A practical review of energy saving technology for ageing populations

CrossMark

Guy Walker [a, *], Andrea Taylor [b], Craig Whittet [b], Craig Lynn [b], Catherine Docherty [b], Bruce Stephen [c], Edward Owens [a], Stuart Galloway [c]

[a] Institute for Infrastructure and Environment, Heriot-Watt University, Edinburgh EH14 4AS, UK
[b] Glasgow School of Art, Glasgow G3 6RQ, UK
[c] Strathclyde University, Glasgow G1 1XW, UK

ARTICLE INFO

ABSTRACT

Fuel poverty is a critical issue for a globally ageing population. Longer heating/cooling requirements combine with declining incomes to create a problem in need of urgent attention. One solution is to deploy technology to help elderly users feel informed about their energy use, and empowered to take steps to make it more cost effective and efficient. This study subjects a broad cross section of energy monitoring and home automation products to a formal ergonomic analysis. A high level task analysis was used to guide a product walk through, and a toolkit approach was used thereafter to drive out further insights. The findings reveal a number of serious usability issues which prevent these products from successfully accessing an important target demographic and associated energy saving and fuel poverty outcomes. Design principles and examples are distilled from the research to enable practitioners to translate the underlying research into high quality design-engineering solutions.

© 2017 Elsevier Ltd. All rights reserved.

1. Introduction

1.1. Fuel poverty and the elderly

Fuel poverty is the confluence of several key research grand challenges. It is brought about by poor energy efficiency, in particular the thermal efficiency of housing stock and heating sources; low household income; and high fuel costs. These in turn reflect back on national energy mixes, the drive towards renewables, and even the geo-politics of an increasingly globalised and interconnected world economy. Definitions of fuel poverty differ. In Scotland, where this study was conducted, a household is in fuel poverty if it requires more than 10% of its income to be spent on household fuel use in order to maintain a satisfactory heating regime. The Scottish and UK Governments have set aggressive targets for tackling this important issue.

Ageing is a particular hallmark of the extreme 'fuel poor' due to higher and/or longer heating requirements combined with declining incomes (Department of Energy and Climate Change, 2014). There is a worldwide demographic trend towards a rising median age, and as such it is becoming much more important for

older people to become willing to invest in, understand, and trust home energy saving technology. This is seen as a key enabler for helping ageing populations feel empowered about their ability to make informed decisions about energy use, and prevent more households falling into fuel poverty. This paper reports on an assessment of the behavioural and usability aspects of a range of commercially available home energy saving technologies, and their ability to benefit ageing populations in this way. The assessment was conducted as part of a significant UK Engineering and Physical Sciences Research Council (EPSRC) project called APAtSCHE (Ageing Population Attitudes to Sensor Controlled Home Energy) which investigated the technical and social issues surrounding the development and deployment of home automation technology in residential premises inhabited by older people (EPSRC, 2014).

1.2. Home energy products

The market for home energy products is currently large and growing. There are two main types of product: home energy monitors and automated energy systems.

Home energy monitors are designed to increase householders' awareness and understanding of energy usage, connecting routine behaviour to consumption in order to motivate conservation behaviour and reduce energy bills. Most energy monitors are made up of three parts: an in-home display, a sensor, and a transmitter.

The sensor clamps on to a power cable connected to the electricity meter and measures the current passing through it. The transmitter sends the data wirelessly to the display unit. Typically, electricity usage is displayed in units of energy used (kWh), cost (£) or carbon emissions (CO_2).

A previous survey of energy use has concluded that typical central heating controls, such as room thermostats, "seem to live incognito in many homes" (Shipworth et al., 2010, p. 31) and that householders are more likely to change their behaviour if new controls are designed that are appealing and usable. On the plus side, research has shown annual electricity savings of 5–15% resulting from home energy monitors (Darby, 2006). This energy saving potential provides part of the explanation for the current enthusiasm for new domestic technologies. On the debit side, users have reported difficulty understanding the displays, ranging from confusion over the features available to misinterpreting or misapplying the data (Darby, 2010; Strengers, 2011). This highlights a persistent need for improved user interfaces. Even when householders are able to understand the display, there is limited evidence that simply presenting information about energy usage reliably causes people to take action. This assumption is contained within the Information-Deficit Model (Hargreaves et al., 2010). The model assumes that the householder, once in receipt of the 'correct information', will make rational, economic decisions about energy consumption based on their individual attitudes and beliefs. Despite this model running counter to over forty years of research in decision making and cognitive biases (e.g. Kahneman, 2011), and the model itself being widely refuted in the literature (e.g. Strengers, 2011; Hargreaves et al., 2010; Gram-Hanssen, 2008), most home energy research still relies on the assumption that if the 'correct' information is 'made 'visible' then users will respond in ways that are predictable and desirable. In reality, an initially high level of engagement with information providing devices diminishes over time due to disinterest once the initial discovery phase has passed. Turning devices on and off, and watching how much energy is used, is initially compelling for users. Alerting householders to everyday practices considered to be 'non-negotiable', such or tumble-drying rather than air-drying laundry, are not. Suggestions of this kind fail to address embedded social norms around comfort and cleanliness (Pierce et al., 2010; Snow et al., 2013; Strengers, 2011). Shove (2004) argues that policy makers' preoccupation with technical efficiency has "blinded" (p. 1054) them to major transformations in what people take to be normal and ordinary. The example of washing is again pertinent. Domestic machines are increasingly efficient with people washing at lower temperatures, however, concepts of cleanliness have changed resulting in more frequent laundering, thus negating the net efficiency gain.

Given the challenges faced by energy monitors in motivating long term change more sophisticated automated energy systems have been proposed. Research by Koehler et al. (2013), Scott et al. (2011), and Yang et al. (2014) report users' experiences with systems incorporating occupancy sensing, prediction and machine learning to automatically control home heating. Interestingly, all three studies propose finding a balance between automation and user interaction to maximise energy savings and respect users' desire for comfort and control. Yang et al. conclude that existing systems can be better designed. For example, while applauded for its pioneering aesthetic design, the Nest Learning Thermostat has been criticised for breaking and ignoring user experience principles and heuristics, including the element of taking away user control. Similarly, a UK Government study into what people want from their heating controls found that participants were sceptical about whether automation would work for them and were generally reluctant to cede control (Rubens and Knowles, 2013). Taking control away from householders may also inadvertently legitimise high-demand practices and disengage householders from understanding and managing their resource use (Strengers, 2008).

1.3. Domestic energy behaviours

Over the past decade there have been numerous policies and programmes to address fuel poverty. In the UK, these include the Energy Company Obligation scheme where obligated energy suppliers liaise with occupiers and landlords to identify and implement suitable energy efficiency measures (Ofgem, 2015); home insulation schemes, e.g. Home Energy Efficiency Programmes for Scotland (Scottish Government, 2008a,b); consumer information, e.g. Home Energy Scotland advice service (Energy Saving Trust, n.d.); and not least smart meters and in-home displays as previously discussed (GOV.UK, 2015). Despite these great changes in the domestic energy landscape there has been remarkably little movement in how individuals like to heat their home (Shipworth et al., 2010; Shipworth, 2011) nor the device they use to do so. In 1984, UK households set their heating thermostats to a mean of 19.3 °C, which is virtually identical to the mean setting (19.6 °C) selected in 2007 (Shipworth, 2011). The typical heating thermostat, with its circular dial, originates from a design released as far back as 1953 by Honeywell called the 'T87 Round'. Shipworth (2011) further highlights that most domestic thermostats were selected and installed by previous owners or landlords, and 90% of respondents in a study by Peffer et al. (2011) rarely or never adjusted them. The advent of programmable central heating controls has done comparatively little to change this situation. According to Peffer et al. (2011) 20% of the programmers they surveyed in a large study were showing the wrong time, 53% were not in automatic mode (and were switched on or off manually by the user), indeed, 85% of people who said they did use the programmable features often did not (45%). As a result, more sophisticated and information-rich central heating controllers can actually use more energy than manually controlled ones (Peffer et al., 2011). This represents a serious challenge to the widespread assumption that if the sophistication of home energy controls is increased, then users will be able to perform more rationally and save energy. It is for the reasons elucidated in Peffer and Shipworth's studies, and others, that the applied ergonomics research is often far less optimistic than the widespread assumptions contained in government policy and the wider engineering community.

At a fundamental ergonomic level, interpretation of a home energy control relies on 'internal constructs' held by users, which "help them to understand the world and select the appropriate course of action" (Revell and Stanton, 2014, p. 363). These mental models are often very limited, particularly with regards to ecological usage patterns (Sauer et al., 2004). This simplicity is revealed by Kempton (1986) 'theories' of thermostat operation. Users holding the so-called feedback theory believe the thermostat turns the boiler on or off and the temperature set on the thermostat is the on/off temperature. For example, if the temperature is set at 22 °C the boiler will remain on until this level is reached, after which it will turn off. This is aligned most closely to how domestic thermostats actually do work. Users can hold an alternative mental model called the valve theory. Users in this case believe the thermostat controls the rate or intensity of heat generation. Like a tap, "a higher setting causes a higher rate of flow" (Kempton, 1986, p. 78). This offers an explanation for why some users will turn a heating control up further than normal when entering a cold room in order to try and heat it more quickly. Other models have been put forward, including the timer theory (Peffer et al., 2011), in which users select greater values of temperature set point for when they desire longer periods of boiler operation (e.g. Revell and Stanton, 2014)and the

switch theory (Norman, 1988), where users simply use the thermostat as an on/off switch. Both Kempton (1986) and more recent work by Revell and Stanton (2014) highlight how a user's mental model of a home energy control might not represent the actual way it functions, yet despite this can give rise to better or worse energy consumption. A key issue for ecological performance and fuel poverty is that the advice normally given to households in terms of thermostat usage (the 'correct' feedback theory of operation) may actually lead to greater energy usage (Revell and Stanton, 2014).

1.4. Usability issues

The root of user issues with home heating controls lies in a gulf between the designers' and users' mental models. A gulf of evaluation makes it difficult for users to perceive the state of the system, and a gulf of execution prevents users from knowing what behaviours to perform to get the outcome they want (e.g. Norman, 1988). Bridging these perceived and interpreted expectations is the cornerstone of usability research (e.g. Clarkson and Coleman, 2015) and has the potential to yield a breakthrough in older people's willingness to invest in, understand, trust, and become empowered by home energy saving technology.

Applied Ergonomics has been publishing research into usability since its inception in 1970. There is no shortage of good ergonomic design guidance available for product design engineers, and no inherent reason why home energy controls cannot be made suitable for elderly users. It can be expected, therefore, that significant progress will be evident since Gardner et al. (1993) published a critique of 28 products specifically marketed to elderly people as aids to living. Their study showed that many of the products were not appropriate or adequate to perform the tasks for which they were intended and some were of poor quality and hazardous to the home environment. This is the call to action. The present study is, to some extent, a replication of this earlier work but targeted at an appraisal of commercially available home energy technologies for whom elderly consumers are a key future market.

1.5. The study

What initially appears as a simple problem, of controlling domestic heating and energy use, rapidly reveals itself to be highly complex (Revell and Stanton, 2015). More so when the intended benefactors of new home energy devices are elderly persons with specific and pressing needs for better interface design and usability. The following sections of the paper describe the study performed to analyse this issue. They describe the specific home energy products placed under test, the method of usability testing, and the analysis outcomes. The aims of the study are twofold. The first research question is to consider the real-world impact of ergonomics research, using Gardner et al.'s (1993) first study as a benchmark. The second research question is more specific. It is about the ability of home energy products such as these to appeal to elderly users and, in turn, their potential to make an important contribution to reducing fuel poverty. These two aims ensure the paper is not merely about describing the problem but about proposing practical solutions and design principles that ergonomists and designers can put to immediate use.

2. Method

2.1. Participants

A total of 81 participants took part in the study. The sample was comprised of 41% male participants and 59% female, with a mean age of 69 years (SD = 10.86). The minimum age was 50 years (defined in gerontology as constituting 'young old'), while the maximum age was 87 years (defined similarly as 'old-old'). It is worth noting that categorisations based purely on chronology are not always widely supported, hence the use of broader social, psychological, 'service uptake' and life expectancy normalisers in this study. Participants were recruited from residential areas of South Western Scotland known from census data to contain elderly residents; by identifying venues such as social and bridge clubs known to be popular with elderly participants; and via stakeholder organisations such as Glasgow Housing Association and Dumfries and Galloway Housing Partnership who were part of the APAtSCHE project. The study was subject to ethical approval within the host organisations.

2.2. Design

A total of 12 home energy saving products and systems were purchased for the study, ranging in price from £14.99 to £123.07. The project team, based at the Glasgow School of Art and with no affiliation to a particular product or analysis method, purchased the products from normal retail outlets (e.g. department stores, electrical retailers, on-line shops etc.): none were provided by manufacturers or sales agents. The main criterion for inclusion was easy availability through normal UK retail channels and a price not exceeding £125. In other words, the products were chosen to provide an overview of the market sector rather than single out any particular manufacturers.

A team of analysts (n = 15) were allocated a notionally fixed budget to purchase the products. Six of the analysts were able to perform the assessment individually because their products did not exceed the notional individual budget. Three groups of two, and one group of three, convened in order to pool the notional individual budgets and purchase more expensive items. The division of labour and financial resources was agreed at a group level following an initial investigation of available products, and under the direction of the Principle Investigators.

The analysis itself was exploratory. In recognition of the potentially sensitive elderly user-group and the varied opportunities available to access them, a flexible toolkit approach was adopted. The toolkit approach orientated around two key methods. The first was a high level task analysis (method 1). The second was a product walkthrough (method 2: Stanton et al., 2013). Following these initial methods the analysts went on to develop a more tailored analysis based on the issues discovered in the high level tasks analysis and walkthrough, the willingness of the participants to engage in further study, and the characteristics of the product in question. Table 1 shows the 12 methods selected as being suitable for this study domain, and the principle characteristics which allowed the analysts to design their method strategy. These characteristics were:

1. The insights the method is designed to provide (based on the high level task analysis and walk through some of these issues will be more or less relevant).
2. Whether the method is on-line (applied to, or requiring the involvement of, participants) or off-line (something that can be constructed, modelled, represented etc. based on the task analysis and walkthrough data rather than direct involvement of participants)
3. Engagement/ability of the participants to undertake or take part in the data collection activity (some methods will be easy to apply, others will be more demanding and potentially unsuitable for specific groups or individuals).
4. Time/effort involved (in designing the specific toolkit approach some participants will have a large time budget available, others

Table 1
A toolkit approach was adopted for the analysis of the sample products, involving selecting from 12 methods based on the willingness/ability of the participants to engage and the time/effort involved in applying the method.

Method	Insights provided	On-line or off-line technique	Willingness/Ability of the Participant to Engage	Time/Effort Involved in Applying the Method
		Selection Criteria		
Heuristics (e.g. Stanton and Young, 1999)	A flexible subjective approach in which observations during product usage are recorded.	On-line	Suitable for engaged participants	Moderate
Immersion Analysis (e.g. Hanington and Martin, 2012)	Immersion in the research process from the point of view of the user for design empathy and insight. This included simulating physical disabilities such as arthritis and poor vision. This involved analysts taping weights to their fingers to reduce the strength and range of motion of each finger and thumb, and/or glasses smeared with Vaseline (petroleum jelly) to simulate reduced vision.	Off-line	Suitable for cases in which participant's willingness and/or physical ability to engage is low.	High
Focus Groups (e.g. Langford and McDonagh, 2002)	Group interviews where participants are selected on the basis they would have something to say on the topic and would be comfortable talking to the interviewer and to each other. These took place at social and bridge clubs, and sheltered housing centres, with a facilitator. The sessions were structured around the product walk-through, with the facilitator taking the participants through each step and inviting descriptions of participant's experiences, thoughts and key issues concerning the product's overall ease of use.	On-line	Suitable for highly engaged participants	Moderate/High
Semi-Structured Interviews (Stanton et al., 2013)	Pre-ordered questions and themes presented to participants by the interviewer, but with scope to branch off into other relevant areas as required.	On-line	Suitable for highly engaged participants	Moderate/High
Function Flow Diagrams (e.g. Kirwan and Ainsworth, 1992)	Graphical representation of device function and events that occur during the performance of a task.	Off-line	Suitable for cases in which participant's willingness and/or physical ability to engage is low.	Moderate/High
Abstraction Hierarchy (Naikar, 2013)	A model of the system in terms of a hierarchy of functions, from the most abstract of functions to the most local of processes, and their relationships to one another.	Off-line	Suitable for cases in which participant's willingness and/or physical ability to engage is low.	Moderate/High
Microsoft Product Reaction Cards (Benedek and Miner, 2002)	A set of cards with a word (adjective) written on each card that people are asked to select from to describe their response to a product.	On-line	Suitable for highly engaged participants	Moderate
Personas (e.g. Hanington and Martin, 2012)	A synthesis of the full participant pool into a subset of fictional characters that embody the dominant traits in the sample.	On-line/off-line	Personas can be constructed based on moderate engagement by participants	Moderate
Cambridge Impairment Simulator (Cambridge EDC, n.d.)	Filters are applied to image and sound files to simulate some of the main effects of common visual and hearing impairments.	Off-line	Suitable for cases in which participant's willingness and/or physical ability to engage is low.	High
Co-Creation/Video Prototypes (e.g. Hanington and Martin, 2012)	Visual prototypes that are taken to users in order to gather initial design feedback.	On-line	Suitable for highly engaged participants	High
Photo Diary (e.g. Hanington and Martin, 2012)	A technique whereby users themselves can take photos of device issues as they are encountered over a longer time period and without an analyst being present.	On-line	Suitable for highly engaged/capable participants	Moderate
Design With Intent Toolkit (e.g. Lockton et al., 2010)	Cards and worksheets that act as different 'lenses' through which common problems can be viewed and new perspectives gained.	On-line	Suitable for highly engaged participants	Moderate

only small, and that 'budget' will be spent in ways that try to maximise insight).

The use of a large sample of participants and devices enables these exploratory findings to be pooled in order to provide results that meet the research objective. The pooling process involved a workshop at which the analysts presented their method results, and worked with the PI's to summarise and synthesise the key findings that were persistent, recurring and/or particularly marked.

2.3. Products and systems reviewed

The devices purchased for the study were a selection of energy monitors and automated energy systems as follows:

2.3.1. Energy monitors

The following energy monitors were tested: EnviR by Current cost (Current Cost, 2008), Eco-Eye Elite (Eco-Eye, n.d.), Eco-Eye Mini (Eco-Eye, n.d.), Efergy e2 Classic (Efergy, n.d.), Efergy Elite Classic (Efergy, n.d.), OWL + USB (OWL, n.d.), and OWL Micro + (OWL, n.d.). These take the form of displays that communicate information about total household energy use. The display unit communicates wirelessly with a device attached to the main meter feed cable. In addition, two plug-in energy monitors were tested: the Belkin Conserve Insight (Belkin, 2013) and Energenie Energy Saving Power Meter (Energenie, n.d.). Plug-in energy monitors (or socket monitors) measure the electricity usage of individual appliances. The monitor is plugged into an electrical socket and an appliance is in turn plugged into it. The display screen is typically incorporated into the plug and a sensor/transmitter is not required as a single appliance rather than the whole home is being

monitored.

2.3.2. Automated energy systems

An automated energy system from LightwaveRF (LightwaveRF, n.d.) and the EnergyEGG (EnergyEGG, n.d.) were also included in the analysis. The former comprises a range of Wi-Fi enabled devices connected to the Lightwave Link (hub) to allow household members to remotely control and monitor lighting, heating and power via an App on their smartphone or computer. For the purposes of the project, the Lightwave Link, an energy monitor, and a remote controlled dimmable light bulb were analysed. The EnergyEGG uses occupancy sensing to turn off an unused appliance plugged into an adaptor that is in turn plugged into an electrical socket. The ST320 smart thermostat from Salus (Salus, n.d.) was also purchased. This is an electronic as opposed to mechanical device with an enhanced interface and control logic.

2.4. Procedure

2.4.1. High level task analysis

An initial task analysis was created based on the 'out of the box' product experience. This included everything from the process of unpacking and revealing the product for the first time to installing and configuring it. Procedures and processes were documented and a high level sequential task description was produced. The task analysis was kept at a high level for the purposes of efficiency. A detailed task analysis would have placed an unwelcome time burden on the participants who would be required to go through the product/device functions exhaustively. Instead, the high level task analysis served as an organising structure around which to guide the product walkthrough, and a more targeted analysis using a 'toolkit' approach (explained below).

2.4.2. Product walkthroughs

The product walkthroughs employed the procedure laid down in Stanton et al. (2013). The high level task analyses were used to define representative scenarios that covered all aspects of energy monitoring and control, including the definition of who would be performing each step. The analysts then took each product/scenario, and working with elderly users, performed a verbalised/observed walkthrough in the participant's own homes. The full spectrum of scenarios, from unpacking the product, installing it and operating it were covered, and the scenarios were frozen at key points to allow for in-depth questioning. Key insights were documented, recorded and/or photographed as appropriate.

2.4.3. Usability testing via a toolkit approach

Procedures and processes identified during the product walkthrough as being particularly problematic were subject to further on-line (with participants) or offline (experimental/desk-based) research. A wide range of established usability methods and tools were employed contingent on the situation and problem to be tackled, and the willingness of the participants to engage. These ranged from the informal (i.e. Heuristics; Stanton and Young, 1999) through to the advanced (i.e. Abstraction Hierarchy; Vicente, 1999; Naikar, 2013), with selection based on the desired method outputs and the time/effort involved in their application. This information was gained from Stanton et al. (2013). The methods used within the toolkit approach are shown in Table 1.

The analysts and principle investigators convened at the conclusion of the data collection phase and undertook a presentation workshop in order to synthesise, cross check and group the findings. These outcomes also informed the subsequent long-term sensor deployments and participant engagement strategy within the wider APAtSCHE project.

3. Results and discussion

3.1. Personas

The research identified a number of behavioural and usability problems with the packaging, set-up process and user interface. A number of direct age-related impairments were reported by participants or observed by the analysts including poor vision, arthritis, loss of hand dexterity, weak hand strength, pain and stiffness on bending down, and the after effects of more serious illnesses such as strokes. Despite the use of a common term such as 'elderly', it is apparent that the sample is more diverse than this simple label would initially indicate. This diversity was captured in the project by the development of 'personas' as shown in Table 2.

A range of attitudes towards home energy saving technology was revealed in the analyses, which the personas try to capture. For example, referring to automation systems, one participant commented, "I do not have or want Internet and I hate computers! Most technology actually, I wouldn't trust home automation" whereas another participant remarked, "I think this system looks ideal, I love using the latest technology and I am thinking of buying something like this when I do up the house." This diversity is reflected in the user personas. For example, Eileen is not worried by her energy bills and believes that she could not keep adequately warm if she were to use less energy, whereas Lorna makes conscious decisions about her energy use to save money and to help the environment. The personas help to inform more differentiated design solutions.

3.2. High level task analyses and product walkthroughs

The high level task analyses (Fig. 1) allowed for the identification of key task steps in unpacking, installing and configuring each product and system. The product walkthroughs allowed for the identification of physical and cognitive challenges in performing the given tasks.

Table 2
The 81 participants were grouped into three distinct personas.

| Persona	Description
Young Old	Lorna, 67, pensioner, lives alone, has a son and daughter who each have three children, lives on her pension and savings and has a small disposable income, tries to be eco-friendly so as to not harm the environment and to save money, recently started gardening for a hobby and enjoys crosswords and watching television, has diabetes and a nerve problem causing blurred vision and involuntary shaking.
Old	Eileen, 75, pensioner, lives alone, in poor health, rarely ventures out and has meals delivered, enjoys watching television and reading books in her living room with the electric fire on a very hot setting, the bills do not worry her unduly as she only uses this one room and could not cope with using less energy, set in her ways and does not want to change her lifestyle or understand more about energy at her age.
Old Old	David, 84, pensioner, lives alone, enjoys socialising with friends and family and being active in his local community, spends a significant portion of his pension on energy bills but doesn't want a cold home, finds his energy bills confusing and cannot understand the calculations, has arthritis and poor vision and struggles using products that are too stiff or small to grasp or that have small text to read.
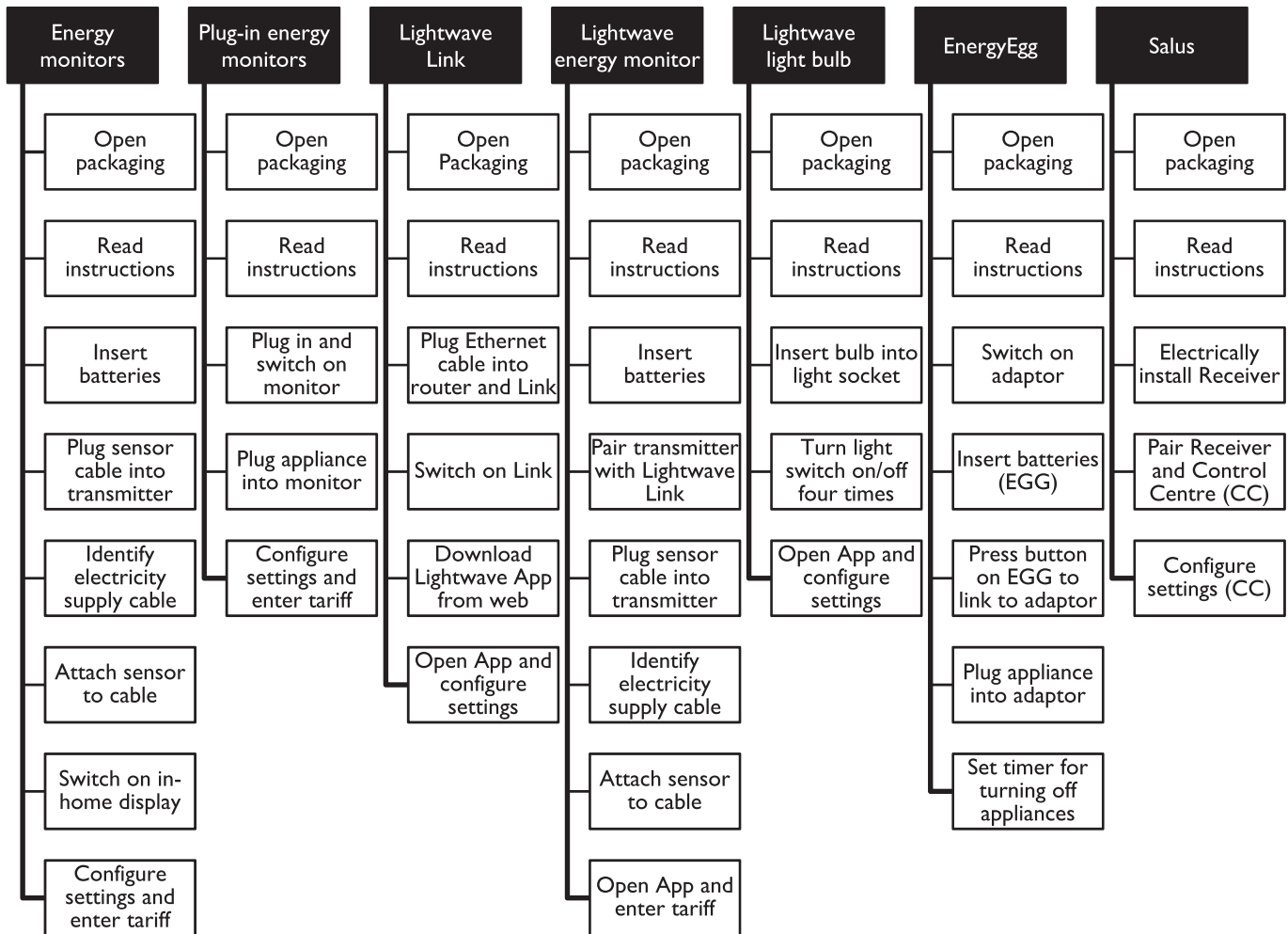
Fig. 1. High level task analysis for all the devices under evaluation.

Fig. 2. Opening the sensor and clipping it onto the electricity supply cable proved a major challenge.

3.2.1. Energy monitors

Seven high level tasks were identified beginning with opening the packaging and reading the instructions, through to configuring the settings and inputting the tariff. The plug-in energy monitors followed a similar but reduced series of steps (both shown in Fig. 1).

The energy monitor product/scenario walkthroughs revealed the main physical challenges to be:

1. Accessing the electricity meter if it is mounted in a hard-to-reach location
2. Opening the sensor clip and attaching it to the power cable due to the stiffness of both the clip and the cable (Fig. 2) and
3. Viewing the display units, as these are not backlit.

The main cognitive challenges that emerged were:

1. Understanding the set-up instructions, which are generally presented as a large volume of small sized text with few information graphics such as diagrams
2. Identifying the main power cable from the other electrical cables (just one sensor provided feedback via an LED indicator that the correct cable had been picked out) and
3. Navigating the menu options and entering tariff information (Fig. 3).

3.2.2. Automated energy systems

Six high level tasks were identified for the Lightwave Link (hub), once again beginning with opening the packaging and reading the instructions through to downloading the Lightwave App from the web and following the instructions to configure the settings. An

Fig. 3. Participants struggled to find and enter their tariff information on the information display.
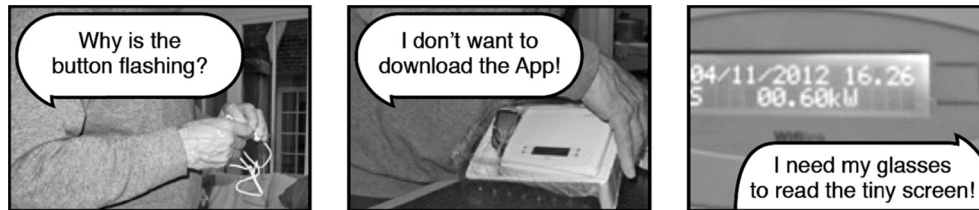

Fig. 4. Information provided on the in-home displays was typically not large enough to read comfortably.

additional eight high level tasks were identified to set up the Lightwave energy monitor. The main difference compared to the standard monitors is that the information is presented on the Lightwave Link or via the App. The high level task analysis starts with opening the packaging and reading the instructions, through to pairing the transmitter with the Lightwave Link and opening the App to enter the tariff. Five high level tasks were needed to install the remote controlled dimmable light bulb, again, beginning with opening the packaging and reading the instructions through to quickly turning the light switch on and off four times to put it into 'learning mode' and configuring the App settings to dim the light bulb. The high level task analyses are also shown in Fig. 1.

The automated energy product/scenario walkthroughs revealed the main physical challenges to be:

1. Accessing the electricity meter if it is mounted in a hard-to-reach location
2. Viewing the information on the Lightwave Link as the display is very small, not much bigger than a matchbox (Fig. 4) and
3. Turning the light switch on and off quickly enough to initiate the set up process.

The main cognitive challenges were:

1. Accessing and identifying the main power cable from the other electrical cables (Fig. 5)
2. For people unfamiliar with pairing devices, pairing the transmitter with the Lightwave Link and
3. Downloading the App and configuring the settings.

Seven high level tasks were associated with the 'out of box' experience of the EnergyEGG (Fig. 1) beginning with opening the packaging and reading the instructions through to plugging an appliance into an adaptor (itself plugged into an electrical socket) and turning the dial to set the timer for when appliances are automatically turned off.

The EnergyEGG product/scenario walkthroughs showed that the main physical challenges were:

1. Reading the timer dial, which is printed in small size text and
2. Gripping and turning the timer dial due to its small size and placement in a cone-shaped cavity (Fig. 6).

The main cognitive challenge was linking the EnergyEGG with the adaptor.

Five high level tasks were associated with the Salus thermostat (Fig. 1) beginning with opening the packaging and seeking professional advice (e.g. from an electrician) if unsure how to install it, followed by pairing the Receiver (heat on/off control) and the Control Centre (user interface and temperature sensing) devices. Other tasks included using the touch ring and buttons on the Control Centre to display and change the current set temperature and other settings.

The Salus product/scenario walkthroughs revealed the main physical challenges to be:

1. Reading the small-sized icons and
2. Easily moving the Control Centre from one room to another as it is screwed into the wall.

The main cognitive challenges to emerge were:

1. Comprehension of the electrical wiring instructions to install the thermostat
2. For people with no prior knowledge with pairing devices, pairing the Receiver with the Control Centre and
3. For people unfamiliar with touch screen technology, learning how to use the touch ring to configure and adjust the settings (Fig. 7).

3.3. Issues discovered via methods toolkit

3.3.1. Overview of findings
Issues raised by the initial product walkthrough were further developed by applying the toolkit approach. Table 3 presents a summary of what methods were applied to what products to what end.

3.4. Common behavioural and usability problems

As revealed by the product walkthrough, specific difficulties participants encountered were reading the set-up instructions because the text size was too small, and understanding the instructions, which were often perceived as overwhelming and complex particularly when presented as a large fold out sheet of

Fig. 5. A very common challenge was ease of access to the electricity meter and identifying the correct cable to clamp the sensor onto.
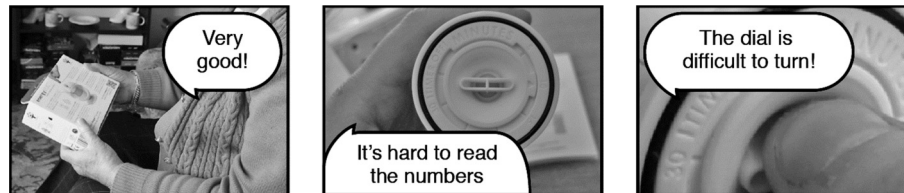

Fig. 6. EnergyEGG was attractively packaged and easy to unpack but the timer dial was difficult for the elderly participants to read and adjust.
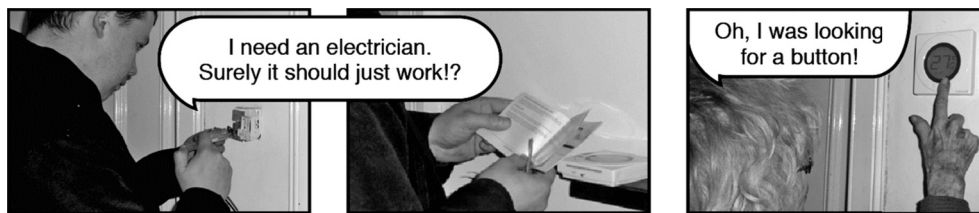

Fig. 7. Installing the Salus thermostat was particularly challenging. Configuring and adjusting the settings was more straightforward once the touch ring was learned.

paper. One participant commented, "I don't know that I can be bothered to read this! It's so long and the words are so tiny." Another participant exclaimed, "The instructions are like reading a novel!" A single product included 'quick start' instructions, which were considered helpful. Other common difficulties included removing products from shrink-wrapped packaging, often requiring a knife or scissors, and identifying and making sense of the separate parts (with exception to the single part plug-in energy monitors). One participant was disappointed that a product labelled 'eco' required six disposable batteries and included seven paper booklets.

Most participants had difficulty understanding electricity usage on the information displays, when expressed as kWh or CO_2, a finding reported elsewhere (e.g. Strengers, 2011), and preferred to view their electricity usage in units of cost (£). However, inputting tariff information (electricity pricing), which is necessary for an accurate display of cost, proved particularly problematic. Despite the reforms by UK energy regulator Ofgem to simplify energy tariffs, most people still find their energy bills too complicated to understand (Which?, 2014). Several participants found it interesting to see their real-time consumption jump up and down when particular appliances, such as the kettle, were switched on, although other research has shown that householders often misinterpret the data and wrongly assume that devices causing a sharp spike consume the most electricity in their home over time (Strengers, 2011). Several participants commented that the usefulness of the various displays was limited, as it did not convey whether their level of consumption was normal, or too high or low, nor give appliance-specific feedback. For example, a participant commented, "I don't think looking at our energy total would encourage us to use less, as I do not know what appliance that energy is being used by."

With the exception of the EnergyEGG, which does not include an information display, most participants experienced difficulty reading the displays as well as interpreting the feedback information. The information display on the Lightwave Link (hub) is very small compared to other in-home displays, however, while participants found the text too small and low contrast to read, no one wanted to put in the extra effort to download the App even though this provides much greater depth and clarity of information. One participant complained, "I need my glasses on to read the tiny screen!" but then asked, "I don't want to download the App. Can't I just use this?" All the information displays used a fixed LCD screen with a narrow viewing angle making it hard to read other than in the hand. Only the Lightwave Link and Salus had a backlit display. One participant pointed out, "It's very unlikely that I'll notice what it's telling me as I'm going around doing my day-to-day things." The analysts observed that adjusting the angle to make the display more readable (where possible) was difficult for participants with weak hands due to the stiffness of doing so. One participant commented, "I find the meter in the cupboard easier to read because it ticks faster when it's high and slower when it's low."

Additional issues with the user interface included too small and/or awkward to reach buttons, dials and mechanisms, and button press sequences which were uncomfortable or painful to some participants. For example, some participants found it hard to pinch and rotate the timer dial on the EnergyEGG for turning appliances off when no one is in the room, as the dial itself is short and set into a shallow recess. Also, some participants struggled to set up the remote controlled light bulb from LightwaveRF, which requires deftness in rapidly turning the light switch on and off several times. Participants also complained about button labels with small text size, poor colour contrast, and ambiguous icons. One participant commented, "I don't really know what the earth sign and

Table 3
Summary of usability toolkit results.

Method	LightwaveRF	EnviR	EnergyEGG	Eco-Eye	OWL	Salus	Belkin	Efergy	Energenie	Key Insights
Heuristics	■				■		■			The heuristic approach revealed major problems with opening the packaging including a hurt hand; identifying the power cable connected to the electricity meter; reading the very small information display on the Lightwave Link (hub); and understanding some of the icons.
Immersion Analysis	■							■		Loss of dexterity in the hands and vision impairments were identified as the main issues affecting participants. Simulating these states, e.g. using tape and weights to restrict finger mobility, revealed that the sensor was fiddly and the printed instructions and screen were very difficult to read.
Focus Groups									■	Participants found the viewing angle of the monitor too narrow—they needed to continually adjust it to see the information clearly. They also found the units of electricity usage too abstract i.e. was their level of consumption normal or too high, and they were not interested in usage expressed as CO_2.
Semi-Structured Interviews	■								■	A key theme from the interviews was a lack of trust among participants that home energy saving technology could help them save money, partly due to participants not considering their energy use as wasteful or not seriously considering changes in certain practices such as laundering.
Function Flow Diagrams			■							The diagram highlighted that the EnergyEGG beeps eleven times in the minute before powering off electrical appliances, after which it must be manually turned back on again (timer restarted), which is at odds with the 'set and forget' slogan of the product. High pitched beeps are often not audible to elderly persons.
Abstraction Hierarchy									■	The model of the system helped the analyst prioritise areas for improvement by establishing key values, functions, and processes. E.g. 'enjoyable user experience' was identified as a key value, linked to functions and processes relating to turning off unused appliances.
Microsoft Product Reaction Cards				■					■	The direction of participants' responses to the products was mixed: two products were described entirely using negative words (n=17) with the word 'confusing' selected for both, while the third product was described using mainly using positive words (n=12).
Cambridge Impairment Simulator						■				Filters applied by the analysts to images of the information screens revealed legibility issues for individuals with vision impairments, however, backlighting on the Salus considerably improved legibility by increasing the colour contrast of the information and the background.
Co-Creation/Video Prototypes					■					Participants' feedback on initial design concepts highlighted their preference for a larger information display because the text and graphics can be read more comfortably, big buttons, and electricity usage expressed only in units of cost (£).
Photo Diary							■			Participants' photographs revealed they were interested in and surprised by their electricity usage across a range of appliances, and only viewed their usage in units of cost (£). A frustration was not being able to monitor radiators and ceiling lighting.
Design With Intent Toolkit									■	The cards inspired solutions for identified opportunities such as angling the screen to make the information easier to read and at a glance; and repositioning, resizing, and increasing the number of buttons (one button per function) to make them more comfortable to use and less confusing.

lightening sign mean, even though I've pressed them" and, "I've got to get the glasses on for these small buttons."

3.4.1. Specific problems with the energy monitors

Many of the elderly participants expressed strong reservations about tampering with their electricity meter to install an energy monitor, for fear of accidental damage or receiving an electric shock. One participant commented, "All the external wiring is covered. I'm a bit anxious about taking the covering off." Another participant, while pointing at the tight packing of their meter box commented, "It's a bit worrying jamming my fingers in here with all these wires and warnings." Also, where the box is situated outside the home, participants did not consider it to be their property to access. Most people had difficulty identifying the electricity supply cable and attaching the sensor. Indeed, a study of finger pinch strength found that handgrip strength of elderly males and females in the study (defined as 60–89 years old) was 60% and 68% that of the adult males and females (defined as 18–40 years old), and that pinch strength also decreased from the adult to elderly age group (Imrhan and Loo, 1989). In mitigation, energy suppliers are required to install smart meters—the next generation gas and electricity meters—in all UK homes by 2020 and some will offer consumers an in-home display, potentially solving these installation issues. Similar rollouts are underway worldwide.

Installing the plug-in energy monitors was found to be much simpler because they did not incorporate a sensor or transmitter. One participant commented, "It's similar to my travel adaptor plug" highlighting the value of taking design cues from technologies that people are already familiar with. The analysts had surmised that the Energenie monitor was too large, but participant feedback suggested that it was a comfortable size to hold, although participants did find it fiddly to insert the batteries. Explains one participant, "The bigger the better! I like to have big telephones, TV remotes and calculators despite what the grandkids think!" A few participants were further confused how to orientate the device, with one asking, "Which way up does it sit?"

3.4.2. Specific problems with the automated energy systems

Some participants found the beeping and flashing light on the EnergyEGG, which warns that appliances are about to be turned off, excessive and distracting to the point of re-entering the room to see what was happening. The analysts also encountered mistrust by participants over switches remaining in the ON position when automatically turned off. Indeed, several participants commented that they habitually turn appliances off when not in use, or use light timers, and so do not need or want to invest in automated systems. One participant stressed the importance of keeping mobile, commenting, "I wouldn't want to be able to control lights and plugs without getting up. It just seems lazy and it is important to keep moving at this age." The need for one controller per dimmable light bulb for the LightwaveRF system was criticised by a participant who commented, "I do like the brightness control, but not the idea of having lots of controls around the house."

3.5. Product design solutions

The results of the analysis were translated into practical design principles against which future products targeted at the elderly can

Table 4
Key usability issues and examples of user-centred design concepts generated by the analysts.

Key Problems	Design Principles	Design Concept Examples
Opening shrink-wrapped packaging.	Environmentally responsible and easy to open packaging.	n/a
Identifying the power cable connected to the electricity meter and attaching the sensor.	Safe and easy installation for someone with no technical background.	Redesigned sensor clip: a combined clip and transmitter simplifies the set-up process by removing a key step; a thinner profile makes it easier to manoeuver between cables; the addition of levers and a spring-loaded open/close mechanism makes it easier to open the sensor clip and attach it to the power cable; and audio and visual feedback indicates that the correct wire has been picked out.
Reading and understanding instructions with a large volume of small sized text and few information graphics.	Clear, illustrated, step-by-step instructions (which are large enough to be read by the target user).	Redesigned setup instructions: a software wizard presents a sequence of dialog boxes on the in-home display that leads the user through a series of well-defined, illustrated steps to set up the product; a larger size text improves the readability of the instructions.
Pairing or linking devices, where no prior experience can be drawn upon.	Pre-paired and pre-linked devices where possible. Devices that 'just work'.	Redesigned linking of devices: supplying devices that are already paired or linked simplifies the process of installation by removing a key step that can be especially problematic for people unfamiliar with pairing devices.
Interpreting ambiguous icons and needing to put on spectacles to read user interface elements.	Large, readable text and graphics, and intuitive icons.	Redesigned user interface: a larger screen improves the legibility of text and graphics; extra large numbers (displaying the cost of energy usage) are easy to read from a distance; larger buttons reduces the risk of pressing surrounding buttons; and adding labels to icons avoids ambiguity.
Understanding electricity usage when expressed as kWh or CO₂ and inputting tariff information.	Contextualised information, with helpful guidance on where to find the required tariffs and/or other meaningful measures that people could use 'out of the box'.	Redesigned usage feedback: in this concept householders' energy usage is related to the state of a flower—if the flower is flourishing then energy usage is normal, conversely if the flower is languishing then energy usage is too high. Here, the form of the object itself is an interface giving feedback, which might also motivate conservation behaviour (taking care of the flower).
Operating small and awkward to reach controls.	Comfortable to use buttons, dials and mechanisms.	Redesigned timer dial: a rotating base mechanism makes it easier to grip and turn the timer dial; learning time is decreased by taking design cues (a simple twist action) from a familiar product—an egg timer; and larger size text with increased colour contrast (black on white) improves the readability of the time intervals.
Reading fixed LCD screens with narrow viewing angles and no backlighting.	Noticeable, backlit information display that is large enough to read.	Redesigned screen: an adjustable and backlit screen, with larger size text, makes it easier to situate the device so that the information can be glanced at and quickly read, particularly useful for awkwardly located electrical sockets.
Understanding visually busy information displays.	Clear, uncluttered user interface.	Redesigned user interface: a greatly simplified screen showing a smiley or frowning face, on a green or red colour background respectively, makes it easier for householders to understand at a glance whether their current energy usage is normal or too high; pressing the single button gives more detailed information.
Distracting beeping sounds and flashing lights.	Options for setting audio and visual alerts.	Redesigned alerts: options for setting the timing of alerts enable householders to schedule when information, such as energy usage and energy saving tips, pops up on the bottom of their television screen, as the in-home display; and larger size text improves the readability of the alerts.

be easily evaluated, or against which new functional requirements can be developed. More fundamentally, the design principles express a holistic 'design thinking' approach by synthesising the inputs of multi-stakeholders (and multi-methods) and their collaborative exploration of viable solutions. Brown (2008) defines design thinking as, "a human-centred, creative, iterative and practical approach" to address the complex issues facing society today, of which ageing populations, fuel poverty and end-user energy reductions are a prime example. The approach has gained prominence in the business and management spheres since the 1990s as a way of supporting competitiveness and innovation (Martin, 2009; Verganti, 2013; D'Ippolito, 2014). Davis et al. (2016) identified design thinking as having an enabling function in the innovation process by supporting spaces for knowledge creation (Nonaka and Konno, 1998), allowing multi-stakeholders to explore diverse perspectives in a respectful and productive environment,

removing barriers to engagement and stimulating co-created outputs. It also represents a way in which applied ergonomics insights and methods could be leveraged for even greater impact. The principles developed in this paper are an expression of this design thinking and enable us to drive out a number of illustrative design concepts, all of which are shown in Table 4.

4. Conclusions

From the results of this study it seems, sadly, that we are no further forward than Gardner, Powell and Page's study conducted in 1993. Like this previous study we too conclude that "many of these products were inappropriate or inadequate to perform the tasks for which they were intended." (Gardner et al., 1993, p.35). It is important to note that this sample of products were chosen on a purely opportunity basis from normal retailers. They are not representative of specially selected 'worst case' examples; they are simply a broad cross-section of energy saving products available for elderly people to purchase at the current time. As a representative cross section of the product market there are clear usability issues. In fact, these usability issues are so acute that in many cases they prevent these products from successfully accessing an important target demographic and giving rise to the beneficial energy saving and fuel poverty outcomes for which they are designed. It is a sad state of affairs that despite half a century of Applied Ergonomics practice, and the widespread availability of practical methods with which to make progress on these issues, that we have to conclude so negatively. It is hoped that such a conclusion will provide impetus for the home energy sector to take advantage of applied ergonomic insights and improve this situation: to the sector's benefit as well as the end-user's.

On a more positive note it has been possible to show how ergonomic principles can be made easily manifest in this class of product. Indeed, like many other similar problems the ergonomic insights required to deliver potentially a step change in the user experience, and in doing so realising the benefits of reduced fuel poverty and energy usage, are neither significant nor substantial. Indeed, they are expressive of a broader sociotechnical principle of design which states that, currently, we have complex products that, in reality, only permit users to do simple or arbitrary tasks. The reverse situation should be the goal: simple, usable products that allow people to do complex, real-life tasks. The design principles presented in this paper aim to collect these long standing and 'non-controversial' ergonomic insights into one place. The aim is to help the practitioner translate the underlying research into high quality design-engineering solutions for subsequent testing. In a manner of speaking, to help shortcut the design process by arriving at candidate solutions, which are defensible based on the underlying science and evidence-base, more quickly.

Looking to the future it is clear the market for home energy products will continue to grow. Whether it will continue to fail in understanding a core user-group depends largely on the extent to which user-centred insights are given the prominence they clearly warrant. It appears that despite a large body of confounding evidence the (often tacit) assumptions contained in the Information-Deficit Model persist. Many of the sampled products present a larger quantity of information that users have difficulty accessing, understanding, and/or translating into useful behaviour. The mass market is being badly served. The work of this paper, and project APAtSCHE that it supports, focusses specifically on the aging population demographic. It continues to work on understanding their attitudes to home energy control and what constitutes, in practice, good user-centred design. It is this group, and the varied lifestyles that it contains, who will play an increasingly important role in the energy sector as more responsibility for energy management is passed to the consumer.

References

Belkin, 2013. Belkin Conserve Insight Energy Use Monitor [WWW Document]. http://www.belkin.com/conserve/insight/ (Accessed 15 October 2015).

Benedek, J., Miner, T., 2002. Measuring desirability: new methods for evaluating desirability in a usability lab setting. In: Proc. UPA, vol. 2002.

Brown, T., 2008. Design thinking. Harv. Bus. Rev. 86 (6), 84—92.

Cambridge EDC, n.d. Cambridge Engineering Design Centre [WWW Document]. URL https://www-edc.eng.cam.ac.uk/(Accessed 31 October 2015).

Clarkson, P.J., Coleman, R., 2015. History of inclusive design in the UK. Appl. Ergon. 46, 235—247.

Current Cost, 2008. Current Cost EnviR [WWW Document]. http://www.currentcost.com/ (Accessed 15 October 2015).

Darby, S., 2006. The Effectiveness of Feedback on Energy Consumption a Review for Defra of the Literature on Metering, Billing and Direct Displays [WWW Document]. http://www.eci.ox.ac.uk/research/energy/downloads/smart-metering-report.pdf (Accessed 15 October 2015).

Darby, S., 2010. Smart metering: what potential for householder engagement? Build. Res. Inf. 38, 442—457. http://dx.doi.org/10.1080/09613218.2010.492660.

John, Davis, Docherty, Catherine Ann, Dowling, Kate, 2016. Design thinking and innovation: synthesising concepts of knowledge Co-creation in spaces of professional development. Des. J. 19 (1), 117—139.

Department of Energy & Climate Change, 2014. Annual Fuel Poverty Statistics Report, 2014 [WWW Document]. https://www.gov.uk/government/statistics/annual-fuel-poverty-statistics-report-2014 (Accessed 15 October 2015).

D'Ippolito, B., 2014. The importance of design for firms' competitiveness: a review of the literature'. Technovation 34 (11), 716—730.

Eco-Eye, n.d. Eco-Eye Elite 2 [WWW Document]. URL http://www.eco-eye.com/product-monitor-elite (Accessed 15 October 2015a).

Eco-Eye, n.d. Eco-Eye Mini 2 [WWW Document]. URL http://www.eco-eye.com/product-monitor-mini (Accessed 15 October 2015b).

Efergy, n.d. Efergy e2 Classic 2.0 [WWW Document]. URL http://efergy.com/eu/e2v2-monitor (Accessed 15 October 2015a).

Efergy, n.d. Efergy Elite Classic [WWW Document]. URL http://efergy.com/uk/products/electricity-monitors/elite-classic (Accessed 15 October 2015b).

Energenie, n.d. Energenie Energy Saving Power Meter [WWW Document]. URL https://energenie4u.co.uk/index.php/catalogue/product/ENER007 (Accessed 15 October 2015).

Energy Saving Trust, n.d. Home Energy Scotland [WWW Document]. URL http://www.energysavingtrust.org.uk/home-energy-scotland (Accessed 20 November 2015).

EnergyEGG, n.d. energyEGG [WWW Document]. URL http://energy-egg.com/the-energyegg/(Accessed 15 October 2015).

EPSRC, 2014. Aging Population Attitudes to Sensor Controlled Home Energy [WWW Document]. http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/K002708/1 (Accessed 15 October 2015).

Gardner, L., Powell, L., Page, M., 1993. An appraisal of a selection of products currently available to older consumers. Appl. Ergon. 24, 35—39. http://dx.doi.org/10.1016/0003-6870(93)90158-6.

GOV.UK, 2015. Smart Meters [WWW Document]. https://www.gov.uk/smart-meters (Accessed 20 November 2015).

Gram-Hanssen, K., 2008. Consuming technologies — developing routines. J. Clean. Prod. 16, 1181—1189. http://dx.doi.org/10.1016/j.jclepro.2007.08.006.

Hanington, B., Martin, B., 2012. Universal methods of design: 100 ways to research complex problems, develop innovative ideas, and design effective solutions. Rockport Publishers. http://dx.doi.org/10.5860/CHOICE.49-5403.

Hargreaves, T., Nye, M., Burgess, J., 2010. Making energy visible: a qualitative field study of how householders interact with feedback from smart energy monitors. Energy Policy 38, 6111—6119. http://dx.doi.org/10.1016/j.enpol.2010.05.068.

Imrhan, S.N., Loo, C.H., 1989. Trends in finger pinch strength in children, adults, and the elderly. Hum. Factors 31, 689—701. http://dx.doi.org/10.1016/0003-6870(91)90177-J.

Kahneman, D., 2011. Thinking, Fast and Slow. Penguin, London.

Kempton, W., 1986. Two theories of home heat control. Cogn. Sci. 10, 75—90. http://dx.doi.org/10.1207/s15516709cog1001_3.

Kirwan, B., Ainsworth, L.K., 1992. A Guide to Task Analysis: the Task Analysis Working Group. CRC press.

Koehler, C., Ziebart, B.D., Mankoff, J., Dey, A.K., 2013. TherML. In: Proc. UbiComp, vol. 2013, pp. 103—112. http://dx.doi.org/10.1145/2493432.2493441.

Langford, J., McDonagh, D., 2002. What can focus groups offer us?. In: Contemporary Ergonomics 2002. CRC Press, pp. 502—506.

LightwaveRF, n.d. LightwaveRF [WWW Document]. URL http://www.lightwaverf.com/(Accessed 15 October 2015).

Lockton, D., Harrison, D., Stanton, N.A., 2010. The Design with Intent Method: a design tool for influencing user behaviour. Appl. Ergon. 41, 382–392. http://dx.doi.org/10.1016/j.apergo.2009.09.001.

Martin, R., 2009. The Design of Business: Why Design Thinking Is the Next Competitive Advantage. Harvard Business Press, Boston, MA.

Naikar, N., 2013. Work Domain Analysis: Concepts, Guidelines, and Cases. CRC Press.

Nonaka, I., Konno, N., 1998. The concept of "ba": building a foundation for knowledge creation. Calif. Manag. Rev. 40 (3), 40–54.

Norman, D., 1988. The Psychology of Everyday Things. Basic Books. http://dx.doi.org/10.2307/1423268.

Ofgem, 2015. Energy Company Obligation 2015–17 (ECO2) Guidance: Delivery [WWW Document]. https://www.ofgem.gov.uk/publications-and-updates/energy-company-obligation-2015-17-eco2-guidance-delivery (Accessed 15 October 2015).

OWL, n.d. OWL Micro + [WWW Document]. URL http://www.theowl.com/index.php?cID=185 (Accessed 15 October 2015b).

OWL, n.d. OWL + USB [WWW Document]. URL http://www.theowl.com/index.php/energy-monitors/standalone-monitors/owl-usb/ (Accessed 15 October 2015a).

Peffer, T., Pritoni, M., Meier, A., Aragon, C., Perry, D., 2011. How people use thermostats in homes: a review. Build. Environ. 46, 2529–2541. http://dx.doi.org/10.1016/j.buildenv.2011.06.002.

Pierce, J., Fan, C., Lomas, D., Marcu, G., Paulos, E., 2010. Some consideration on the (in)effectiveness of residential energy feedback systems. In: Proc. DIS, vol. 2010, pp. 244–247. http://dx.doi.org/10.1145/1858171.1858215.

Revell, K.M., Stanton, N.A., 2014. Case studies of mental models in home heat control: searching for feedback, valve, timer and switch theories. Appl. Ergon. 45, 363–378. http://dx.doi.org/10.1016/j.apergo.2013.05.001.

Revell, K.M., Stanton, N.A., 2015. When energy saving advice leads to more, rather than less, consumption. Int. J. Sustain. Energy 1–19. http://dx.doi.org/10.1080/14786451.2014.999071.

Rubens, S., Knowles, J., 2013. What People Want from Their Heating Controls: a Qualitative Study. A report to the Department for Energy and Climate Change. New experience. DECC, London.

Salus, n.d. ST320 S-Series Digital Thermostat [WWW Document]. URL http://www.salus-controls.com/products/thermostat/digital-thermostat/_c1_20_sseries-digital-thermostat/(Accessed 15 October 2015).

Sauer, J., Wiese, B.S., Rüttinger, B., 2004. Ecological performance of electrical consumer products: the influence of automation and information-based measures. Appl. Ergon. 35, 37–47. http://dx.doi.org/10.1016/j.apergo.2003.09.001.

Scott, J., Bernheim Brush, A.J., Krumm, J., Meyers, B., Hazas, M., Hodges, S., Villar, N., 2011. PreHeat. In: Proc. UbiComp, vol. 2011, pp. 281–290. http://dx.doi.org/10.1145/2030112.2030151.

Scottish Government, 2008a. Home Energy Efficiency Programmes for Scotland. n.d. [WWW Document]. http://www.gov.scot/Topics/Built-Environment/Housing/warmhomes/eap (Accessed 15 October 2015).

Scottish Government, 2008b. Scottish Government's Fuel Poverty Policy. n.d. [WWW Document]. http://www.gov.scot/Topics/Built-Environment/Housing/warmhomes/fuelpoverty (Accessed 15 October 2015).

Shipworth, M., 2011. Thermostat settings in English houses: No evidence of change between 1984 and 2007. Build. Environ. 46 (3), 635–642.

Shipworth, M., Firth, S.K., Gentry, M.I., Wright, A.J., Shipworth, D.T., Lomas, K.J., 2010. Central heating thermostat settings and timing: building demographics. Build. Res. Inf. 38, 50–69. http://dx.doi.org/10.1080/09613210903263007.

Shove, E., 2004. Sustainability, System Innovation and the Laundry. System Innovation and the Transition to Sustainability: Theory, Evidence and Policy, pp. 76–94.

Snow, S., Buys, L., Roe, P., Brereton, M., 2013. Curiosity to cupboard. Proc. OzCHI 2013, 245–254. http://dx.doi.org/10.1145/2541016.2541025.

Stanton, N.A., Salmon, P.M., Rafferty, L., Walker, G.H., Baber, C., Jenkins, D.P., 2013. Human Factors Methods: a Practical Guide for Engineering and Design, second ed. Ashgate, Farnham, UK.

Stanton, N.A., Young, M.S., 1999. What price ergonomics? Nature 399 (6733), 197–198.

Strengers, Y., 2008. Smart metering demand management programs. In: Proc. OZCHI, vol. 2008, pp. 9–16. http://dx.doi.org/10.1145/1517744.1517747.

Strengers, Y., 2011. Designing eco-feedback systems for everyday life. Proc. CHI 2011, 2135–2144. http://dx.doi.org/10.1145/1978942.1979252.

Verganti, R., 2013. Design Driven Innovation: Changing the Rules of Competition by Radically Innovating what Things Mean. Harvard Business Press.

Vicente, K.J., 1999. Cognitive Work Analysis: toward Safe, Productive, and Healthy Computer-based Work. CRC Press.

Which?, 2014. "Simplified" energy tariffs still too confusing. n.d. [WWW Document]. http://press.which.co.uk/whichpressreleases/simplified-energy-tariffs-still-too-confusing/ (Accessed 15 October 2015).

Yang, R., Newman, M.W., Forlizzi, J., 2014. Making sustainability sustainable. In: Proc. CHI, vol. 2014, pp. 823–832. http://dx.doi.org/10.1145/2556288.2557380.