Intelligent energy saving in the home: a user centred design perspective

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Chapter 9
Intelligent energy saving in the home: a user centred design perspective

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Intelligent homes have been a vision for decades, with the 'home of the future' promising an automated, sophisticated place to live, packed with technology that responds to our every need. With a new focus on energy saving, intelligent homes are again being heralded as the way to a low-carbon future. However, history demonstrates that people may not find the proposed technology simple to use, with issues of control, compatibility, trust and accessibility making this a problematic approach.

This chapter discusses the potential for intelligent energy saving in the home, and explores the human factors that create pitfalls to the successful roll-out of smart energy-saving devices. The importance of understanding the user needs as a critical success factor and the role of user-centred design in the development of intelligent products, services and systems is outlined. While focused on the domestic sector, there are learnings relevant to all buildings where there are users.

9.1. What makes an intelligent home?

The terms 'smart home' and 'intelligent home' are used interchangeably to refer to homes where information and communication technology (ICT) can anticipate and respond to the needs of occupants, in order to enhance their comfort, convenience, security and entertainment (Aldrich, 2003). This concept is not a new one, with the term 'smart house' first used formally in the USA in the mid-1980s (Harper, 2003). Despite ongoing research interest in the area and a resurgence of commercial interest in the concept in the early 2000s, smart homes have, to date, failed to break significantly into the mainstream, and still remain the domain of technology enthusiasts. Today, the concept is again attracting considerable commercial attention, fuelled by ubiquitous connectivity within the home enabled by wireless and mobile broadband communications, the growing popularity of smart phones and tablet devices, and the ongoing roll-out of smart meters. Energy providers and, increasingly, policy makers are exploring ways to use smart-home technologies to reduce domestic energy demand in a way that is attractive to consumers.

The UK Government has set legally binding targets to ensure that the net UK carbon account for the year 2050 is at least 80% lower than the 1990 baseline (DECC, 2008). Burning of fossil fuels such as coal, gas and oil release carbon dioxide and other greenhouse gases, and so, if we are to meet this target (and other interim targets along the way), there must be a significant reduction in the use of fossil fuels. Renewable technologies provide a low- or zero-carbon alternative, but these are not being developed at a sufficient rate to make a substantial impact on their own. Reducing demand is an essential part of the strategy. The UK Government plans to roll out smart meters to every home in the country by 2019, as they are seen as playing an important role in Britain's transition to a low-carbon economy, providing consumers with real-time information about their energy consumption. With the growing popularity of renewable technologies in the home, such as photovoltaic panels, which provide householders with the opportunity of selling 'spare' electricity back to the grid, smart meters provide a mechanism for managing this complex energy trading.

In the UK, around 36% of all gas and all electricity is used in homes (DECC, 2011). Of this energy, 66% is used for space heating and hot-water provision (Palmer and Cooper, 2011). Therefore, the largest gains within the domestic sector are to be made from focused attention on heating. While significant efforts to reduce the energy used through appliances, cooking and lighting will all assist towards the carbon-reduction targets, addressing energy used for space and water heating will offer the biggest potential success.

There are emerging opportunities for saving heating energy through building intelligence into the home, through metering, monitoring, control and feedback devices. Many homes are already embedded with intelligence, through their security systems with passive infrared (PIR) sensors linking to a security company, the central heating system with thermostatic radiator valves and programmable timers, and home media centres linked through a wireless network. However, despite the intelligence often built into these systems, they will not be effective without successful interaction with the occupants. The home is a socio-technical system, and both the technology and occupants need to work together to reap the benefits of the intelligent home and achieve the overall goals of comfort, convenience and energy saving. While the focus on energy saving and comfort is gaining momentum, convenience is often neglected, resulting in systems that are overly complex and unattractive to householders, and so use of the systems is limited and often abandoned. This can be particularly true for older people, who may be less technologically capable, but arguably would benefit most from a comfortable, efficient, warm home.

There is a range of systems emerging onto the mass market that are aimed at providing more information about energy use and offering the householder increased control. These include the following.

- Energy meters that provide feedback about current energy (usually just electricity) use. They provide options for current or total energy use, in a range of units including kilowatt-hours (kW h), carbon dioxide (CO_2) and monetary cost, with some providing an ambient indication of use through coloured lights or symbols in an attempt to simplify the information.
- Smart meters that communicate with the energy supplier, allowing meters to be read remotely, accurate feedback to the occupants on energy use (by way of an in-home display) and, if relevant, amount of home-generated electricity communicated back to the utility company. These devices form an integral part of the smart grid.
- Smart appliances that can connect to this smart grid and to other appliances in the home, allowing for remote or automated control and intelligent operation, reducing peak demand or aligning with variable price tariffs. This shifting of loads should reduce overall energy demand with only a minimal loss of service to the individual. This demand-responsive mode of operation is designed to take advantage of variable time-of-day electricity tariffs, resulting

in benefits to consumers (through lower electricity bills) and utilities (through reducing the peak loads in electricity demand and the requirement for expensive generation capacity).

Home energy management systems (HEMSs) bring together these technologies so the householder can actively monitor and manage energy use. Intelligent technology can also provide a wealth of additional functionalities to household appliances, providing new services and interaction opportunities to users. These are envisioned to be controlled by way of smart mobile devices (such as the iPhone) to enable consumers to take an active role in controlling the functions of their home, either when present in the home or remotely. The challenge is to develop products and services with which customers will actively engage, particularly given increasing energy costs and emerging social pressures for reducing demand.

Energy feedback devices are based on the assumption that many people lack awareness and understanding about their everyday energy behaviours and so feedback is provided to attempt to bridge this 'environmental literacy gap' (Froehlich *et al.*, 2010). However, this assumes that people want to change their energy behaviours and are able to, once aware. While energy-saving behaviour in other environments, such as the workplace, can be more easily managed, the home environment provides a significant challenge.

9.2. Key human factors issues

While technology can offer great potential for domestic energy saving, it can also increase the complexity of the home and, if not designed to meet user needs, the anticipated energy savings may not materialise. The following sections introduce some of the key human factors issues that need to be addressed if energy-saving intelligent homes are to become a reality.

9.2.1 Understanding behaviour change

Energy savings from smart meters and in-home displays have been, to date, much lower than expected. This can be partly attributed to the 'rebound' or 'take-back' effect (e.g. Hong *et al.*, 2006), whereby householders make improvements to the efficiency of their home (through improvement to the fabric, more efficient appliances or better controlled systems) and take back any savings made through increased temperatures or greater use of the heating and hot water. This draws on the Jevons paradox, which asserts that increasing the efficiency with which a resource is used tends to increase (rather than decrease) the rate of consumption of that resource. Energy-efficiency improvements in the home result in the occupant being able to achieve increased comfort levels without an increase in energy bills, but any carbon savings are negated by this increased use. The user requirements are met, but the government targets are not.

Studies have also shown that, whereas householders are initially interested in receiving feedback on their domestic energy consumption and may adjust their behaviour to make initial savings, there are many energy-consuming components of daily life that householders are not willing to change or give up (Strengers, 2011). These 'non-negotiable practices' might be valued for the comfort or convenience they afford (e.g. long hot showers), or might in fact be long-established culturally embedded habits such as airing a house in the morning and thus inadvertently allowing warmed air to escape.

9.2.2 Control

A key issue concerning the design of the intelligent home, and intelligent appliances in particular, is the issue of control. Although building intelligence into appliances and domestic systems can potentially optimise energy demand at grid level and provide cost savings for the consumer, the degree to which householders will be willing to relinquish control over when they carry out daily tasks, such as using the washing machine, is, as yet, poorly understood. Where user research has been conducted, it has been heavily biased towards the inclusion of academics and technologists as study participants (Hauttekeete *et al*., 2010), and further research including the diversity of the population is needed. Control interfaces are needed that allow users to make informed decisions about when to override automated choices made by systems or appliances. Ensuring such interfaces are usable and do not add complexity will require careful consideration of user needs and how interaction with such products will be embedded in the everyday routines and practices of everyday life (Dourish, 2001).

9.2.3 Privacy and trust

Much research into the intelligent home is directed towards creating artificial intelligence (AI) systems that use data from sensors embedded in devices, appliances and the home environment to provide home automation that learns the preferences and behaviour of users. Often the goal of such research is to create control systems, for example, for lighting and heating, that do not require explicit user control. In theory, such systems could provide considerable convenience and energy savings for the householder (e.g. by turning the heating off in unoccupied rooms), but consideration must be given to both privacy and trust issues for such systems to gain widespread acceptance. Intelligent home systems will create large amounts of raw data that have to be processed to provide relevant control information (Cook, 2012). This processing could take place within the home but, particularly within a smart-grid context, processing is most likely to take place outside the home by a service provider. Cook highlights that householders are reluctant to install sensors in their homes because of the potential for external commercial parties to exploit the data trails they leave for their own, rather than the householders', advantage. Many commercial players, including energy, telecommunications, media, computing and internet providers, have shown resurgent interest in the smart-home market in recent years, and this is at least partly driven by the anticipated commercial value of the data on householder behaviour that smart-home services potentially provide. Considerable efforts must therefore be directed at understanding who owns these data and how householder interests can be protected when data are aggregated and used beyond the home. An interesting response to this issue has been proposed within European Union guidelines to protect data privacy within ubiquitous computing systems. The 'privacy razor' concept (Lahlou *et al*., 2005) proposes that everything the system knows about the users is listed and then everything that is not 'absolutely necessary' to provide the service is excluded from data collection and storage (e.g. personal identification). However, this suggestion may oversimplify householder needs and preferences. Research is still needed, therefore, to better understand what future intelligent-home occupants are actually willing to provide in terms of data in return for incentives such as cheaper services or tariffs that more closely reflect their actual usage.

9.2.4 Usability

Poor usability has long been accepted as a key reason for the slow uptake of smart-home technologies. One has only to consider the complexity of many of today's advanced heating controllers to understand that increased sophistication in terms of control and automation often results in greater system complexity, reduced usability and low user satisfaction (Combe *et al*., 2012). Furthermore, where the goal is to use system intelligence to reduce energy demand, then these savings are unlikely to be realised if users are unable to optimally configure the system to meet their needs and preferences.

Many industry-generated visions of the future intelligent home depend on smart-phone applications as a key component of user acceptance. Because the iPhone epitomises ease of use, the assumption is often made that interaction with smart-home technology will become easier and more convenient if smart phones are used as the primary control device (e.g. Zhong *et al.*, 2011). However, such visions must be treated with caution, as previous examples of technology push within consumer markets have shown that industry hype does not necessarily translate into user value (Pantzar, 2002). Despite their growing popularity, not all segments of the market will want or be able to control their heating and appliances using a mobile phone. If smart-home technology is to gain mass-market acceptance, it must be universally accessible; the needs of the elderly, disabled and those less familiar with technology must therefore also be taken into account. Many of the benefits espoused for smart-home technologies relate to provision of improved healthcare and welfare for elderly and disabled people. Those who might really benefit from smart heating control (as they are sedentary at home or have health issues that need a stable thermal environment) may also be those who are on lower incomes or less familiar with technological advances. Designers of these systems should, therefore, place significant emphasis on achieving usability for these more vulnerable householders.

The intelligent home of the future is likely to comprise a multitude of systems, both purchased by the householder over time and embedded in the infrastructure of the building. Therefore, usability should not be considered in relation to individual devices or appliances, but also at a system level. The interoperability of devices and systems will have a significant impact on the overall usability of the intelligent home and its perceived complexity, especially as the technical capability of most homes will evolve over time. Consideration must therefore be given to how easy it is to set up intelligent systems in the home and configure them to suit the preferences of users.

9.3. The complexity of the home environment

As the home is often a very private space, understanding people's requirements in the domestic setting provides an added level of complexity. The essence of the house being a home, more than just a place to live, is critical. Bound up with this are the sentimental values people place on their home and the things within it. It is not possible to simply apply a standard energy-saving measure to an occupied home and expect it to work successfully. This contrasts with other types of building, for example, workplaces, where the occupants often do not need to interact directly with the embedded technology as it is managed by trained specialists. People in the workplace are often more willing to conform to the ways of working such that they accept the ambient temperature, or at least acknowledge that automated systems control their environment. In the home, the occupants are often responsible for paying directly for the energy they use, choosing the technology they install in their home and, critically, deciding whether and how they use it. With this freedom, the home environment offers a significantly wider spectrum of users that must be accommodated if intelligent energy saving is to be achieved.

Home occupants cover the entire spectrum of the population, from newborn babies to very elderly or severely disabled people. Meeting these diverse and often demanding needs is a significant challenge. Homes are multi-occupancy; each occupant has his or her own preference for how he or she lives, but has to share common spaces and systems. People's lives can be chaotic, their occupancy changeable and their preferences for an indoor environment inconsistent. This complexity makes it difficult to use consistent proxies for predicting behaviour. Some intelligent-home energy devices attempt to predict occupancy and energy use by drawing on electricity-demand profiles. This can give inaccurate information if householders use their appliances on timers or when they go to bed, for example, maximising cheaper night-time tariffs. An unsophisticated system might assume that the householders are still up and about late at night and so require heating, when in fact this could be wasting energy. Intelligence is needed to draw on a range of indicators of, not just occupancy, but also the need for energy at particular times, to ensure the home is warm or cool when needed, hot water is available in the right quantity, stored food is kept cold, washing can be laundered on time, and communication and entertainment are provided when needed.

Multi-occupancy also presents a challenge to intelligent sensing. Many systems can detect movement of an occupant, but it may not be easy to identify *who* is moving about the house, including whether it is a person or a pet! Movement sensors are not effective during times when the householder is stationary, perhaps when watching TV or sleeping, but understanding his or her energy use at this time might be crucial. Nor is it easy to determine *how many* people are moving around when people move from room to room in groups. These factors all lead to incomplete or inaccurate data sets which, if used to inform automated processes, are likely to result in dissatisfied householders. People at work are often happy to carry identification cards that could be used to recognise where they are in a building, but at home the concept of individual tagging is generally unacceptable. In the future, it is conceivable that individual identification could be possible through smart-phone identification, and as more and more individuals carry such devices with them wherever they go, this could be an identification device of the future home. However, this relies on people keeping the phone with them at all times, and accepting the invasion of privacy that this type of data collection brings. The potential for innovation in this area is rapid, but it must be appropriate to the needs of the users.

9.4. A user-centred design approach to the intelligent home of the future

If we are to meet the challenge of domestic energy saving through technological approaches, it will be important to understand user needs and behaviour in order to shape the design of all aspects of the intelligent home. User-centred design (UCD) offers a process by which the user is considered central to the system and design solutions (which could be products, services or systems); it provides a means to ensure the context of use, and user needs are included within the design process by considering physical, cognitive, social and cultural factors. However, UCD can be considered in a wider context, as a philosophy – that the process of design should focus on the needs of the user as a central tenet, seeking to ensure that the needs and wants of users are considered throughout the product-design process (Norman, 1998). The long-established premise for UCD is that an early focus on user requirements leads to the design of useful, useable and desirable products. The principles of UCD (Gould and Lewis, 1985) are generally accepted to be: an early focus on users and tasks; empirical measurement; and iterative design. Preece *et al.* (2002) suggest five further principles that expand and clarify the first principle.

- Users' tasks and goals are the driving force behind the development.
- Users' behaviour and context of use are studied and the system is designed to support them.
- Users' characteristics are captured and designed for.
- Users are consulted throughout development, from the earliest phases to the latest, and their input is seriously taken into account.
- All design decisions are taken within the context of the users, their work and their environment.

Although users do not actively need to be involved in design decisions, designers should remain aware of their requirements when making design decisions. Clear communication of needs and requirements to designers in a way that is meaningful and relevant is therefore a crucial component of UCD.

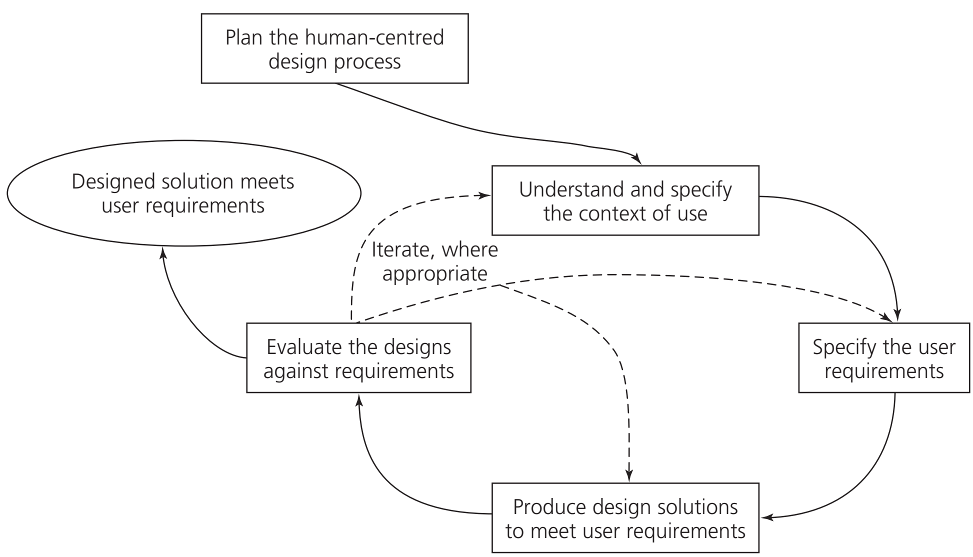
UCD methodologies are often based on the international standard ISO 9241-210 : 2010 (ISO, 2010), which provides principles for involving users in design but does not prescribe the methods. Four main activities are recommended within an iterative development cycle, including

- understanding and specifying the context of use
- specifying the user requirements
- producing design solutions
- evaluating the design.

The process of human-centred design set out in ISO 9241-210 : 2010 (ISO, 2010) is shown in Figure 9.1.

Following planning, the first stage within the iterative process is to understand and specify the context of use. This includes understanding how people live in their homes, who they are, what it is they value about their homes and the systems within them, what their goals and motivations are for how they live, and how technology fits in within this often complex and messy system. The requirements for the design of products, systems and services can then be specified, based on a real understanding of the context. This understanding of the users' requirements enables that designs meet people's needs. By working with users from the outset of the design of a product, service or system, it is possible to understand how future intelligence within the home can be designed to fit successfully into the practices of everyday life.

Figure 9.1 Interdependence of human-centred design activities. Reproduced from ISO, 2010



9.5. The future

Smart homes of the past have not been wholeheartedly successful, sometimes for technical reasons, sometimes for social reasons. Examples such as the WAP (Wireless Application Protocol) phone have shown that technology-led innovation is not always taken up by the market. But when design and development is done properly, intelligent devices can deliver the experience people want. Smart phones are now ubiquitous, and their bridge to home energy-management systems is inevitable, but their success relies on the correct mixture of technology development, creation of appropriate economic models, and appropriate user experience maturing sufficiently to deliver an attractive service proposition.

Homes of the future are likely to be quite different from today in terms of technology. In the near future, it might be commonplace to have energy displays in every room, variable tariff pricing to take advantage of less expensive fuel, with appliances and heating systems that are responsive to these variations. Mobile control is inevitable through smart phones or their successors, and remote access will be available to monitor and control our homes in detail. A central interactive display may allow access to all parts of the home computer network at the touch of a finger (Park *et al.*, 2003). Remote live video streaming may be possible to monitor the home, passive sensors and intelligent appliances may learn our habits and patterns of behaviour. Energy storage may enable local generation to be utilised when needed, powering the heating, electric vehicle or appliances locally. Communication technology may encourage dispersed family living within the home, rather than the traditional sharing of the main living spaces. Older people may be able to live independently for longer, with improved connectivity allowing carers to monitor health and activity remotely. However, the human-factors issues will remain, despite these other advances, and so a user-centred approach is critical to the success of the future intelligent home to ensure a balance of usability, inclusivity and sustainability with a lasting legacy of acceptable technology.

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