. Architects, designers, builders and landlords need feedback from occupants on how these buildings perform in practice and how they are used. This information would allow those working in the house building and management professions to understand how best to design and manage them. Architects need to find ways of integrating user involvement in building performance. Resident and buyer feedback should be obtained as this provides a valuable source of information on sustainability features or products used and lessons for future development.

Janda also argues that reducing energy use in buildings requires changes in the fabric of society. A significant contribution to the use of energy is the low level of knowledge about energy issues among the general population. Janda suggests that education on energy use should be much more comprehensive and interactive and suggests that it should start in schools. Many people spend 90% of their time indoors but few of them understand how buildings work. People learn from their surroundings and can learn from buildings. Janda argues that the general public should be educated on how to use buildings in less energy-consuming ways. Therefore there is a need to increase knowledge and understanding of energy use amongst the general population and also to increase levels of training both for the professionals involved in new homes and for the occupants.

3.3 In-home displays

The Government plans a mass roll-out of 53 million smart meters to 30 million UK homes and businesses to be complete by 2019. It is anticipated that the use of in-home displays will both help consumers save money and reduce carbon emissions. The benefits of in-home displays include:

- Energy data can be measured and displayed and this should encourage consumers to see which items use the most energy and learn to use energy more efficiently.
- Householders will be able to see how much energy is costing them. Saving money should act as a driver to encourage them to behave more energy efficiently.
- Meters will transmit energy consumption data to suppliers so allowing suppliers to offer consumers targeted home energy advice and a wider choice of energy tariffs.
- The ability to automatically shift between different tariffs throughout the day and night. Higher prices charged at peak times could encourage occupants to shift their usage, for example using the washing machine during cheaper tariff periods.

The Department for Energy and Climate Change (DECC, 2011) estimates that smart meters will reduce average household energy use by 2% and that smart meters will save 1.5 M tonnes of CO_2 emissions per year by 2020 from reduced electricity consumption and 1.7 M tonnes per year by 2020 from reductions in gas use.

For many people, attempts to understand energy use is difficult and people can find it hard to estimate the costs and benefits of their actions on energy consumption. Currently, many people do not fully understand the costs of their energy use or how to save energy. They have no way of knowing how much energy is being used when, for example, the heating is on or the tumble drier is in operation.

> *'Energy use, most of the time, is invisible to the user. Most people have only a vague idea of how much energy they are using for different purposes and what sort of difference they could make by changing day-to-day behaviour or investing in efficiency measures. Hence, the importance of feedback in making energy more visible and more amenable to understanding and control.'* (Darby, 2006).

Energy bills are not specific enough and they do not provide information at the time of use, but rather several weeks, or even months, later. The use of direct debit to pay for energy used further separates current use of energy from paying for it. Consumers who use direct debit to pay for their energy may be completely unaware of how the heating load is spread over the year (Darby, 2006). Research shows that providing immediate feedback on energy use can help fill the information gap and so reduce consumption (Darby, 2006). Darby reviewed research in this area and found that direct feedback can lead to savings of between 5 and 15% in energy consumption. Darby found that feedback is likely to be most effective when it has helped occupants develop new habits and when it has led to them investing in efficiency measures. Instantaneous, easily accessible displays are particularly effective because they can show the relative consumption of different appliances.

However, there is doubt over whether smart meters can actually change behaviour and encourage people to use less energy. Some findings suggest that energy savings are inconsistent. However, feedback would not necessarily have the same effect on all demographic groups. Research suggests that feedback may have less of an impact on low energy users: it may not necessarily motivate households with low consumption to reduce their energy use, and may even lead to increased consumption among this group particularly if the information displayed compares their energy use with other, higher energy users. In addition, there is insufficient evidence that feedback measures lead to quantifiable, long-term behavioural changes and energy savings. Feedback, used together with incentives to save energy, may change behaviour, but feedback alone may not be the answer. Darby found that, in general, a new type of behaviour formed over a three-month period or longer, appears to be likely to endure, although continued feedback is necessary to help maintain the change. More research is needed to establish which types of intervention measures, or combination of measures, would be the most effective.

Darby suggests that persistence savings will happen when feedback has helped people develop new habits and when it has acted as a spur to investment in energy-efficiency measures (Box 2). People may need additional help in changing their habits and this is where well thought-out energy advice can be of use. Where feedback is used in conjunction with incentives to save energy, behaviour may change but the changes are likely to fade away when the incentive is taken away.

Box 2 Effective feedback

The Electric Power Research Institute (2009) reviewed research on the issue of feedback and suggest that feedback is more effective when it is:

- presented clearly and simply
- provided frequently, as soon as possible after a completed behaviour (so, for example, if an occupant turns up the central heating, the display immediately shows the amount of energy that is being used)
- presented relative to a meaningful standard of comparison (for example, $KWh.m^2$)
- provided over a long time period
- customised to a household's specific circumstances.

Other factors can influence energy use. Increased knowledge is needed of people's behaviour 'because occupants behave in more complex ways than designers account for: they open windows, leave doors open, generate body heat, keep tropical fish tanks and install plasma TV screens' (Janda, 2011). Occupants' energy-using behaviour may not be rational and predictable but rather may be idiosyncratic. Behaviour may be connected in some way to technologies and innovations and providing more information may not necessarily alter behaviour. So, for example, if people want the latest gadgetry they may be determined to buy it and not care about the fact that it will increase their energy use.

Martiskainen (2007) reviewed research into occupant behaviour and energy consumption and found that behaviour is a complex combination of emotions, morals, habits, social and normative factors and it can be difficult to change any of these (Martiskainen, 2007). To reduce domestic energy use, measures such as feedback displays and better billing may assist in increasing awareness of energy consumption and so influence behaviour. However, Martiskainen suggests that to be effective, interventions should include a combination of measures, for example, a combination of energy advice with display units and more innovative billing. This would provide households with a mix of improved information and feedback on their energy consumption and this mix of guidance and feedback should raise awareness and so lead to behavioural change. Martiskainen suggests that the most effective intervention measures need to be:

- clearly presented with simple messages
- contain information that is relevant to the occupant
- involve some kind of goal or a commitment
- be visible, consistent and frequent.

Martiskainen suggests that occupants are more likely to carry out energy-efficient behaviours if measures have direct benefits to them, are easy to carry out, and meet their goals and motives.

The effects of smart meters on behaviour appear not to be clear-cut and there is uncertainty as to their long-term effects. It would seem that people frequently behave in idiosyncratic ways and possibly the most effective way to change behaviour is with a combination of measures, this is examined further in the following section.

3.4 Behavioural science theories of behaviour change

According to Martiskainen (2007), any measures intended to change behaviour should take into account both internal and external factors. Martiskainen outlines several theories that have been developed in social-psychological research and have been used in pro-environmental behaviour research. Two examples are Rational Choice Theory and Social Learning Theory. Rational Choice Theory proposes that consumers calculate the expected costs and benefits of their actions and choose those actions, which will be the most beneficial or least costly. Social Learning Theory proposes that people learn from their experiences, from social models and from observing others (such as family, friends, colleagues and people in the public eye).

The Environment Agency (2005) distils many concepts from the behavioural sciences into seven key principles, which need to be considered when trying to change energy-consuming behaviour (Box 3). If applied in relevant situations, these principles should be able to increase the impact of policy interventions to change people's behaviour.

Box 3 Principles of changing behaviour

The Environment Agency (2005) seven key principles, which need to be considered when trying to change energy-consuming behaviour:

- Other people's behaviour matters – people observe and copy other people's behaviour and feel encouraged to do things when they think other people will approve.
- Habits are important – behaviour is often based on habits and routines, which people do without thinking about them. Habits are difficult to change even when people want to.
- People are motivated to 'do the right thing' – money may be de-motivating for people's behaviour in some instances where it undermines their intrinsic motivation.
- Behaviour is influenced by people's self-expectations – people want their actions to match their values and commitments.
- People are averse to loss – they want to keep what is theirs.
- People are bad at computation – they tend to concentrate on the near future when making decisions and therefore concentrate on short-term gains.
- People need to feel involved and effective to make a change – information and incentive alone are not necessarily sufficient.

Another Government guide aimed at helping policy makers to encourage sustainable behaviour is based on four principles: enable, encourage, engage and exemplify (HM Government, 2005, cited in Martiskainen, 2007):

- Enable people to make responsible choices by providing them with information, education, providing viable alternatives and removing barriers.
- Encourage behaviour change through regulations, reward schemes, grants and recognition/social pressure.
- Engage people by community action and involve them by giving them responsibility.
- Exemplify through leading by example.

These guidelines, provided by the Government, are based on previous models and combine several key principles from behavioural sciences. The main message is the need for increasing information and education. Other important points are to engage people and make them feel involved and motivate them to do the right thing. Many of these principles are relevant to energy-consuming behaviours, especially the notion of habits as many actions are carried out without people thinking about them, for example leaving the TV on in the background even if not watching it. These principles are important because they can be applied to a wide range of different behaviours to change people's energy consumption.

In summary, the findings suggest that increased awareness and knowledge appear to be key to changing behaviour, particularly if they lead to changes in habits. In-house displays that provide both guidance/information and feedback appear to be effective, at least in the short term. However, the long-term effects on behaviour have not yet been evaluated. Research indicates that a combination of measures may prove to be the most effective way of changing behaviour.

Box 4 Intervention measures

Martiskainen (2007) suggests future research on intervention measures should examine:

- What the most effective combination of intervention measures are likely to be.
- The best way of designing intervention measures to ensure maximum impact, for example the best place to locate displays, the best way to present consumption information (for example graphs, numbers?) and what is the relationship between feedback and consumption, costs and environmental impacts.
- The best way to ensure that intervention measures bring about long-term changes in behaviour.
- Does a combination of feedback and other measures, such as rewards and goals, lead to effective long-term behaviour change?

3.5 Are efficiency measures alone sufficient?

Another important issue that is relevant to reducing energy consumption is the issue of whether energy efficiency alone is sufficient. Several studies show support for the view that energy-efficiency measures are not enough, on their own, to reduce energy consumption. Energy efficiency is affected by the fabric of the building and can also be affected by the use of controls. The majority of experts suggest that a 'fabric-first' approach is best.

According to Moezzi (1998), energy-efficiency measures do not necessarily save energy, but instead can act as permission to consume energy. For example, a product may be labelled as energy efficient but still use more energy than a non-energy-efficient labelled counterpart. An 'energy efficient' electric toothbrush can be labelled as 'low energy' or 'energy efficient' however, a manual toothbrush is not labelled and yet uses no energy. Or an 'energy efficient' television will still use more energy than not having a television at all.

Furthermore, Moezzi (1998) argues that the narrow application of energy-efficiency measures concentrates on the technological aspects of energy use and ignores the human behaviours that drive energy consumption. Increasing energy efficiency does not necessarily save energy at a national level either. Although energy efficiency has increased in large parts of the Western world, net energy consumption per capita has also increased. There is an important 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.'

In a report for the Market Transformation Programme, Jackson (2005) states that efficiency improvements cannot, by themselves, achieve the environmental targets demanded by the Government. The scale and pattern of consumption must also be taken into account and this involves the need to understand and to influence consumer attitudes, behaviours and lifestyles.

In a report prepared for the European Council for an Energy Efficient Economy, Calwell (2010) highlights some of the weaknesses in the energy efficiency approach. Calwell argues that efficiency on its own is not enough to stabilise energy consumption at sustainable levels. Energy-efficiency standards should be progressive in nature. For example, a large television consumes more energy than a small television, therefore a large television should have more stringent requirements for energy use per square inch than a smaller one. If these requirements are not applied, products will be more efficient but they will keep consuming more and more energy. Calwell examines how approaches to specifying, labelling and mandating the energy use of consumer products could change in response to increasingly urgent climate constraints.

Energy efficiency is not about conservation: improvements in efficiency allow reduction in energy use without any inconvenience or loss of amenity. Energy efficiency can be thought of as a measure of relative consumption: bigger and more powerful products get to use proportionately more energy and power and still be labelled as efficient as long as they use less energy than other, equally big and powerful, products.

Efficiency policies have led in many cases to slower rates of growth in absolute energy consumption but have not reduced it. In fact, energy efficiency can result in greater usage. Several terms are used to describe this effect – 'take back', 'rebound effect', 'bounce back' or 'Jevons's paradox'. It is what happens when more energy-efficient technologies lower the cost of using a particular product, allowing people to use it more extensively without increasing cost. Potential energy savings are reduced because the user changes their behaviour and so offsets some of the savings. For example, energy saving could lead to additional activity through either an increased use of the same product or for 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. Some argue that this effect means that energy-efficiency measures are leading to increased energy use; others argue that the effect is only slight and does not mean that energy efficiency is a waste of time.

Calwell provides three examples to illustrate the weaknesses in the energy efficiency approach: housing, refrigerators and televisions. In terms of housing, Calwell cites four major studies that have been carried out in the USA since 2002 that compare the annual energy use of ENERGY STAR-labelled homes to non-labelled homes. Most of the studies found that ENERGY STAR homes tend to use similar or more energy than non-ENERGY STAR homes, mainly because the labelled homes are, on average, larger. They may be more efficient per square foot, but they contain more square feet of living space. One of the reasons for this may be that the 'green' aspects of ENERGY STAR homes are generally more attractive to affluent buyers, who prefer larger homes and use more electricity.

Although the average new refrigerator sold today consumes about 75% less energy per litre of interior volume than its 1975 predecessor, refrigerator sales are growing steadily – many Western homes now have a second refrigerator and use is increasing in the developing world. So Calwell argues that refrigerators could actually be using more energy worldwide. Similarly, with televisions, sales of televisions are rising and average hours of operation and size are increasing, they are now less costly and so available to more people. Calwell argues that the present specification approaches do little to discourage the market trend towards ever-larger screen sizes and more TVs per home. This will inevitably lead to greater overall energy use associated with these products.

Absolute consumption is the root cause of the problem of increasing energy use and where policy efforts should be focused. The solution is one that combines efficiency of technology, and so on, with sufficiency in energy services.

So, the views expressed in this section are suggesting that energy efficiency on its own is not sufficient to reduce energy consumption. Moezzi is arguing for an increase in energy conservation measures and Calwell is arguing for energy-efficiency specifications to be progressive in nature in order to limit total energy use and for the focus to be on absolute consumption not the consumption of individual products relative to one another.

4 Controls and user interfaces

4.1 The use of controls

The main way in which occupant behaviour impacts on energy use is through the use of controls. The potential influence is two way with the use of controls being influenced by behaviour but also the user's behaviour being influenced by the type of controls used.

> 'Control interfaces are where the users and the technology of a building come together.' (Bordass *et al*, 2007)

Although the focus for this review is on new homes many of the findings on commercial buildings are also relevant to domestic buildings and it is important that the lessons learned on control interfaces and automated systems in the commercial sector are carried over into the domestic sector.

Control systems have the potential to both improve individual comfort levels and reduce energy consumption. Heating controls can help to reduce energy consumption by allowing occupants to heat only the parts of the home that are being used and programmable room thermostats allow occupants to control heat when people are actually in a room (CIPHE, 2008). However, when people move between rooms it is likely that the lag time to heat the new room to a comfortable temperature will be too high to provide the control users desire. If this is the case then it is likely that the other parts of the dwelling may still get heated even when unoccupied. Substantial energy savings can be made by ensuring that householders are using their controls more effectively. The right controls reduce carbon emissions and make a significant difference to the overall energy performance of a home. If the right controls are not in place or if occupants cannot use them as they should be used, households are limited in the way they can reduce their energy use.

Controls also influence occupants' satisfaction ratings of the buildings they are in. Bordass *et al* (2007) found a positive relationship between ratings of occupant satisfaction and levels of perceived control. People prefer conditions that are easily controlled, but it is important that at the same time controls allow occupants to avoid conditions that are too hot or cold, glary or gloomy, stuffy or draughty. Rapid response is very important to occupant satisfaction and perceived control as occupants tend to prefer buildings that respond quickly to their comfort needs. In addition, buildings with good local controls tend to be more energy efficient because systems are more likely to operate only when occupants need them.

Heating controls in domestic dwellings provide occupants with a means of achieving the room temperature they want at different times. This typically involves programming the heating system to match occupancy times, or manually turning the heating on when cold and then using thermostatic control of heat output to provide the temperature desired. Most people are not interested in the technology behind systems, they just want results and to be able to make adjustments with their controls as quickly and simply as possible to achieve an environment that suits their needs.

However, research suggests that occupants do not understand how to use their controls and are not using them effectively:

> 'There is evidence that a significant proportion of householders do not understand their heating controls, do not set them appropriately or do not use them at all.'
> (Market Transformation Programme, 2006)

Combe *et al* (2010) found that 66% of occupants of a low-carbon housing development could not programme their controls as they wished to be able to. This results in systems not being used effectively. Rathouse and Young (2004) estimated that a heating system that is controlled correctly can save around 20% of the energy that would be consumed by an uncontrolled system; nationally that amounts to 67 TWh/yr.

Some research indicates that occupants' understanding of how their appliances and controls work is often over estimated. There is 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 consumer and the 'expert') and those derived in a focus group or interview. BRE post-operational evaluation studies on homes, for example Home Group (2009, unpublished), 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 energy efficient and effective ways.

A study carried out by Pett and Guertler (2004) examined user behaviour in energy efficient homes. The focus was on existing homes, but many of the findings on the use of heating and controls are equally applicable to new homes. They found a lot of evidence that occupants do not understand the role of thermostats and heating programmers. Combinations of heating and ventilation can further confuse an occupant with a bewildering array of buttons and switches. If occupants do not understand how to get the environment they want, they simply turn things on and off as required, or open windows if it gets too hot. This is often not the most energy efficient way to heat or cool a house. The Easthall project (EAS, 2002, cited in Pett and Guertler, 2004) found these types of behaviour were common. Pett and Guertler found that only 68% of occupants knew how to use their heating controls, the rest did not really understand them, 'sort of' understood them, left them to someone else, or just left them as they were set. However, the majority of occupants (86%) did get the results they wanted from their heating systems (Pett and Guertler, 2004).

Research suggests that occupants tend to understand their systems well enough to achieve the environmental conditions they want. However, these conditions are not always achieved in the most energy efficient ways. Many occupants will, for example, manually turn the heating on when they feel cold and manually turn it off when they feel warm enough, rather than using an automated heating control device such as a programmer or thermostat for example. This often means the heating system has to heat the house from a relatively low starting temperature and often generates a higher peak temperature than would be necessary for the occupants to be comfortable.

Box 5 Case study

In 2004, the Market Transformation Programme commissioned BRE to examine the use of controls for domestic heating (Rathouse and Young, 2004). Six focus groups were carried out with members of the public who lived in homes with gas central heating. The findings are summarised below:

Use of controls
The way occupants control their heating at home varied greatly. Some people avoided using their programmer altogether, either because they found it difficult to use or because they believed that it was more efficient to leave their heating on all the time. People who did use their programmer were generally flexible and used their heating controls to respond to changes in their routines. However, some people stuck strictly to the programmed times. There were large variations in use of thermostats: at one extreme, people adjusted them every time they felt too hot or too cold, going out, coming in, going to bed or getting up in the morning; at the other extreme, people did not adjust them at all (but this was very rare). Similarly, some people reported changing the setting on their thermostatic radiator valves on a daily basis while others said they never changed them in spite of dissatisfaction with the temperature in a room.

Regarding window opening behaviour, people said they opened windows for a short time to cool down their home when it had overheated. They also reported leaving windows open for longer while the heating was on in order to have fresh air as well as warmth and showed little concern about the waste of energy.

Understanding controls
There were large variations in how well people understood the workings of their heating controls. Some people admitted to a lack of interest in how they worked. A number of misconceptions about heating controls were mentioned, such as believing that the room thermostat is simply an on/off switch or thinking that it works like a lighting dimmer switch. Some people understood how their use of heating affected energy consumption; however, some did not realise that turning down the thermostat would reduce energy consumption. There was also considerable debate about whether intermittent or continuous use of central heating is more efficient.

Importance of comfort, cost and energy
For the majority of people, comfort was the main consideration in determining heating use. Although some people were extravagant, others were careful with their heating because of the cost implications. Most participants barely considered the environmental impacts of heating use, even those people who said they were concerned about the environmental impacts of energy consumption in other contexts.

Views about controls
The majority of people reported that programmers were too complex. There was a clear message about the need for larger buttons from both young and older people. However, some people found programmers straightforward. The position of programmers had a large impact on ease of use: problems reported included programmers placed too high, too low, out of reach, somewhere dark, or partly hidden.

Views about information
Generally people found their manuals difficult to understand. Suggestions for improvements included using more photos, pictures and diagrams and simplifying the instructions and making them procedural. The manuals should be kept short by focusing on the basics. Some people had asked installers for advice but they reported that they had not been able to spend enough time with them.

Rathouse and Young (2004, Box 5) recommend that the use of heating controls could be improved in the following ways:

- Raising awareness with occupants about the cost and environmental impact of heating use.
- Introducing education programmes on heating controls and associated concepts in schools.

- Informing installers about the ways that they can help households improve their use of heating controls.
- Redesigning products so they have large buttons. A variety of products of different complexity to suit different needs are needed; the complexity should be indicated so that an appropriate product can be selected; instructions should be written in a more user-friendly way.
- Installers should select heating controls that are appropriate for the household; heating controls should be placed in convenient positions; installers should be prepared to spend time providing advice on operation.

Research by Hadi and Halfhide (2009) examined the impact of occupant behaviour on energy efficiency by investigating the way that people actually use their buildings. They held focus groups with building users to determine how easy the participants found it to control their environmental conditions and their understanding of controls. Their main findings on controls were that switches can be overly complicated and that switches with too many functions incorporated can cause confusion. 'Rocker' type switches were highlighted as being particularly difficult to understand, especially if they were not labelled or if they did not provide feedback indicating the current state of the system.

Research by Bordass *et al* (2007) supports the previous findings that controls are too complex and are not being used effectively. They found that systems are unlikely to operate effectively or efficiently if the user controls are ambiguous in intent, poorly labelled or fail to show whether anything has changed when they are operated. Thermostats can be problematic in that people either turn them up too much and waste energy or turn them down too much and then feel cold. The report focuses on user controls for heating, cooling and ventilation. It also covers natural ventilation, natural and artificial lighting, glare and solar gain. Although mainly concerned with offices and public buildings, many of the findings are applicable in a domestic setting, particularly those concerned with complexity of controls and the need to provide instant, tangible feedback to occupants on whether a system is operating (see Box 6 for an outline of the main findings).

Box 6 Outline of main findings

Bordass, Leaman and Bunn (2007) main findings:

- Controls can be too complex and the designs are usually driven by the producers of the controls rather than the users. More setting-up time is required.
- Many environmental control systems do not work as well as they should. This includes simple switches, blinds and room thermostats, many of which are often not well thought-out or well-integrated.
- Features that are hard to understand, complicated or confusing, tend to be ignored or by-passed.
- Better performing systems do not have to be expensive but have usually received careful attention to detail in briefing, design, specification, installation, commissioning and handover, and also in the user interfaces.

The report by Bordass *et al* (2007) also includes a list of iconography recommended by the Building Controls Industry Association (BCIA), such as a thermometer icon for temperature control and a snowflake symbol for cooling control. However, more research is needed into whether such symbols are easily understood by users and whether they are recognised internationally.

Although some of these recommendations appear to relate to non-domestic control systems, many of them still apply in a domestic setting, particularly to the automated control systems being developed for the domestic market (for example the latest Wattbox, Passiv systems and Honeywell controllers).

A frequent problem experienced in new homes, especially high technology, low energy homes, is that the many different systems installed in the houses have different control systems rather than integrated whole house systems. This can lead to systems competing with one another and cause confusion for the occupant as to how to control all the systems. This was found to be an issue by Bell *et al* (2010) at Elm Tree Mews low carbon housing development. They found that the systems used a complex set of different technologies, each with their own control device. These were confusing for the occupants who had to cope with different buttons and setting processes. Because occupants were confused over the operation of the controls, they tended to leave things set as they were at installation or following advice from a member of staff. Controls' manufacturers report that even services experts and installers often do not understand how best to control certain systems; this problem is exacerbated when there are multiple, interacting systems in a home; for example, a hot water system, which is heated by both solar thermal panels and a conventional boiler.

4.2 The behaviour of occupants when using controls

Cole and Steiger (1999) carried out a comparative analysis of innovative naturally conditioned office buildings to discover the extent of satisfaction with environmental conditions and engagement with the control of heating, cooling, ventilation and lighting. Post-occupancy evaluations showed that occupants had many coping mechanisms to help solve discomfort problems. Cole and Steiger state that it is widely accepted that personal control over indoor environmental conditions is central to occupant comfort and satisfaction. It is also widely known that actual building performance is often significantly different from that predicted during design and this mismatch between expectation and performance is the result of the differences between assumed and actual patterns of occupancy, the use of controls and building operation. Leaman (1999, cited in Cole and Steiger, 1999) argues against the use of rational models of building operation and use assumed in design, and instead presents a set of 'real' building user reactions and responses. These have important implications for the designers of controls.

The findings from their study indicate that occupants tend to:

- act in response to random, external events
- often wait for some time before taking action, typically when they reach a 'crisis of discomfort'
- leave systems in their switched state, rather than altering them back again (at least until another crisis of discomfort is reached)
- not decide to use switches or controls in advance but only after something has happened that prompts them to do so
- frequently overcompensate in their reactions to relatively minor annoyances
- take the quickest and easiest option and use the controls or systems that are most convenient.

The Probe studies (for example Bordass and Leaman,1997 and Leaman and Bordass, 2001) carried out post-occupancy evaluations of non-domestic buildings. They provided feedback on the performance of the buildings to designers, their clients, Government and the industry. This included information on whether innovations have been successful and where improvements might be made. The surveys highlight the issues of occupant satisfaction, energy efficiency and the technical performance of environmental control systems and provide valuable insights into the strengths and weaknesses of increasing building automation.

Following on from the findings of the Probe studies, Bordass *et al* (2007) (Box 7) propose that controls should:

- be easy to understand and use, and preferably intuitively obvious
- work effectively, with sufficient fine control to give the required level of adjustment

- give instant, tangible feedback to indicate that the device has operated (for example, a simple click)
- not need to be used too often or require too much intervention
- make allowances for the fact that some devices may only be used occasionally and people may forget basic actions
- be located as close to the point of need as possible.

Box 7 Essential design principles

Bordass *et al* (2007) suggest the following essential design principles should be considered:

- What the control is for: user controls are provided to allow users to choose the conditions they desire, or to avoid conditions they don't, and to help ensure that systems operate efficiently, so reducing CO_2 emissions rather than increasing them.
- Who the control is for: needs for control vary with both the type of user and the type of space.
- Positioning of controls: user controls should be at the point or points of need such as entrances to the space or near the item being controlled.
- The design intent should be clear to the end users: the control should tell the user what it is for and how to use it. The purpose should be made explicit, in layout and labelling, to make the intent clear.
- The system status should be clear to the end users: the controls need to communicate to the user what is happening.

In summary, the research examined in this section supports the view that control systems are often too complex for people to understand. This complexity is leading to heating and other systems not being used as intended and so being used inefficiently. For example, when occupants feel too cold they turn the thermostat up unnecessarily high, or when they feel too hot they open a window. Occupants often leave controls as they are set because they do not understand how to adjust them. The main solutions appear to be to ensure the design of controls is user-friendly and intuitive, to provide more and better advice on their operation, and increase knowledge of the environmental impact of use of heating.

4.3 Automated versus manual control systems

Automated controls have been used for many years in commercial buildings; they have been developed to control the lighting, shading, heating, and ventilation. In the last few years automated control systems have started to be developed for domestic buildings too and their use is expected to increase. There has been a great deal of research on automated control systems in commercial buildings, some of the findings are relevant to domestic dwellings. These systems have the potential to save energy, ie automatically turn themselves down or off. They are also designed to improve occupant comfort, as they aim to produce 'ideal' environmental conditions for when occupants are in the building and use reduced energy when occupants are not present. However, findings suggest that all too often the control designs do not take enough account of how buildings are actually used and so lead to wasted energy and unnecessary discomfort for occupants. In fact these systems often waste energy by running longer and less efficiently than manual systems. Some automated controls remove too much control from the occupant. This can lead to the occupants sabotaging or tricking the systems to achieve the conditions they want.

Findings from the Probe studies (see section 4.4) suggest that buildings that allow occupants some control over their environmental conditions tend to be preferred to buildings with fully automated control systems. According to Bordass *et al* (1993), fully automatic control systems not only lead to building services running wastefully and unnecessarily but can even act as barriers to the effective control of buildings. It is important that systems are able to respond effectively when, for one reason or another, conditions are seen as unsatisfactory. Furthermore, according to Bordass and Leaman (1997), too many buildings deliver less than they promise. Leaman and Bordass (2001) found that automated controls can lead to thermal discomfort. Variations in conditions between rooms (for example some rooms being too cold and others too hot) can anger occupants, particularly if they have no effective means of control. Designers and clients often seem to ignore or under-estimate how systems and occupants can conflict with each other so pulling performance levels down. Uncertainty and inefficiency in systems' operation and use can readily develop through insufficient attention to detail for occupants' requirements.

Steemers (2003) suggests that intelligent automated systems should respond to occupant interactions with the building. For example, at a simple level, the act of opening a window should automatically turn off heating or cooling. The result would be a more dynamic mixed-mode operation of buildings, where the building services the occupant. The building can still revert to an 'optimum' state (in energy and comfort terms) after a given time period or in response to occupancy sensors. A possible answer may be to combine climatic design (for example high mass, moderate glazing) with intelligent controls and components, in order to ensure maximum adaptability. Although this would not completely prevent conflicts between occupant behaviour and optimum performance, it would offer an integrated approach to resolving occupant satisfaction and environmental impact. Such flexibility and adaptability gives the control back to the occupant and enables them to respond to environmental conditions through their interactions and relationship with the building and its systems (Steemers, 2003).

4.4 Users are 'satisficers' not optimisers

'Satisficing' is a term that describes conditions which adequately meet perceived needs without going to extremes (Simon, 1981, cited in Leaman and Bordass, 2001). Most people want the conditions they live and work in to be 'good enough'. People tend to want a degree of control over what they are doing and how they achieve it (Boxes 8 and 9). People are more likely to tolerate discomfort if they have control of their environment. This is something that is often not appreciated by designers when they remove control from occupants and design for ideal environmental conditions. The Probe occupant surveys suggest it is important for occupants to have the power of intervention to control, override or at least trade-off some of the heating, cooling, ventilation, lighting and noise parameters. This is not so much to optimise their comfort as to reduce local sources of discomfort to acceptable levels. BRE research has shown that if there is no way to easily control or override an automated system occupants will sabotage the systems or will try and trick the system to achieve the conditions they want.

Even in the best building surveyed in the Probe studies, 65% of occupants reported that they were unhappy with some aspect of their internal environment. This shows that it is rare to find 'just right' conditions or that users' ideas of just right varies between users. However, good enough conditions can be achieved by providing occupants with the means to alleviate their discomfort, rather than to rely solely on automated systems to do it for them. Occupants are more satisfied with simpler systems with usable controls and interfaces rather than elaborate systems with control interfaces, which are poor in function, location, clarity and responsiveness.

Box 8 Key principles and the implications for designers

Usability is usually recognisable when the following three conditions are present:

- Predictable and reasonably acceptable 'default' states.
- Opportunities to make interventions or corrections if needs or conditions change.
- Ability to act quickly and to know immediately that there has been an appropriate response.

Simplicity and convenience of intervention are reported to be of most importance. Well-designed, computer-assisted intelligence can be particularly good at establishing (and especially restoring) safe, comfortable, convenient and efficient default states. However, the controls must allow the occupant to adjust these default states even if this is just for a short period of time.

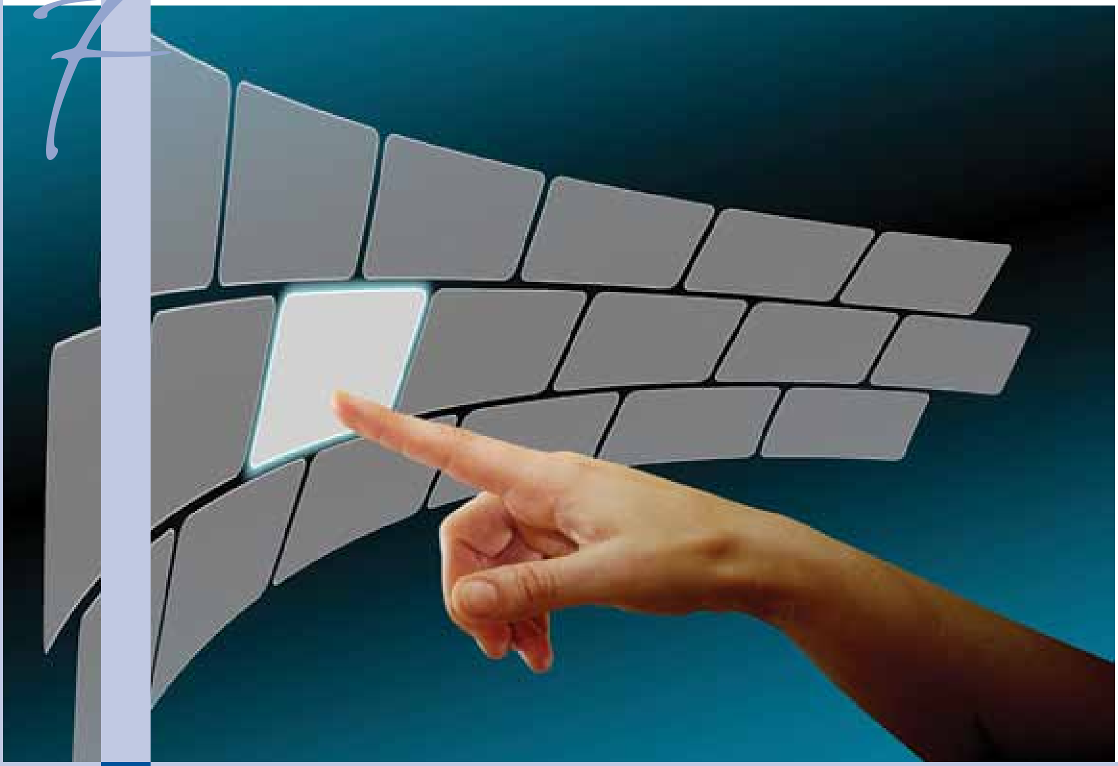
It is usually a mistake to remove control completely from occupants as they can become frustrated:

- When they cannot change undesirable environmental conditions to preferred conditions.
- If they cannot achieve fast and effective responses from their own actions, control systems or other people.
- If they are unable to choose the lesser of two evils, for example between increasing ventilation or less noise when it is hot and humid.
- If they suffer from unsatisfactory conditions over which they have little control, such as draughts from grilles or occupancy-sensor lights in peripheral vision.
- When apparently random changes in a system occur, which they can perceive but cannot override, for example, automatic blinds that come down when it is sunny, when the occupant might want to enjoy the sun on a warm spring day; or from automated windows, which open and let in noise or cause draughts.

Box 9 Strategic implications

- It is best not to focus on the 'average' or typical occupant, but to consider the full range of users and contexts.
- Where possible, allow occupants some control.
- Ensure default states are comfortable and efficient.
- Allow effective facilities for intervention.
- Performance should be monitored and feedback of information should be set-up and managed.
- Automated systems should operate imperceptibly; if they don't, whatever they do will be perceived as wrong by some occupants. This is also true for manual control systems and the challenge is in zoning to satisfy individual requirements.

The studies by Bordass and others have advocated the benefits of allowing occupants some control over building systems. However, some research suggests that allowing individual control may lead to increased energy consumption and can also increase the difficulty of predicting the energy performance of a building. There is a considerable ongoing debate over whether automatic or manual control systems are the most effective and more research is needed into the use of these systems in a domestic setting. Whilst it may be seen as acceptable or even expected to have little control over the conditions in a non-domestic building (for example place of work), it is anticipated that this will be less acceptable for the majority of people when 'in their own home'.



5 Future user interfaces

5.1 Smart homes

Some of the latest low energy houses are being referred to as early examples of smart homes, but what is a smart home? Scott (2007) defines a smart home as 'a dwelling incorporating a communications network that connects the key electrical appliances and services and allows them to be remotely controlled, monitored or accessed'.

The four key elements of a smart home are intelligent controls that manage the system, an internal network through which devices communicate with each other, sensors that collect information and smart features, such as intelligent heating systems, which respond to information from sensors or user instructions (King, 2003, cited in Scott, 2007). Smart homes can allow occupants to communicate with their home remotely, for example using their mobile phone to switch heating on when they are on their way home. Smart homes and smart features are different as the latter can work without a home network. For example, an in-home display can provide information to occupants on electricity use and communicate with energy suppliers without a full home network. A full network allows more sophisticated interaction between appliances, for example, security alarms and heating controls would interact so that when an occupant arrives home and turns the alarm off, the heating or ventilation would turn on automatically.

An example of smart homes in the UK is the Elephant and Castle scheme in central London. Due for completion in 2014, it is a low-carbon scheme for 6000 new homes, retail and public use buildings. The specification includes connecting the entire development to a network that will enable energy management and smart building technology. Smart electricity, heat and water metering are key features of the development. The smart features are intended to provide environmental benefits, for example lights will turn off automatically when rooms are unoccupied and heating and air conditioning will not be used in areas where they are not needed. Unnecessary energy use will be avoided as much as possible and occupants will be encouraged to become more aware of their energy use and to change their behaviour.

According to Scott (2007), smart homes appear to have many benefits; however, the energy-saving potential is yet to be proven, in fact these smart homes may lead to increases in energy consumption. For example, intelligent lighting controls have the potential to increase energy use because of individual preferences, such as the use of dimmers and node lighting for each room in a house. As another example, smart entertainment options can include 'follow me' televisions that turn on room to room as occupants move around the house and therefore require numerous screens. More research is needed into energy use in smart homes; the benefits need to be clarified and quantified, for example how and when do smart features deliver environmental benefits and in what circumstances are they most effective?

Research on smart technology was carried out by BRE for the NHBC Foundation (Holleron and Tilford, 2011). It examined the potential of 'whole house shutdown' to reduce energy consumption. In this, sophisticated switching controls (and possibly an internet-based interface) can be used to remotely activate appliances, lights and, possibly with some development, heating systems. A radio-frequency transmitter key fob carried by the dwelling occupant enables the dwelling to detect if a property is empty and to shut down all but the predefined systems. Such a system could also be used to centrally lock all doors and windows, in a similar way to central locking devices on cars. These products are currently targeted at existing housing, but they could transfer to the 'installed' new build market if there is sufficient demand. The research estimated that whole house shutdown has the potential to reduce CO_2 emissions by 19% per year. More sophisticated systems can reduce lighting loads and some systems can be linked to smart meters and report energy information to occupants. However, a weakness is that not all appliances are suitable for shutting down in this way, for example set top boxes and hard drives. These systems need to be shutdown before the power is cut to them and many take time to start up again after being turned off.

These types of systems would need to be carefully designed to allow the occupant to specify which sockets and devices should not be automatically turned off when the house is not occupied. Some products such as fridges and fish tanks would need to stay on. Another weakness is that appliance standby power and lighting consumption are likely to reduce considerably anyway in the coming years, and the proposed features may even be built into appliances in the near future. This would reduce the energy saving potential of such whole house shutdown systems.

Another BRE report (Nicholl and Perry, 2009) showed how smart technologies can be used to improve the environmental, economic and social sustainability of homes. It examined the role that smart home solutions could play in achieving the performance levels set out in the Code for Sustainable Homes. Some of the areas where smart home systems could theoretically add value in the future include:

- Dwelling emission rate: a range of smart building services can support dwelling emission rate performance criteria. They can monitor and inform how SAP-predicted energy efficiency is achieved in practice, including:
  - Where energy use is sub-metered in categories, such as hot water heating, space heating, lighting and appliances, smart building technologies can monitor and inform use of energy in the building.
  - Monitoring the temperatures of indoor air and hot water to identify where energy might be wasted by overheating.
  - Monitoring humidity to determine whether ventilation is working effectively.
- Building fabric: building fabric can be monitored by the use of heat flow sensors linked to an intelligent building system.
- Intelligent lighting: there is a potential for a smart housing system to monitor energy use for lighting, for example through devices such as occupancy sensors, timer switches and central off switches.

- Energy-labelled white goods: white goods can be fitted with electronic energy monitoring and management components to ensure more efficient energy use. For example, the exchange of data between white goods and smart meters could control the machines so that only two or three are in use at the same time. Monitoring electricity use by individual machines will also identify and rank which ones are the primary users of electricity in the home thus enabling occupants to take informed decisions about which machine to switch on and which to switch off.
- Low or zero-carbon technology: smart home technologies can be used to manage the use of energy in the home and so contribute to the reduction of carbon emissions.

Nicholl and Perry suggest that smart home systems could enable improved environmental performance, automatic control for building services, fault reporting, display of energy and carbon usage and billing.

However, although smart home technologies are technologically achievable, currently it is unusual to find all these systems configured and installed using an integrated communications network. Commercial barriers often prevent the effective integration of smart home systems and this will need to be addressed if there is to be an increase in the use of smart home solutions. A critical issue is that systems must have a long maintenance life with the facility for easy upgrading and continuing supplier support.

5.2 Feedback on the latest technologies and interfaces

Some research has examined what people think of the new technologies. Research undertaken by Consumer Issues Research (Integer Partners, 1997) examined consumers' views of intelligent and green aspects of housing. The consumer was often found to be unfamiliar with many of the technologies involved and so had a limited understanding of the implications of their use. This emphasises the need for explanations of these technologies and clear guidance as to how to get the most out them and use them efficiently. Consumers reported that they did not want futuristic or revolutionary homes but prefer ones that are reliable extensions of what is already familiar. Cost is an issue for consumers of intelligent and green products and people will only pay a limited amount for them, they need a clear understanding of exactly what savings are achievable over what period of time.

A prime concern for consumers is the reliability of new technology. This has implications for both initial installation and future maintenance and support, including the training of housing managers and residents. Consumers reported that the most popular intelligent features were self-diagnostic systems for fault-finding, security systems, and environmental management systems.

Research carried out by BRE (Gemmell and Coward, 2010) at the BRE Innovation Park found similar findings in relation to consumers' concerns about new technology. The Park contains full-scale, demonstration, low-carbon houses. BRE's Social Research Team collected feedback from approximately 300 visitors to the Park at the INSITE09 exhibition. An issue highlighted by the research was that many participants expressed concern over the amount of technology/equipment installed in the demonstration homes and the fact that its reliability and performance was unproven. This is an issue that may need to be addressed by house builders so as not to discourage consumers from investing in low-carbon housing. This could possibly be achieved by minimising the reliance on technologies and ensuring that the reliability and performance of any equipment can in some way be assured and demonstrated.

Some of the participants in this study were in a position, as part of their job responsibilities, to purchase multiple properties. This group included representatives from housing associations, local authorities and buy-to-let landlords. They were asked what would encourage/discourage investment in low-carbon houses. Again, serious concerns were expressed about the unknown reliability and durability of the technologies and smart systems used in the houses. It is necessary to ensure that there is a skilled workforce available that can maintain these types of houses. They also reported that technologies that are simple for occupants to control would encourage investment. When asked about what would discourage investment in low-carbon homes, responses included:

- concern that the technologies may be too complex for a landlord to manage
- lack of data from occupants who have lived in the houses
- lack of engineers/technicians qualified to maintain the houses and the technologies
- training tenants to use the technologies.

So, the main factors that are likely to discourage investment are the unknown reliability and durability of the technologies/smart systems used and the lack of feedback from occupants who have lived in these types of houses. More research is needed to reassure potential investors and occupants that the technologies will stand the test of time and that this type of housing will be practical and comfortable for occupants. Research suggests that the issues of maintenance and training are particularly important. People want to have the confidence to know that if they buy these systems, then maintenance systems and processes will be in place. This will require a workforce that is sufficiently trained to provide advice to householders, and that have the abilities to ensure future maintenance of the systems. There is an ongoing need to train and up-skill existing electrical contractors. A number of BRE training courses and seminars have aimed to raise awareness of the technology and provide the skills needs for design and installations of systems.

5.3 Interoperability

Another important issue is interoperability. This is the ability of the various systems to be controlled from a common source or to interact with each other directly to exchange and use information. This will be vital for smart homes to work in the future. Systems need to be able to communicate with each other in a consistent way and products and appliances should not interfere with each other's operation. Work has already started to examine how products from different companies can work together and interact effectively. A recent Technology Strategy Board- (TSB) funded Smart Energy Project, run at BRE, was the first physical validation of Cenelec CWA50560:2010 IFRS (TAHI's Interoperability Framework). The objective was to 'provide a methodology that will give consumers the confidence to install home and building automation products from different companies, both now and in the future, knowing that they will operate together and interact effectively with each other'. (Cenelec, 2010).

A review of building automation interoperability (Osório *et al*, 2010) suggests that one of the challenges is to establish interoperability between sub-systems, since these come from multi-manufacturers and are developed on heterogeneous technologies. A solution is to build a system that implements one of the emergent 'open protocols', such as KNX or LonWorks. These are open, interoperable and multi-vendor, and provide integrated end-to-end solutions across different function areas, such as light, heating and security. KNX for example is used by over 200 manufacturers and has several thousand products certified to the standard. Although in the early stages of development, it is hoped that open protocols will provide the solutions that will make smart homes more viable in the future.

5.4 Future technologies and user interfaces

Future energy-efficiency technologies have been explored in a recent TSB 'sandpit' examining user-centred design in the built environment. The aim was to bring together representatives from different industry sectors, academics, SMEs and other organisations to explore ideas, tools and concepts, which will enable the user to interact with buildings much more effectively, practically and intuitively.

The group reported that in the future people will be interacting with the built environment in many different ways through technologies such as smart phones, PCs, tablets such as the iPad, interactive TVs, etc. The use of smart phone technology and tablet PCs will allow people to interact with their built environment by operating building controls, monitoring the internal environment, energy usage and analysing usage trends. There are new control and monitoring applications (Apps) for iPhone, iPad, the Google Android phone and pad PCs appearing all the time. These Apps are pivotal in increasing the range of options available, providing user-friendly solutions and generally taking the use of flexible controls forward. There is also potential for interacting with buildings with controls developed initially for games consoles, such as the Microsoft Kinect and the Nintendo Wii. These controls react to natural user movements, such as waving a hand, pointing, kicking and clapping.

Another example of the latest technologies is those that can make use of weather data to exploit peak wind and solar energy generation. Occupants may initiate an action, for example switching on a washing machine, but allow the home control system to decide when the machine actually starts. Building controls can provide greater flexibility of control enabling home occupants to focus energy use where and when it is needed, examples include heating or cooling control for individual rooms, remote control of the environmental conditions and technologies from within a house or remote control from elsewhere by mobile phone or via the internet.

Other technological advances could include the introduction of low cost smart chips to every device to give each one a separate IP address. According to this proposal, all the devices in the home would become part of a private secure network to be monitored and controlled via a smart phone, tablet or PC. A Dutch-based company has recently announced GreenChip, which, for a very low cost, enables every light bulb to have its own wireless IP address. This would reduce the costs of creating smart networks and would simplify adding smart connectivity and two-way communications into a wide range of devices. This could also help establish a cross-application standard for wireless connectivity in both residential and industrial environments.

However, flexibility of control can lead to too much complexity and it is critical that controls are straightforward and easy to use. As the number of devices or appliances increases control functions and options will also increase. This may lead to increases in multi-way switches and wall-mounted controls. Research has shown that if a multi-way switch has more that about six options it becomes unintuitive to use and it may be necessary to label individual functions. Often the solution is to provide a display panel with touch control that can be configured with multiple-page displays simplifying each control function.

Smart homes and technologies appear to offer many benefits, such as increased energy efficiency through the use of improved temperature control, automatic lighting and the integration of appliances and renewable-energy technology. However, for these systems to work they must be responsive to occupant requirements and adaptable to occupant needs. Further research and trials are needed to quantify the environmental benefits of smart homes and smart features in a domestic context. More research is also needed into occupant behaviour in smart homes and the effects of smart features on occupant behaviour and subsequent energy use. The research presented earlier in this review suggests that occupants prefer to have at least some control over their environment. If this control is taken away from them in their own homes it may lead to them overriding the controls, or if that is not possible, sabotaging them or replacing them. Research has shown that occupants will make themselves comfortable using whatever method they can. If future smart homes do not allow the occupant to achieve the conditions they require they may well find other ways of achieving those conditions (for example buying additional heating or cooling devices not connected to the smart home network).

6 Summary and recommendations for future research

There has been a great deal of time and effort dedicated to the design and development of new low-energy houses. Improvements to the fabric of the building and the technologies installed should mean new homes use significantly less energy. However, relatively little work has been done to understand the factor that has the single biggest effect on the energy used in the home: the occupant. This review examined the impact of occupant behaviour and user interfaces on energy use and comfort in low-carbon homes.

Research has shown that changing occupant behaviour will allow more energy to be saved than is possible through architectural and technical strategies alone. Differences in individual behaviour can produce large variations of more than three times the average energy consumption, even when differences in housing, appliances, heating, ventilation, air conditioning and family size are controlled for. It is, therefore, vital that more work is done to understand occupant behaviour and how to alter it to minimise wasted energy and ensure energy is used efficiently.

6.1 Energy use in the home

Research has shown that the main factors that affect gas and electricity consumption are:

- number of persons in the household and their occupancy patterns
- type of dwelling and floor area
- tenure
- fabric heat loss characteristics
- social grade/income.

Heating is responsible for the majority of domestic energy consumption and reducing heating in the home would have the most significant impact on reducing the total domestic energy use. Research has found that people in lower social grades, particularly those living in flats/maisonettes, report heating their homes to a higher temperature than those in higher social grades (typically living in larger houses).

Research also suggests that there is a skewed energy distribution towards high energy users and there is an increasing skew in demand over time, particularly for electricity demand. Evidence suggests that the electricity consumption of high energy users is increasing at a greater rate than mid or low energy users. Households with higher incomes tend use significantly more electricity than lower income households. These findings highlight the potential importance of focusing energy policy on those parts of the stock and population where consumption is highest and where it appears to be increasing the most.

Time spent at home is an important issue as the more time people spend at home the more likely they are to have their heating on, use lights, and so on. Lifestyle factors that influence the time spent at home include working from home, unemployment, retirement, ill health, disability and home parenting.

Although, patterns and correlations can be found between the above variables and the energy use/space heating levels, research suggests that lifestyle, occupancy patterns and building type only partly account for the energy used in the home. Studies have shown that if similar households are compared according to all relevant background variables, there is still considerable difference in energy use. This implies that other independent factors related to occupant behaviour, habits and attitudes need to be further explored and better understood.

There are significant variations in occupant behaviour and this leads to variations in the energy consumption of buildings. Behaviour can be influenced by both societal and personal factors, but is defined by habits and routines, which people perform without thinking about them. People often use energy without even considering where the energy comes from or what will be the energy costs of their actions.

In the domestic sector, the use of energy for space heating, lighting and appliances, water heating and other appliances has increased since 1970. Some of these increases are quite dramatic; for example, energy consumed for lighting and appliances has increased by 175%. Much of the energy used is wasted; for example, over two thirds of occupants leave appliances on standby. There are two separate aspects of energy behaviour: buying efficient equipment and using energy efficiently.

During the 1990s there was a change to buying more energy-efficient appliances but at the same time there was a trend to buying more equipment as people became wealthier. For example, extra televisions and other consumer electronics are bought or old TV sets are kept for other rooms. Similarly, if older fridge/freezers are still in working order they tend to be kept and placed in the garage as additional food storage when new fridge/freezers are purchased.

Occupant behaviour can affect the energy used in even the most well insulated dwellings. Even in dwellings that have achieved specific standards energy consumption may be dramatically different depending on the occupants' energy-use behaviour, their lifestyle and any extensions or alterations they make to the house. More research is needed into the effects of occupant behaviour and lifestyles on energy use; this will allow for more targeted interventions to be applied.

6.2 Reducing energy consumption

Changing energy use behaviour is a vital but difficult task – a key question is whether energy consumption in the home can be influenced through behavioural change measures. Long-term behaviour change requires the breaking of old entrenched habits/routines and the development of new ones. It requires widespread changes in habits, ranging from buying more energy-efficient appliances to turning off appliances when not in use. Energy-saving actions can be influenced by several factors. Cost is important, but cultural, educational and social factors, including concern for the environment, also influence peoples' attitudes. Research suggests that, in general, a new type of behaviour formed over a three-month period or longer, appears to be likely to endure, although continued feedback is necessary to help maintain the change.

Research suggests behaviour change can be achieved by providing occupants detailed feedback on their current energy use and information on how they can use energy more efficiently and waste less. Many people find it difficult to understand the costs and benefits of their actions on energy consumption. Even now most people have no way of knowing how much energy is being used when they are using the heating or appliances in their homes. Energy bills are not specific enough and do not provide information at the time of use. Research shows that providing immediate feedback on energy use can increase knowledge of energy consumption and can lead to altered behaviour and subsequent savings of between 5 and 15%. Smart meter and other instantaneous displays are particularly useful because they can show the relative consumption of different appliances. In-home displays measure and display energy data and should encourage occupants to use energy more efficiently. Feedback is more effective when it is presented clearly, simply, frequently, instantaneously and over a long time period. However, there is debate about whether this type of feedback alone actually changes behaviour in the long term. Some research suggests that feedback alone may not be sufficient to break existing and ingrained energy use habits and routines. More research is needed to see what the effect smart meters have on energy-use behaviours.

A significant contribution to the use of energy is the low level of knowledge about energy issues among the general population. Many people spend 90% of their time indoors but few of them understand how buildings work. Some argue that education on energy use should be much more comprehensive and interactive and should start in schools. Research suggests that the best ways of educating occupants on how to use energy effectively and efficiently are to provide them with more information on how to save energy, raise awareness of the best ways to use heating efficiently and increase awareness of how behaviour affects energy use.

Occupants of new low energy homes need clear guidance and information about how to use these homes efficiently and effectively to minimise energy being wasted. To ensure that systems are used effectively, there is a need for more information and training in the sustainability features of new homes, not just for occupants, but also for housing managers and those involved in the maintenance and repairs of the systems. Home user guides need to be improved as occupants tend to find them too complicated and detailed. Quick start guides may be a more effective method of providing information. More research is needed into how manuals and user guides for new homes and the appliances and technologies in them, can be improved. Research needs to look at the type of information that should be included, as well as the format and optimum time for the provision of this information.

The latest research suggests that providing feedback on energy use or information on how to use energy more efficiently in isolation may not achieve the desired long-term behaviour changes. To be effective, interventions should include a combination of measures, for example, a combination of energy advice with display units and more innovative billing. More research is needed to establish which types of intervention measures, or combination of measures, will be the most effective. Research is also needed to better understand how best to display energy use information (for example graphs, numbers, icons) and where best to locate displays to have maximum impact.

Another important phenomenon that requires more research is the rebound effect. The rebound effect occurs when people use the financial savings from energy-efficiency measures to increase their energy use. For example, occupants have been shown to heat their homes to higher temperatures following the installation of insulation; others spend savings on more electrical appliances. More research is needed into rebound effects and their effect on energy consumption for different consumer groups.

6.3 Control interfaces

It is widely accepted that personal control over indoor environmental conditions is central to occupant comfort and satisfaction. Occupants who can control their indoor environment have been found to be more satisfied than occupants who have no control. Findings suggest that the frequently observed gap between the predicted building energy use and the actual building performance is largely due to differences between the assumed and actual patterns of occupancy, use of controls, and building operation.

Research suggests that occupants tend to understand their systems well enough to achieve the environmental conditions they want. However, these conditions are not always achieved in the most effective or energy-efficient ways. This often leads to wasted energy and conditions that are satisfactory but not ideal. If controls are used properly they can reduce energy consumption, for example, they can allow occupants to heat only the parts of the home that are being occupied and used. However, research also indicates that controls are often too complex for occupants to understand and use effectively and efficiently. This is leading to energy being wasted. There is evidence that some occupants are not adjusting their controls as they do not understand how to change the settings.

Research has shown that the way occupants control their heating at home varies greatly. Some people avoid using their heating programmer altogether, either because they find it difficult to use or because they believe that it is more efficient to leave their heating on all the time. People who do use their programmer are generally flexible and use their heating controls to respond to changes in routine and the outdoor temperature. However, many people stick strictly to the set programmed times. There are large variations in the use of thermostats: at one extreme, people adjust them every time they feel too hot or too cold, going out, coming in, going to bed or getting up in the morning; at the other extreme, some people do not adjust them at all. Similarly, some people change the setting on their thermostatic radiator valves on a daily basis, while others never change them, in spite of dissatisfaction with the temperature in a room.

Large variations have also been found in terms of how well people understand how to use their controls (particularly heating controls). Occupants often have misconceptions regarding their controls and how to use them most effectively and efficiently. Many people feel their heating controllers are too complex and often poorly positioned, which can make them harder to use. Findings also indicate that systems are unlikely to be operated effectively or efficiently if the user controls are ambiguous in intent, poorly labelled or fail to show whether anything has changed when they are operated.

Research has shown that occupants:

- act in response to random, external events
- often wait for some time before taking action, typically when they reach a crisis of discomfort
- leave systems in their switched state, rather than altering them back again, at least until another crisis of discomfort is reached
- do not decide to use switches or controls in advance but only after something has happened that prompts them to do so
- frequently overcompensate in their reactions to relatively minor annoyances
- take the quickest and easiest option and use the controls or systems that are most convenient.

A frequent problem experienced in new homes, especially low energy homes with advanced technologies, is that the many different systems installed in the house have different control systems rather than integrated whole house systems. This can confuse occupants who then tend to leave controls as they were set and so not gain the full benefit from them. This can also lead to competing systems and inefficient energy use.

Research suggests that controls should be easy to understand and provide instant, tangible feedback so that occupants know that the system has operated. They should also be located as close to the point of need as possible and have sufficient fine control to give the necessary level of adjustment. There is a need to develop control systems that allow effective zoning of a dwelling, although this needs to be coupled with educating occupants on the need to close doors in winter to prevent bedrooms becoming too warm and living rooms too cool. The main solutions to improving controls are to ensure that controls are intuitive, user-friendly and to provide occupants clearer guidance on how to operate them. Installers also need educating on how they can assist occupants to make better use of their heating controls and provide advice to occupants on the operation of their systems.

Automated controls have been used for many years in commercial buildings; they have been developed to control the lighting, shading, heating, and ventilation. In the last few years automated control systems have also started to be developed for domestic buildings and their use is expected to increase. However, there is some debate as to how appropriate these automated systems will be for domestic dwellings. These systems have the potential to save energy, ie automatically turn themselves down or off. They are also designed to improve occupant comfort, as they aim to produce ideal environmental conditions for when occupants are in the building and use reduced energy when occupants are not present. However, findings suggest that all too often the control designs do not take enough account of how buildings are actually used and so lead to wasted energy and unnecessary discomfort for occupants. In fact, these systems often waste energy by running longer and less efficiently than manual systems.

Some automated controls remove too much control from the occupant. This can lead to the occupants sabotaging or tricking the systems to achieve the conditions they want. It is important that systems are able to respond effectively when, for one reason or another, conditions are perceived by the occupant as unsatisfactory. The occupant must be able to override the system and feel that they are in control when they want to be. This will be particularly important in domestic dwellings.

There is a need for explicit design recommendations for the design of control systems, especially user interfaces. There is also a need to identify how to design control systems/ user interfaces that meet end user requirements while minimising energy use.

6.4 Future user interfaces

Experts suggest that smart homes will be the homes of the future. A smart home is defined as 'a dwelling incorporating a communications network that connects the key electrical appliances and services and allow them to be remotely controlled, monitored or accessed' (Scott, 2007).

Integrated communication networks will be critical to the success of future smart homes. An integrated communication network enables the different smart home systems to communicate with each other, to share information and so support the delivery of improved housing performance. Although smart home technologies are technologically achievable, currently it is unusual to find all these systems configured and installed using an integrated communications network. Commercial barriers often prevent the effective integration of smart home systems and this will need to be addressed if there is to be an increase in the use of smart home solutions.

Smart phones are likely to have a big impact on interactions with the built environment. The use of smart phone technology and tablet PCs mean that people will be able to interact with their built environment by operating building controls, monitoring the internal environment, monitoring energy usage and analysing usage trends.

- A critical issue is that systems must have a long maintenance life with the facility for easy upgrading and continuing supplier support. The issues of maintenance and training are going to be particularly important. People want to have the confidence to know that if they buy these systems, then maintenance processes will be in place. This will require a workforce that is sufficiently trained to provide advice to householders, and that have the abilities to ensure the future maintenance of the systems. There is an ongoing need to train and up-skill existing electrical contractors. Of utmost importance for successful implementation of smart technologies are:

- the need for interoperability
- training for staff on the installation and maintenance of these technologies
- training for occupants on how to use the technologies in efficient ways
- the need to ensure maintenance of systems and processes are in place.

More research is needed to clarify the benefits of smart homes and technologies and to evaluate the effects on energy consumption.

Recent research on the latest low energy homes shows that the main concerns for potential investors in new low energy homes are: the unknown reliability and durability of the technologies and material used, and the lack of feedback from occupants who have lived in these types of houses. More research is needed to reassure potential investors and occupants that the technologies will stand the test of time and that this type of housing will be practical and comfortable for occupants. Consumers do not appear to want futuristic or revolutionary homes but prefer ones which are reliable extensions of what is already familiar. Post-occupancy research on the latest smart homes will be vital to examine how these homes and technologies perform and what the impact is on energy consumption and occupant comfort and satisfaction.

REFERENCES

Bell M, Wingfield J, Miles-Shenton D and Seavers J. (2010) Low carbon housing, lessons from Elm Tree Mews. York, Joseph Rowntree Foundation.

Bladh M and Krantz H. (2008) Towards a bright future? Household use of electric light: a microlevel study. Energy Policy, 36 (9) 3521–3530.

Bordass B and Leaman A. (1997) Design for manageability. Building Research and Information, 25 (3).

Bordass B, Leaman A and Bunn R. (2007) Controls for end users: a guide for good design and implementation. Harlow, Building Controls Industry Association.

Cairns S, Sloman L, Newson C, Anable J, Kirkbride A and Goodwin P. (2004) Teleworking 'Smarter choices – changing the way we travel'. Available at: http://webarchive.nationalarchives.gov.uk and www.dft.gov.uk/pgr/sustainable/smarterchoices/ctwwt/chapter10teleworking.

Calwell C. (2010) Is efficient sufficient? The case for shifting our emphasis in energy specifications to progressive efficiency and sufficiency. Stockholm, European Council for an Energy Efficient Economy.

CENELEC. (2010) www.theapplicationhome.com/NewFiles/CWA50560-2010-IFRS.pdf.

CIPHE. (2008) Taking control of carbon. Being comfortable at home, being kinder to the environment. Hornchurch, Chartered Institute of Plumbing and Heating Engineering.

Cole R J and Steiger M. (1999) Green buildings – grey occupants? Vancouver, Environmental Research Group, University of British Columbia.

Combe N, Harrison D, Dong H, Craig S and Gill Z. (2010) Assessing the number of users who are excluded by domestic heating controls. International Journal of Sustainable Engineering, 4 (1) 84–92.

Darby S. (2006) The effectiveness of feedback on energy consumption. A review for DEFRA of the literature on metering, billing and direct displays. Oxford, Environmental Change Institute, University of Oxford.

DCLG. (2009) Household projections to 2031, England. London, DCLG. Available at: www.communities.gov.uk/documents/statistics/pdf/1172133.pdf.

DCLG. (2010) Code for Sustainable Homes case studies. London, DCLG.

DCLG. (2011) Live tables on household characteristics. London, DCLG. Available at: www.communities.gov.uk/housing/housingresearch/housingstatistics/housingstatisticsby/householdcharacteristics/livetables/?view=Standard.

DECC. (2011) Energy statistics publications. London, Department of Energy and Climate Change. Available at: www.decc.gov.uk/en/content/cms/statistics/publications/publications.aspx.

Defra. (2009) Public attitudes and behaviours towards the environment – tracker survey final report to the Department for Environment, Food and Rural Affairs. London, Defra.

Department for Transport. (2009) Public experiences of home and internet shopping. London, Department for Transport.

Energy Saving Trust. (2005) Community heating serves luxury private apartments: A case study. CE103. London, Energy Saving Trust.

Energy Saving Trust. The habits of a lifetime. London, Energy Saving Trust. Available at: www.energysavingsecrets.co.uk/HabitsOfLifetime.html.

Environment Agency. (2005) Extending the 'Rational Man' model of human behaviour: seven key principles. Briefing note for the Environment Agency. London, New Economics Foundation.

EPRI. (2009) Residential electricity use feedback: A research synthesis and economic framework. Electric Power Research Institute, USA.

Gemmell A and Coward S. (2010) Consumer feedback on low-carbon housing. BRE IP 14/10. Bracknell, IHS BRE Press.

Gram-Hanssen K, Naervig Petersen K and Kofod C. (2004) Different everyday lives: different patterns of electricity use. Summer study on energy efficiency in buildings: breaking out of the box, Panel 7, Pacific Grove, California, 22–27 August 2004. Washington, DC, American Council for an Energy Efficient Economy.

Hadi M and Halfhide C. (2009) The move to low-carbon design: are designers taking the needs of building users into account? A guide for building designers, operators and users. BRE FB 21. Bracknell, IHS BRE Press.

Holleron R and Tilford A. (Unpublished) Energy efficient fixed appliances and control systems. Milton Keynes, NHBC Foundation.

Integer Partners. (1997) The future is a foreign country. INTEGER Intelligent and Green Housing Project. Briefing Stage Report. European Intelligent Building Group with Berkeley Partnership Homes Ltd and Building Research Establishment.

Jackson T. (2005) Lifestyle change and market transformation. A briefing paper prepared for Defra's Market Transformation Programme. London, Defra.

Janda K B. (2011) Buildings don't use energy: people do. Architectural Science Review, 54: 15–22.

Leaman A and Bordass B. (2001) Assessing building performance in Use 4: the Probe occupant surveys and their implications. Building Research and Information, 29 (2) 129–143.

Market Transformation Programme. (2006) Evaluation of heating controls – Phase 1. Didcot, Market Transformation Programme.

Martiskainen M. (2007) Affecting consumer behaviour on energy demand. Brighton, Sussex Energy Group, University of Sussex.

Meier H and Rehdanz K. (2008) Determinants of residential space seating expenditures in Great Britain. Energy Economics.

Moezzi M. (1998) The predicament of efficiency. Berkeley, CA, Ernest Orlando Lawrence Berkeley National Laboratory/University of California Berkeley.

MSN News. (2011). Will teen multitasking give rise to ADD? www.msnbc.msn.com/id/42557051/ns/nightly_news/t/will-teen-multitasking-give-rise-add-study-may-offer-answer.

Nicholl A and Perry M. (2009). Smart home systems and the Code for Sustainable Homes. BRE Report BR 506. Bracknell, IHS BRE Press.

Office for National Statistics. (2006) The time use survey, 2005: How we spend our time. London, Office for National Statistics. Available at: www.statistics.gov.uk/articles/nojournal/time_use_2005.pdf.

Office for National Statistics. (2009) Social trends labour market. Available at: www.statistics.gov.uk/cci/nugget.asp?id=2326.

Osório A L, Colado J M F and Pedro C S. (2006) Building automation interoperability - a review. IWSSIP 2010 17th International Conference on systems, signals and image processing. www.ic.uff.be/iwssip2010/Proceedings/nav/papers/paper_49.pdf.

Pett, J and Guertler P. (2004) User behaviour in energy efficient homes. Energy Saving Trust and the Association for the Conservation of Energy.

POST. (2005) Household energy efficiency. POST Note. London, Parliamentary Office of Science and Technology.

Pyle J, Jones K and Coffey M. (1996) The impact of the end user on building energy performance and consumption. London, School of Land and Construction Management, The University of Greenwich.

Rathouse K and Young B. (2004) Domestic heating: use of controls. Didcot, Market Transformation Programme.

Ruiz Y and Walling A. (2005) Home-based working using communication technologies. Labour Market Trends, London, Office for National Statistics, pp. 417–426.

Scott F. (2007) Teaching homes to be green: smart homes and the environment. London, The Green Alliance.

Shipworth M, Firth S K, Gentry M I, Wright A J, Shipworth D T and Lomas K J. (2009) Central heating thermostat settings and timing: building demographics. Building Research and Information, 28 (1) 50–69.

Shorrock L D and Utley, J I. (2003) Domestic Energy Fact File 2003. BR 457. Bracknell, IHS BRE Press.

Sleep Council. (2007) Junk sleep: the new health threat to teenagers. Available at: www.sleepcouncil.org.uk/?s=junk+sleep.

Steemers K. (2003) Establishing research directions in sustainable building design. Technical Report. Norwich, Tyndall Centre for Climate Change Research, University of East Anglia.

Summerfield A J, Lowe R J, Bruhns H R, Caeiro J A, Steadman J P and Oreszczyn T. (2007) Milton Keynes energy park revisited:changes in internal temperatures and energy usage. Energy in Buildings, volume 39, issue 7. 39: 783-791.

Summerfield A J, Pathan A, Lowe R J and Oreszczyn T. (2009) Changes in energy demand from low-energy Homes. Building Research and Information, 38 (1) 42–49.

uSwitch.com. (2008) Number of stay at home parents hits lowest level in 15 years: cost of living pushes over 1 million new parents back to work. Available at: www.uswitch.com/press-room/press-releases. https://s3-eu-west-1.amazonaws.com/uswitch-press-room//number-of-stay-at-home-parents-hits-lowest-level-in-15-years-cost-of-living-pushes-over-1-million-new-parents-back-to-work.pdf.

WBCSD. (2007) Energy efficiency in buildings: business realities and opportunities. Summary Report. Geneva, World Business Council for Sustainable Development.

Yohanis YG and Mondol JD. (2010) Annual variations of temperature in a sample of UK dwellings. Applied Energy, 87(22), pp. 681-690.

Further reading

H&V News (2010). User behaviour key to buildings' emissions. Available at: www.hvnplus.co.uk/intelligence/user-behaviour-key-to-buildings-emissions/8604489.article.

All URLs accessed 28 November 2011. The publisher accepts no responsibility for the persistence or accuracy of URLs referred to in this publication, and does not guarantee that any content on such websites is, or will remain, accurate or appropriate.

NHBC Foundation recent publications

Part F 2010: where to start

This publication guides designers and housebuilders to decide which Part F 2010 strategies are most appropriate by explaining, in simple terms, ways for new homes to comply and works through possible solutions on a range of common house and apartment types. The guide also explains some of the terminology, gives a broad understanding of the changes and points the builder and designer towards the relevant tables and data that must be consulted as well as requirements for installation and commissioning. ***NF 37*** November 2011

Fire performance of new residential buildings

The move towards non-traditional construction has mostly been brought about by the need to achieve both construction efficiency and better energy performance from the finished building. But could the increasing use of thermal insulating products – some of which are combustible – result in constructions being more susceptible to disproportionate damage in the event of fire? To present a balanced view of the risks involved, this guide provides useful information on the risks and best practice guidance for designers, builders and those involved in the fire safety aspect of new homes. ***NF 36*** November 2011

How occupants behave and interact with their homes

This review examines research about how domestic occupants (end users) use and perceive controls and user interfaces, and domestic user guides and product manuals. It also reviews occupant behaviour and behaviour change, occupant feedback on low energy homes, and consumer perceptions of microrenewable technologies. ***NF 35*** October 2011

NHBC Foundation publications can be downloaded from **www.nhbcfoundation.org**

NHBC Foundation publications in preparation

- Building sustainable homes at speed: Risks and rewards
- Energy efficient fixed appliances and building control systems

NHBC Foundation

Housing research in partnership with BRE Trust

www.nhbcfoundation.org

The impact of occupant behaviour and use of controls on domestic energy use

How is energy used in the home and does occupant behaviour affect energy consumption? This review explores the factors that affect energy use and looks at the ways in which energy consumption can be reduced.

It also explores future user interfaces and 'smart homes', as well as recent consumer research on the latest low energy homes. The concerns of consumer groups about the technologies and interfaces installed is also reviewed.

NHBC Foundation

Housing research in partnership with BRE Trust

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 house builders in developing strong relationships with their customers.

NF38
Published by IHS BRE Press on behalf of the NHBC Foundation
March 2012
ISBN 978-1-84806-245-0