User-centred improvements to energy efficiency products and renewable energy systems: research on household adoption and use

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USER-CENTRED IMPROVEMENTS TO ENERGY EFFICIENCY PRODUCTS AND RENEWABLE ENERGY SYSTEMS: RESEARCH ON HOUSEHOLD ADOPTION AND USE

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ABSTRACT

The development and rapid consumer adoption of energy efficiency products and renewable energy systems are key elements of UK and EU carbon reduction strategies to meet the challenge of climate change. Many such technologies are available for domestic use, but despite government incentives to meet carbon reduction targets consumer adoption has been slow. This Open University research with 111 in-depth interviews plus an on-line survey with nearly 400 responses, investigates consumer adoption, non-adoption and use of these technologies. Results show it is important to research consumer use experiences, problems and requirements when designing and developing 'green' technologies. With results tailored to each technology, this study shows that user-centred improvements are required to improve functionality, ergonomics, interconnectedness with other systems and symbolic value, and to reduce cost and payback. User-centred research supports new product/system design and development to promote more rapid adoption and carbon-saving use of energy efficient and renewable technologies in homes

Keywords: energy efficiency, renewable energy, consumer surveys, user-centred design and marketing.

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ABSTRACT

The development and rapid consumer adoption of energy efficiency products and renewable energy systems are key elements of UK and EU carbon reduction strategies to meet the challenge of climate change. Many such technologies are available for domestic use, but despite government incentives to meet carbon reduction targets consumer adoption has been slow. This Open University research with 111 in-depth interviews plus an on-line survey with nearly 400 responses, investigates consumer adoption, non-adoption and use of these technologies. Results show it is important to research consumer use experiences, problems and requirements when designing and developing ‘green’ technologies. With results tailored to each technology, this study shows that user-centred improvements are required to improve functionality, ergonomics, interconnectedness with other systems and symbolic value, and to reduce cost and payback. User-centred research supports new product/system design and development to promote more rapid adoption and carbon-saving use of energy efficient and renewable technologies in homes.

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INTRODUCTION

In order to tackle climate change, in the 2008 Climate Change Bill the UK Government set a binding target of reducing the nation's carbon emissions by 26% to 32% by 2020 and by 60% from their 1990 levels by 2050, and is expected to exceed its Kyoto Protocol commitment to reduce greenhouse gas emissions by 12.5% between 2008 and 2012 (DTI, 2006a; House of Lords, 2008). The development and rapid consumer adoption of energy efficiency products and renewable energy systems together with the construction of energy efficient and zero carbon new housing, are key elements of the Government's strategy to reduce the 28% of UK carbon emissions from homes (H.M. Treasury, 2005; DTI, 2007).

This is the context for considering the importance of user research and user-centred innovation in domestic energy efficiency products, such as home insulation, heating controls and energy-efficient lighting and renewable energy technologies, including solar thermal systems, micro-wind turbines, solar photovoltaics (PV) and wood-fuelled stoves. Consumer adoption of these products and systems in the UK has been slow. For example, about 60% of 25 million existing UK homes could benefit from new or increased loft insulation to the 270mm thickness required for new dwellings, which would save an estimated 1.28m tonnes carbon per year (DTI, 2005). Another indicator is the UK's low share of the total European market for newly installed solar hot water and heating systems, which in 2006 was only 2%, while Germany had a 50% share, Austria 10%, Greece 8%, and France 7% (ESTIF, 2006). More generally, it is estimated that the UK market for domestic low carbon and renewable energy technologies could reach 9 million installations by 2020 with an ambitious policy support framework, although by 2007 there were only an estimated 95,000-98,000 such household installations (Element Energy, 2008). Most of these installations (90,000) were solar thermal water heating systems, although this represents a tiny fraction of the potential 19 million suitable UK homes (DTI, 2006b). If solar water heating systems were installed in all suitable UK homes, and provided about 50% of a household's annual hot water demand, this would save an estimated 1.7m tonnes carbon per year (DCLG, 2006).

Existing research on energy efficiency and renewables, especially research conducted on behalf of the UK government, has tended to focus on addressing the financial, regulatory and informational drivers and barriers to household adoption (See Caird, Roy *et al,* 2007a, 2007b). Improvements in the energy performance of products and systems that have taken place during the past decade have therefore been driven mainly by regulation and information, such as EU energy labelling of lighting and appliances. This narrow view of the factors influencing adoption and use of these technologies is partially explained by the dominance of a techno-centric model of innovation that assumes that consumers are rational decision-makers who will adopt these products and systems and use them effectively once they become aware of their environmental and money saving benefits. However, there is a body of sociological and anthropological research (e.g. Veitch and Gifford, 1996; Shove, 1998; Guy and Shove, 2000; Wilhite, 2007) which suggests that peoples' motivations and actions on energy use are more complex than suggested by a rational model of decision-making based on information, regulations and economics. For example, householders who install solar water heating or other renewables often do so for non-economic reasons, given that the likely payback period may be longer than the expected system life. As a report on *Local Energy* from the House of Commons Trade and Industry Committee observed,

"*…most households that have purchased solar panels or wind turbines have tended to be early adopters who are not necessarily motivated by a rational cost benefit-analysis…. They are instead motivated by other factors. For example, they may be technology enthusiasts who are keen to own the latest environmental innovation....*"
(House of Commons, 2007 p. 29).

Another factor in the slow take-up of energy efficiency products and renewable energy systems, especially beyond the enthusiast early adopters, is that often they have been designed and installed without taking sufficient account of user requirements and usability – that is the ease, safety and satisfaction with which they may be used by different consumers (See Hirai et *al*, 2007). These products and systems tend to be viewed by manufacturers, installers and policy-makers as purely functional, energy saving devices, without sufficient regard for their compatibility with existing buildings and household systems, ergonomic design, aesthetics and symbolic value. For example, compact fluorescent lamps (CFLs) have taken many years to achieve only limited penetration into UK homes, even when subsidised to reduce their purchase price. This appears to be because of issues such as their size and shape, incompatibility with existing light fittings and colour temperature compared to conventional incandescent light bulbs. Designers and manufacturers need to address product compatibility and usability issues, as well as conventional price and promotional strategies to reach beyond early adopters into the wider market (See Matzler and Hinterhuber, 1998).

Understanding the ways people actually use energy efficiency products and renewable energy systems is also important because savings in energy and emissions is not guaranteed by their adoption. Consumers often cancel out the carbon saving benefits by increasing consumption or because they lack understanding, experience problems in use, find it difficult to make adjustments in their lifestyle, or simply do not use the technologies as expected. Many people, for example, waste fuel because they fail to understand, or could not be bothered with central heating controls, such as thermostatic radiator valves or central heating programmers (MTP, 2004). Users of compact fluorescent lamps (CFLs) may leave them switched on longer because of their lower running costs, slower warm-up time or fears of shortening life, or install additional lighting in the home or the garden because it is energy efficient. There may also be effects, such as taking some or all of the benefits of home insulation in higher room temperatures. Such 'rebound' effects reduce the effectiveness of energy efficiency and renewable technologies in saving energy and reducing emissions (Herring, 2005).

There has been little user-centred research on the factors influencing adoption and use of energy efficiency products and renewable energy systems and their importance for product design. The design of these systems largely reflect a regulation-driven, techno-centric model of innovation that contrasts with Von Hippel's user-centred innovation process where users may be the source of, and sometimes the first to develop new products or systems (Von Hippel, 2005). '*Does the engineer forget the user?*' asks Knut Holt, arguing that users are often neglected in engineering product design when close user/developer interactions lead to a higher probability of successful product development and diffusion (Holt, 1989).

New management approaches to product development recognise the importance of the customer and user for innovation success and attempt to integrate the rich resource of consumer know-how and feedback, as co-designers, innovators and users (Abramovichi and Schulte, 2007). For example, Luthje found that a third of end users of consumer sports goods had generated ideas for new and improved products, while 9% had gone so far as building prototypes (Luthje, 2004). More typical 'passive' consumers can also provide useful information on typical user requirements and product usability.

In order to draw on the knowledge of both passive and more expert users, a project by the Open University Design Innovation Group surveyed the views of consumers who had adopted and were using, or had considered but decided against adopting, four established energy efficiency products (loft insulation, condensing boilers, heating controls, and energy-efficient lighting) and four renewable energy systems (solar water heating, solar photovoltaics, micro-wind turbines and wood-burning stoves). We considered that consumer decisions about the adoption of technologies whose function is improving energy efficiency, such as loft insulation, may differ from those also involving user interaction, such as heating controls, or are part of interior design, such as lighting (Stokes *et al.*, 2006), or those with symbolic or status value such as solar energy systems (SEA/RENUE, 2005). The research investigated the experience of adoption, non-adoption and actual use of household energy efficiency products and renewable energy systems and identified users design requirements and ideas for improving these products and systems. Our findings set challenges for designers, marketers and manufacturers to develop more user-friendly and desirable products and systems that can be used to deliver the expected carbon reductions and fuel bill savings, and appeal to wider consumer markets.

Aims and research questions

The main questions addressed in the project were:

1. What contribution does research with adopters, non-adopters and users of energy efficiency products and renewable energy systems offer user-centred design of these technologies for household use?
2. What factors influence consumer adoption and non-adoption of energy efficiency products and renewable energy systems?
3. What experiences do users of energy efficiency products and renewable energy systems have during installation and use, including problems, benefits and rebound effects?
4. What ideas for improvements to, or innovations in, energy efficiency products and renewable energy systems would make them more desirable to consumers and effective in reducing carbon emissions?
5. What actions by designers and manufacturers would promote the development of more user-centred energy efficiency products and renewable energy systems?

METHODOLOGY

Many methods are available to research user requirements and usability, including systematic methods for working with users to gather explicit and latent information, ranging from user interviews and questionnaires to focus groups and participant observation studies (See Hirai et al, 2007). Given the range of technologies concerned, from simple home insulation products to domestic renewable energy systems, it was not possible within the time-scale of the project to employ user-centred design techniques such as consumer evaluations of simulations, mock-ups or prototypes, and observation of the products or systems in use. It was also beyond the project's scope to employ organisational methodologies for developing new products or evaluating particular manufactured brands, such as Quality Function Deployment and Kano's model of customer satisfaction (Matzler and Hinterbuber, 1998). Instead a two stage survey approach was used, based on methods employed for user needs assessment for product development and innovation (Holt 1989).

Exploratory study and Research Model

An exploratory study was first conducted comprising a literature review, fourteen pilot interviews with volunteer consumers, plus a survey of 50 energy professionals, who specify or offer advice on energy technologies, such as local authority housing officers, architects and consultants, (conducted via an online energy newsletter). This data was used to identify the many factors influencing consumer adoption and use of domestic energy efficiency and renewables and hence to develop the methodology for the main phase. From the findings of the exploratory study a consumer decision-making model of the adoption and use of energy efficiency products and renewable energy systems was developed (Figure 1). It identified four key groups of variables that influence consumers' adoption decisions and use behaviours:

- The socio-economic context (e.g. fuel prices, regulation);
- Communication sources (e.g. professional, interpersonal);
- Consumer variables (e.g. income, attitudes, lifestyle);
- The properties of the product or system itself (its functional utility, interconnectedness with other systems, symbolic value, and price, after Murphy and Cohen, 2001).

FIGURE 1 HERE

From the pilot interviews different consumer categories were identified and incorporated into the model. These included: 'potential adopters' (i.e. those considering adoption); 'adopters' and 'adopter-users' (those who installed and used energy efficiency products and renewable energy systems); 'non-adopters' (those who considered but decided against adoption); and 'reject-users' (those who rejected a product or system after using it). The exploratory phase confirmed the value of this model for classifying the influences on the adoption and use of different energy efficiency and renewable energy technologies (Roy, Caird and Potter, 2007).

Main study

The model together with the improvement ideas from the exploratory study helped develop the interview schedules and an online questionnaire to survey consumers for the main phase of the research. The online questionnaire was available via the websites of a 2006 BBC TV series on climate change and the Energy Saving Trust, UK and produced 390 responses from consumers who had adopted – or considered but rejected – one or more of the above energy efficiency products and renewable energy systems. This questionnaire was designed to obtain both multiple-choice and open ended responses concerning at least one energy efficiency or renewable energy technology, with questions about the purchase, installation and use experience (e.g. Have you experienced any of the following problems with this technology? What improvements would you ideally like to see to this technology or how it is installed?) and questions about non-adoption of one or more seriously considered but rejected technologies (e.g. What were the main reasons for deciding against installing this technology? What improvements would encourage you to install it?) The survey also included questions on the household and property demographics (e.g. main earner's occupation, environmental attitudes and behaviour, household size, property type, etc.).

The research team also conducted 111 in-depth telephone interviews in 2006, with a different randomly selected group including (a) 83 clients who received advice (between 2004-2005) from two of the UK's network of Energy Efficiency Advice Centres (EEACs) and who adopted, or considered but rejected, one or more of the four chosen energy efficiency measures; (b) 28 people who received advice from a renewable energy charity, the National Energy Foundation, in 2005-6 on solar water heating; about half of whom went on to install a system.

The respondents to the online survey were self-selected and not unexpectedly were 'greener' and from higher socio-economic groups than the UK population as a whole. Most online respondents said that they were concerned about the environment, recycled their household waste and tried to save on energy, water and car use. Of the sample interviewed by telephone, almost all the energy efficiency and solar water heating (SWH) enquirers we contacted agreed to be interviewed. They claimed similar levels of 'greenness' to the online respondents. This is therefore a purposive rather than a representative survey; necessary when investigating the pioneer adopters of innovative technologies such as household renewable energy, and to a lesser extent also for established energy efficiency measures many of which are still at the early adoption stage in the UK

We relied on users' responses and estimates of household energy use rather than objectively measure carbon and fuel bill savings following installation of energy efficiency products and renewable energy technologies. Online survey results were analysed for cross-tabulations and for descriptive statistics using SPSS and Excel software to provide results for use of energy efficiency and renewable technologies generally and for each technology. Interview results were separately analysed using descriptive statistics and qualitative analysis methods, and triangulated with the online survey results to provide an in-depth understanding of experience of using these technologies in the home, together with user-centred improvements.

ENERGY EFFICIENCY TECHNOLOGIES

Nearly three-quarters of our respondents had purchased one or more energy efficient lamps and/or new or replacement heating controls within the past four years. Over half had installed new or top-up loft insulation and about a quarter bought a condensing boiler. Table 1 shows the numbers adopting, and considering but rejecting, the energy efficiency measures we investigated.

Table 1 Adoption and non-adoption of energy efficiency measures

Energy efficiency measures	Adoptions [1]	Non-adoptions
New or additional loft insulation of up to 250mm depth (LI)	229 (59%) 28 interviews	59 (15%) 7 interviews
Central heating timer/programmer (T/P)	286 (73%) 21 interviews (bothT/P, TRV)	13 (3%) 0 interviews
Thermostatic radiator valves (TRVs)	214 (55%) (21 interviews: (both T/P, TRV))	53 (14%) 0 interviews
Condensing central heating boiler (CB)	109 (28%) 7 interviews	97 (25%) 0 interviews
Compact fluorescent lamp(s) (CFLs)	275 (71%) 17 interviews	23 (6%) 3 interviews
Light emitting diode (LED) lighting	28 (7%) 0 interviews	62 (16%) 0 interviews
Total online survey sample [2]	390	390
Number interviews	73	10

Notes: 1 Some multiple adoptions. 2 Percentages are based on total online survey sample (which includes responses for both energy efficiency measures and renewables)

Adoption, use and improvement of energy efficiency technologies

The adopters of energy efficiency measures do so for many reasons; but in the on-line survey the most frequently reasons cited by the adopters of loft insulation, timer/programmers condensing boilers and CFLs were: saving energy; reducing fuel bills and concern for the environment. Loft insulation adopters also wanted a warmer home, while wood-burning stoves were mainly bought by people seeking the pleasure of a real fire. In the following sections, we look in more detail at these technologies, and whether the reasons for adoption were satisfied, together with the barriers to adoption, the benefits and problems experienced by users, and ideas for improving design and development of new energy efficiency products.

Loft insulation

The majority of our on-line survey respondents installed loft insulation (LI) to save energy (84%) and/or fuel bills (81%) and/or to have a warmer home (77%). Over two thirds (68%) also responded that they installed LI to reduce environmental impacts; a driver reflecting this group's green attitudes. The interview sample was less green, most installing LI to save money and for warmth, with only 21% adopting for environmental reasons. Other reasons for adoption were that loft insulation is a zero maintenance product (35%), can be installed as a do-it-yourself job (30%) and/or as part of other home improvements (23%).

Fewer were satisfied that they achieved their initial objectives after installation, about half (58%) of adopters said the main benefit of loft insulation was a warmer house, while less than a third said they also had lower fuel bills (29%) and/or energy consumption (31%). These results may typify the well-known 'rebound effect' of home insulation, where adopters take some or all the benefit in higher room temperatures, heating more of the house or for longer periods, resulting in less than expected fuel savings.

Relatively few on-line respondents (15%) seriously considered but rejected loft insulation, mainly because of losing loft storage space (37% of non-adopters), a barrier to do with the interconnectedness of insulation with other building elements. 10% of users complained about the loss of storage space in their loft as a result of installing insulation and this has led some to remove insulation or compress it under boarding. These actions would reduce the energy savings of loft insulation. In the open comments, several respondents were concerned about the irritant effects of the glass or lava fibre normally used for loft insulation, some mentioning their preference for eco-friendly materials that are less problematic for health (such as recycled paper and wool).

Table 2 shows loft insulation improvements that many on-line survey adopters, non-adopters and energy professionals thought were good ideas and would encourage adoption and efficient use of loft space.

Table 2 Loft insulation – improvements considered good ideas/would encourage adoption and efficient use of loft space.

Improvement idea (on-line survey)	*Adopters (%)*	*Non-adopters (%)*	*Energy professionals (%)*
Thinner/less bulky insulation materials	143 (60%)	29 (54%)	45 (90%)
Systems to provide storage space above insulation	93 (39%)	17 (31%)	Some Recommendations
More user and environmentally friendly loft insulation materials	180 (76%)	31 (57%)	Some recommendations
Loft clearance and storage service as part of the installation process.	24%	20%	
N online responses to questions on insulation	237	54	50

Nearly a third of non-adopters would have installed insulation given a better post-insulation storage system. Post-insulation loft storage clearly needs a better solution than those currently available; a professional task of raising the joists and boarding or individual 'bodged' solutions. Some survey respondents suggested the solution concept of a demountable loft storage platform with optional storage boxes. Some solutions e.g. pre-insulated boarding is available to the professional but not the DIY user. Some survey respondents would favour pumping insulation material into spaces under loft boarding (like cavity wall insulation) to avoid the storage problems posed by loft insulation depth. Other worthwhile innovations such as under-floor insulation (for retrofitting in lofts and other areas) remain to be developed.

Most adopters and non-adopters would also like design improvements to insulation materials. Over half of the non-adopters said that non-irritant, eco-friendly and/or higher performance, less bulky insulation materials would have encouraged them to install. Such insulation materials (e.g. Aerogels, multi-layer thermo-reflective sheeting) have been developed but because of their cost and/or performance are not available in UK subsidised schemes. Desirable innovation could thus focus on improvement and cost-reduction of high performance insulation materials.

Central heating controls and condensing boilers

Over 90% of UK homes have central heating, mainly from a gas-fired boiler and radiators plus one or more controls, such as thermostatic radiator valves (TRVs). Under 2005 UK Building Regulations new or replacement boilers must be high efficiency condensing designs, which if installed in 17 million suitable homes would save about 7% of household carbon emissions (DTI, 2005). With increased boiler efficiencies, effective controls are relatively more important. If people used existing controls properly, estimates are that about 3% of UK heating energy consumption could be saved, while installing improved controls could save about 1% of UK household carbon emissions (MTP, 2004).

Most of our on-line respondents installed timer/programmers and/or TRVs to reduce energy consumption (78% and 57% respectively) and/or their fuel bills (74% and 59%). A smaller number (57% and 45%) claimed that they installed these controls to reduce environmental impacts. Condensing boilers were installed for similar reasons – saving energy (77%), money (69%) and/or the environment (60%) – but the main driver was often that an existing boiler needed replacing (60%).

Fewer were satisfied they achieved these objectives after installation. Less than half (about 40%) of the on-line adopters of heating controls and condensing boilers noticed reductions in fuel bills and/or energy consumption. A third noted a warmer house and a quarter (23%) of users admitted they took the main benefit of new controls in additional heating or hot water, suggesting some rebound effects resulting in less than expected fuel savings associated with these technologies.

As condensing boilers are now virtually mandatory in the UK, the barriers to installation since 2005 apply to early replacement of conventional boilers. Unsurprisingly, the majority (70%) of non-adopters of condensing boilers both pre- and post-2005 considered them too expensive. Other deterrents to adoption include the shorter life expectancy of condensing boilers (43%) associated with a reputation for unreliability that affected early designs introduced into the UK.

A few users (9% of on-line heating control adopters) find electromechanical timers fiddly to adjust, others (11%), especially the elderly, find electronic programmers with tiny buttons and LCD displays difficult to see and too complex to understand. One adopter stated '*the digital programmer installed with the condensing boiler is far more complex than others I had. It is difficult to set and not at all logical. I asked my daughters to look at it and they cannot set it either. It has 3 settings for upstairs and downstairs space heating, and another for water heating is difficult to adjust for different seasons'*. Adopters also mentioned difficulties using TRVs with their small markings unrelated to room temperature, which need to be set on each radiator by trial and error. Such problems often mean that controls were rarely adjusted or simply not used.

Experiences with heating controls and condensing boilers suggest some improvement ideas and design challenges. Some professionals agreed that condensing boilers design would be improved if the boiler's working efficiency was displayed (66%), and was easier to service (48%). Nearly half (46%) of non-adopters of condensing boilers would like more durable designs (Table 3). However, this innovation could increase product complexity, and costs. One user suggested installation costs could be reduced with design to evaporate the condensate or design an alternative to the need for an expensive condensate drain.

Table 3 Condensing boilers – improvements considered good ideas/would encourage adoption and effective use

Improvement idea (on-line survey)	*Adopters (%)*	*Non-adopters (%)*	*Energy professionals (%)*
More reliable and durable condensing boilers.	31 (32%)	40 (46%)	
A boiler that displayed its working efficiency.	51 (52%)	28 (32%)	33 (66%)
An easier to service condensing boiler.	33 (34%)	26 (30%)	24 (48%)
Number online responses to questions on condensing boilers	98	87	50

For heating controls, over half of adopters agreed with or mentioned the following as good ideas: controls that automatically optimise comfort and energy use; provide feedback on energy consumption; designed for all users (including the elderly and disabled); display room-based heating times and temperatures; and detect where heating is required (Table 4). A quarter to a half of non-adopters said these improvements would encourage them to install new controls.

Table 4 Controls – improvements considered good ideas/would encourage adoption and effective use

Improvement idea (on-line survey)	*Adopters (%)*	*Non-adopters (%)*	*Energy professionals (%)*
Heating controls designed for all users	158 (56%)	10 (33%)	32 (64%)
Controls that respond to room use and detect where heating is most required	154 (55%)	13 (43%)	Some Recommendations
Controls that operate automatically to optimise comfort and save energy	144 (51%)	12 (40%)	39 (78%)
Controls that display set heating times and temperature for each room	148 (52%)	10 (33%)	Some Recommendations
Controls with feedback on money and energy used/saved	150 (53%)	11 (37%)	34 (68%)
Better instructions on effective use	102 (36%)	8 (27%)	32 (64%)
Number online responses to questions on heating controls	282	30	50

Such responses suggest consumer interest in 'inclusively' designed, intelligent heating controls that operate automatically to optimise comfort and fuel use and provide feedback provide on energy consumption, heating times and room temperatures. More innovative concepts suggested by our respondents included:

- central heating controls that can be adjusted remotely via a portable device or the internet,
- TRVs that can be calibrated for set temperatures, perhaps with child locks.
- A computer program to enable users to control their heating to optimise comfort and energy use taking into account the characteristics of their dwelling, heating system and needs.

While some of these user ideas have been incorporated in heating control designs, mainly for non-domestic applications, there is scope for the integration of controls as part of future home networking systems. Future Energy Solutions (2005) estimate that home networks for controlling lights, appliances, etc. could save 0.4m tonnes carbon per year by 2020 and could provide sufficient advantages over existing controls that consumers will decide to adopt them rather than rely on their old heating controls when installing a new heating system.

Energy-efficient lighting

Energy efficient lighting includes compact fluorescent lamps (CFLs) and emerging technologies such as Light Emitting Diodes (LEDs), which the DTI (2005) estimate could save about 1.5% of UK household carbon emissions if widely adopted. About 70% of on-line respondents had installed at least one CFL to save energy (91%) and/or reduce fuel bills (82%) and/or for environmental reasons (82%). However, only about a quarter of CFL adopters in the on-line survey noticed reduced electricity bills, suggesting some rebound effects, as about 10% of users chose to leave CFLs switched on longer than incandescent lamps and/or installed additional CFL lighting in the home, in the garden or for security. Indeed some installed energy efficient lighting in order to provide some 24 hour lighting. One adopter stated *'I am less concerned about switching them off, although I try to remember to, when they are not required. I first installed them in places where lights might be left on unnoticed, like cupboards, and am gradually extending them over the rest of the house'*.

Only 6% had considered CFLs but decided not to get any. The biggest deterrent was their size and perceived ugliness (42% of non-adopters), followed by their cost, incompatibility with existing shades and fittings and/or dimmers and/or their light quality (all 33%). These are barriers that involve interconnectedness with existing products and home interiors. These barriers also stopped adopters from installing additional CFLs in certain locations, with complaints about size and/or shape (41%), warm-up time (34%), incompatibility with light fittings (29%) and dimness (26%). However, these responses indicate that many didn't realise that CFL design and technology had improved considerably since their first introduction.

The improvements respondents most often wanted were smaller, even more efficient CFLs in various shapes compatible with existing fittings, especially halogen spotlights and dimmer switches (Table 5). Although manufacturers have introduced many of these innovations, the non-standard CFL designs e.g. spot-lamps, miniature lamps, dimmable lamps, etc. are only available from specialist suppliers. It is not surprising therefore that most consumers (and as our exploratory survey indicated, also many energy professionals) are unaware of their existence.

Table 5 CFLs – improvements considered good ideas/would encourage adoption

Improvement idea (on-line survey)	*Adopters (%)*	*Non-adopters (%)*	*Energy professionals (%)*
CFLs that fit existing light fittings	191 (72%)	11 (45%)	15 (30%)
Different colour rendering	111 (42%)	11 (45%)	7 (14%)
CFLs that can be dimmed	147 (55%)	10 (42%)	3 (6%)
More powerful CFLs (e.g. 150 watt equivalent)	108 (41%)	6 (25%)	Some Recommendations
Wider range of lamp fittings for CFLs	106 (40%)	8 (33%)	Some Recommendations
Even higher energy efficiency	171 (64%)	7 (29%)	Some Recommendations
Wider availability of different CFL designs	44%	29%	Some Recommendations
Number online responses to questions on CFLs	266	24	50

LEDs are a relatively new technology and only 16% energy professionals had a good knowledge or experience of LED lighting in 2005 and 54% mentioned that consumers are not aware of the potential of LEDs for lighting and the implications for domestic energy-efficient lighting. Few respondents had installed light emitting diode lamps (7%), or considered but rejected them (16%). The main driver for adoption was saving energy (57% adopters), but only half (51%) were satisfied with their purchase. The main problems, experienced by about 20% of LED adopters, concerned cost and insufficient brightness, making LEDs suitable only for (additional) decorative lighting. One user stated '*LED's provide excellent background and decorative lighting... ideal for watching TV, although you can just about read with the LEDs*'. The main improvements wanted included LEDs suitable for general lighting (Table 6), which manufacturers are trying to achieve partly by using clusters of LEDs and partly by innovations in LED technology.

Table 6 LEDs – improvements considered good ideas/would encourage adoption

Improvements idea (on-line survey)	*Adopters*	*Non-adopters*	*Energy professionals (%)*
LED lamps that fit existing light fittings. e.g. standard light bulb and candle bulb sizes.	16 (46%)	29 (51%)	Some Recommendations
LEDs for all lighting functions and locations (not just decorative lighting).	20 (57%)	26 (46%)	Some Recommendations
Improved light quality, i.e. better brightness, colour and light quality.	16 (46%)	16 (28%)	8 (16%)
New lamp and fitting designs to improve distribution of light.	18 (51%)		Some Recommendations
Number online responses to questions on LEDs	35	57	50

Given the lower energy consumption per unit of light output and much longer life of LED lighting compared to CFLs, this technology has great potential for reducing carbon emissions; one estimate by Future Energy Solutions (2005) is 0.3m tonnes carbon per year by 2020 from households alone. The technical development and diffusion of LEDS for general lighting thus provides an important challenge for engineers, manufacturers, designers and specifiers.

RENEWABLE ENERGY TECHNOLOGIES

There were about 95,000-98,000 domestic low carbon and renewable energy systems installed in the UK by 2007, with solar thermal water heating (SWH) accounting for over 92% of these installations (Element Energy, 2008). Even rarer are other domestic low carbon and renewable energy technologies, including heat pumps, wood-fuelled stoves and boilers, solar photovoltaic (PV) and micro-wind systems. It is estimated that there were only about 5000 such systems in 2007 in the UK (*ibid,* 2007); so as expected there were only a few adopted by our respondents. However, a surprising number of on-line respondents claimed to have seriously considered one or more of these technologies but decided against adoption. Table 7 provides details of the numbers adopting, and considering but rejecting, one or more of the renewable energy technologies in our surveys.

Table 7. Adoption and non-adoption of one or more renewable energy technologies

Renewable energy systems	Adoptions [1]	Non-adoptions
Solar water heating (SWH)	39 (10%) 15 interviews	151 (39%) 13 interviews
Solar photovoltaics (PV)	12 (3%)	130 (33%)
Micro-wind turbine (MWT)	7 (2%)	128 (33%)
Biomass (wood fuelled) stove	63 (16%)	65 (17%)
Number adoptions/non-adoptions (excluding interviews)	121	477
Total online survey sample [2]	390	390

Notes: 1 Some multiple adoptions 2 Percentages are based on total online survey sample (which includes responses for both energy efficiency measures and renewables)

Adoption, use and improvement of household renewables

In contrast to energy efficiency measures, only 10% of respondents installed solar water heating, 16% bought a wood stove, and less than 3% adopted solar PV or micro-wind. People purchase both energy efficiency and renewable energy systems for similar reasons. For wood burning stoves these money, energy and planet-saving drivers are important, but the stoves are mainly bought by people wanting the warmth and appearance of a real fire. Having spare funds to invest was crucial for householders to adopt renewables such as solar water heating and photovoltaics, given the level of UK government grants available, at about 10% to 15% of the installation price (except for the most expensive technology, solar PV, for which up to 50% grants were available during our surveys until they were reduced in mid-2007). In the following sections we look in more detail the experience of adoption and use of these technologies, together with consumers' ideas for improving renewable energy systems.

Solar water heating

Solar thermal water heating (SWH) systems are the most popular of the renewable technologies, although still comparatively rare in Britain. In our on-line sample, SWH was the most commonly adopted renewable energy technology with 39 installations (10% of the sample). The main reasons for installing SWH were to save energy (83% of on-line adopters), reduce environmental impacts (79%) and reduce fuel bills (77%). Another frequent reason (42%) was having available funds – SWH adopters were often retired (45% interviewees and 18% on-line respondents) and willing to invest in a green, money-saving system. Another common reason for adoption, given by three quarters of our interviewees, was seeing working systems in friends', relatives' or neighbours' homes. The reasons were thus a combination of green attitudes, disposable cash and interpersonal communications.

Overall two-thirds (67%) of on-line and nearly half (47%) of interviewed SWH adopters were satisfied with their system. The benefits included lower fuel bills (54% adopters) and energy consumption (46%). However, the most frequent response (65%) was the pleasure of using solar heated water.

The most frequent disappointment was not being able to use solar heated water in the dishwasher or washing machine (31% online and 53% interviews); due to plumbing constraints or because most new appliances are cold-fill only – problems of interconnectedness with other technologies. Adapter valves available in Germany and elsewhere to allow use of solar heated water in cold-fill appliances were not supplied by UK installers. About 80% of interviewed adopters reported problems with: leaks, pumps and valves sometimes leading to several installer recalls for repairs undermining their trust in the reliability and performance of the system.

Other challenges for user-centred design come from problems with the design, installation and use of controls. Many interviewed adopters experienced problems with insufficient storage capacity for days when their system could be delivering more solar heated water; monitoring gauges and adjusting valves to prevent overheating; maintaining often inaccessible components of solar thermal systems in lofts or on roofs; and difficulties of understanding the controls and operating the system to minimise back-up water heating. One adopter complained '*The main problem is in understanding the controls and displays, which are too complicated and even my husband who works with engineers can't understand the controls and displays. There are two dials in cupboard and an electronic display with meaningless numbers. All we do is switch the system immersion heater off if it is sunny*'.

Some rebound effects were admitted by the online sample; 21% were less concerned about using hot water and 8% were aware that they used more – while not consuming extra energy if the water is solar heated, at least using more water. The interviews showed that nearly half (47%) tried to use solar hot water when it was available, giving examples of showering or using their (hot-fill) washing machine in the afternoon or evening when the water is hot, rather than the morning. But more than half (53%) had made no changes to their behaviour.

A significant proportion (39%) of on-line respondents had seriously considered but decided against getting SWH. The overwhelming reason was capital cost (73%), but other reasons were also mainly cost related; namely likely inadequate fuel savings and payback given uncertain reliability and system life (up to 36% non-adopters). As before, these barriers and, problems experienced by users, non-adopters and professionals suggest some design improvement ideas, with online survey results presented in Table 8. Not surprisingly, many non-adopters would like lower cost systems, perhaps using simpler technology. For instance a 'solar lilo' was mentioned, but such ideas would only work in areas receiving high annual solar radiation.

Table 8 Solar water heating system – improvements considered good ideas/would encourage *adoption*

Improvement idea (on-line survey)	*Adopters (%)*	*Non-adopters (%)*	Energy professionals (%)
Lower cost SWH systems	23 (44%)	89 (60%)	
Solar panels integrated with the roof	36 (69%)	72 (48%)	31 (62%)
Packaged systems e.g. SWH plus boiler	25 (48%)	64 (43%)	25 (50%)
Installation of solar panels from inside the house	23 (44%)	44 (30%)	25 (50%)
System designed to give user feedback	29 (56%)	61 (41%)	30 (60%)
Improved visual appearance of solar panels	14 (27%)	34 (23%)	
Guaranteed reliability, durability and payback	25 (48%)	70 (47%)	22 (44%)
System financed by energy supplier paid back via fuel bills	23 (44%)	84 (56%)	
Number online responses to questions on SWH	52	149	50

More adopters and professionals, having experienced use of SWH, felt that systems integrated with the roof and/or involving installation from inside the house to avoid the need for expensive scaffolding were good ideas. Another frequent request from users was for systems that provide feedback on money and energy savings, which reinforces the need for more informative and easier to understand SWH controls. A few respondents were aware of more technically advanced SWH systems available in other countries such as Germany, including systems with controls linked to internet weather forecasts to inform the user when solar hot water was likely to be available. More adopters and professionals than non-adopters would like to see integrated systems, e.g. a SWH and condensing boiler package such as offered by some manufacturers. Such systems could help avoid interconnectedness problems such as experienced by one interviewee who installed a combination boiler (which does not require a hot water tank) not realising it was incompatible with SWH.

In the open comments, some professionals would like a greater availability of more energy-efficient solar panels in different standard sizes, offering greater flexibility for installation. Other ideas and concepts suggested by respondents included:

- A diagnostic system to warn about component failure and to locate leaks in pipes. With existing controls, users are often unaware if their SWH system is not functioning.
- Larger, better insulated tanks to store hot water for days when the system is not collecting solar energy. Larger storage tanks might be possible if a pumped system was developed that allowed the tank to be located in the loft rather than in airing cupboards etc. as is usual in the UK.

Micro-wind

Micro-wind turbines with outputs of 0.5kW to 6kW are established products for remote use on farms, boats, etc. However, 1kW to 1.5kW grid-connected household micro-wind turbines are an emerging technology being sold to UK consumers to generate an estimated 10% to 30% of domestic electricity, but with unproven performance in urban and suburban areas. Element Energy (2008) estimated that there were only 1,100 such installations in the UK by 2007. Indeed many engineers are very sceptical about the value of these micro-wind systems for carbon saving in urban areas, given that the power output of a wind turbine is proportional to its swept area and the cube of the wind speed, and that air turbulence around buildings greatly reduces useful wind speeds. Although there is little data available on the performance of micro-wind turbines, a BRE report found that in windy locations durable, efficient and low maintenance turbines can generate enough energy to pay back (both in terms of carbon emissions and financial costs), but this is unlikely in large urban areas (Phillips *et al,* 2007).
Although only 2% of online respondents adopted micro-wind, a third of on-line respondents said they had seriously considered this technology but rejected it. The main barriers to installation were cost (mentioned by 53% of non-adopters) and long payback. The other main deterrents included finding a suitable location for the unit (33%); noise/vibration (26%); unattractive appearance (22%); uncertainty

about this new technology's performance and reliability (21%); and problems connecting to existing electricity systems (21%). Many considered towns and cities unsuitable for micro-wind because of worries about noise and visual intrusion. Although the sample had little experience of using micro-wind, Table 9 presents some improvement ideas that respondents agreed with or mentioned most frequently

Table 9 Micro-wind – improvements considered good ideas/would encourage adoption

Improvement idea (on-line survey)	*Adopters (%)*	*Non-adopters (%)*
Lower-cost micro-wind systems	12 (67%)	103 (82%)
Wind turbine(s) integrated with roofing.	9 (50%)	76 (60%)
Give user feedback on money and energy saved	6 (33%)	53 (42%)
Visually attractive wind turbine	6 (33%)	38 (30%)
System financed by electricity supplier paid back via fuel bills	7 (39%)	74 (59%)
Number online responses to questions on MWT	18	126

Table 9 shows that the main design improvements that might get people to adopt micro-wind were: lower cost designs; roof-integrated systems; feedback on energy and money saved and visually attractive turbines. One adopter would like to see '*Guaranteed performance and proper comparative tests (since manufacturers' ratings not directly comparable)*' and another suggested *'Some sort of stabilizing system to reduce or eliminate vibration'*. These ideas provide challenges for engineers and designers. At present there is active development of building integrated wind systems in which the building acts to channel the wind flow. Examples include Altechnica's patented design of roof with a wing-like concentrator, which creates a slot within which small turbines exploit an enhanced wind flow.

Solar photovoltaics

Household solar photovoltaic (PV) systems are not considered cost-effective at present given an average payback of 50 years or more, but if installed in the 9 million UK homes potentially suitable would save an estimated 2.5m tonnes carbon per year (DCLG, 2006). Element Energy (2008) estimated that there were only 2,300 such installations in the UK by 2007. Only 3% of on-line survey respondents had installed a solar PV system, mainly for environmental reasons (56%) or because they had the funds (43%). Only a third of solar PV adopters were fairly or very satisfied, with about half of adopters unsure. This is probably due to not enough power being produced or available when required and the poor electricity grid feed-in tariffs available in the UK.

As for micro-wind, a third of respondents had seriously considered this technology but decided against it. The main barriers to the installation of solar PV include capital cost (85%), too long payback (28%), insufficient output (28%), and connecting to the National Grid (24%). In open comments, householders would like more information on performance reliability and connecting to the grid. One non-adopter stated, '*there are no independent performance tests such as in "Which?" reports. I'm not happy to rely on manufacturers' ratings or reliability figures*' and another said '*We need more information about how to connect the electricity generated to our electrical supply'*.

Apart from economic measures (lower cost PV systems, new financing methods and better feed-in tariffs for surplus electricity exported to the National Grid), the main improvements wanted by actual and potential adopters were: systems that give feedback on electricity generated and money saved, and long-term performance guarantees (Table 10). Other improvements suggested by several respondents were solar PV panels integrated with south facing windows, roof lights or conservatories. Suitable semi-transparent PV cells exist but have yet to be used to any extent in domestic buildings because of their cost.

Table 10 Solar PV – improvements considered good ideas/would encourage adoption

Improvement idea (on-line survey)	*Adopters (%*	*Non-adopters (%)*
Lower-cost PV systems.	11 (69%)	99 (80%)
Gives user feedback on money and energy saved	9 (56%)	56 (46%)
Guaranteed reliability, durability and payback.	5 (31%)	56 (46%)
PV System financed by electricity supplier paid back via fuel bills	5 (31%)	68 (55%)
Number online responses to questions on solar PV	16	123

Wood burning stoves

Wood burning stoves were the most widely adopted renewable energy device in our on-line survey, adopted by 16% of this sample. Biomass boilers are quite rare by contrast and Element Energy (2008) estimated that there were less than 600 such installations in the UK by 2007. We did not distinguish simple wood burning stoves from automatic feed pellet stoves and boilers, but it is unlikely that many of the automatic type were included. Wood stoves' popularity is due to their relatively modest cost, but also because they provide a relatively efficient real fire that adds to room décor.

Most (82%) wood stove adopters are very satisfied and two-thirds (65%) mentioned the pleasure of using a renewable fuel. Other benefits mentioned by about a third of adopters were lower fuel bills (37%) and greater energy efficiency (33%). The main problems cited by users were; more dust and dirt in the home (35%) and connecting the stove to radiators and/or the hot water system (28%). Also, there were rebound effects, due to the greater difficulty of controlling the output of wood stoves; some 60% of users said their stove heated one or more rooms to a higher temperature. One adopter said '*We tend to heat the lounge (the room where the stove is) to a higher temperature and then leave doors open so that the heat can travel through the house'*.

The main deterrents for non-adopters of wood stoves reflect the problems experienced in use, including: controlling heat output (43%); extra dust and dirt (41%); lack of fuel storage space (40%); labour of refuelling and ash removal (39%); and finding a suitable location (35%). Table 11 shows the improvement ideas the on-line respondents chose or mentioned most frequently.

Table11 Wood stove – improvements considered good ideas/would encourage adoption

Improvement idea (on-line survey)	*Adopters (%)*	*Non-adopters (%)*
Wood stoves that produce less smoke/pollution	33 (55%)	33 (48%)
Wood stoves with more controllable heat output.	22 (37%)	34 (49%)
Less frequent refuelling/ash removal	25 (42%)	28 (41%)
Wood stoves that produce less dust and dirt	25 (42%)	28 (41%)
Number online responses to questions on stoves	60	69

About half of both adopters and non-adopters wanted less polluting wood stoves, despite modern smokeless designs. Other desired improvements were for controllable, labour- and dirt-saving designs. Additional ideas and concepts suggested by survey respondents included:

- A multi-fuel stove to recycle combustible household waste, with pollution control;
- Ducts between rooms to transfer the heat from a stand-alone wood stove throughout the home.

Differences in desired improvements between adopters, non-adopters and professionals

Tables 2-6 and Tables 8-11 suggest some differences in the improvements that consumers considered would encourage adoption, between people with experience of using energy efficiency products or renewable energy systems, those who had decided against adoption, and the energy efficiency professionals who specify or offer advice on these technologies.

Pearson's chi-square ($\chi 2$) test was therefore performed to test for statistically significant differences between adopters, non-adopters and energy professionals in the improvement ideas, presented in Tables 2-6 and Tables 8-11. In all cases where statistical data was presented, the tests revealed no significant differences (at the 0.05 probability level) between these groups' desired technical and non-technical improvements. This suggests that the improvement ideas are robust and generally desired by different consumers. More detailed methodologies such as QFD (See Matzler and Hinterbuber, 1998) would be required to investigate if there are differential consumer requirements in different market segments.

NON-TECHNICAL IMPROVEMENTS AND INNOVATIONS

Application of good marketing principles i.e. targeting different energy efficiency measures and renewable energy technologies at receptive market segments is vital to ensure their more rapid uptake (Caird et *al*, 2008). Our research shows that there is a critical timing for adopting energy efficiency measures and renewables since they are often installed when moving house, or as part of other home improvements. Where retailers or installers are slow to respond, for example to customers considering loft insulation, this may lead to householders going ahead with their plans with the result that the insulation may not be included as part of the improvements. Additional support services for households that are making big changes to their homes could be offered, such as a loft clearing and storage service as part of the installation process.

In addition to the mainly technical/design improvements discussed above, our respondents suggested non-technical improvement ideas to support the adoption of energy efficiency measures and household renewables. For example, the majority of non-adopters of solar water heating, solar PV and micro-wind systems said they would be encouraged to adopt if energy suppliers offered financial packages to install systems with repayment via fuel bills. Wider public demonstrations, particularly of renewables installed in public buildings, would also inspire consumer confidence and interest in these technologies.

Understanding networks of communication between actual and potential adopters is also important in view of the evidence from our interviews of the strong influence of friends and neighbours in decisions to install insulation and solar water heating. Manufacturer's communications with customers could be improved by addressing their uncertainties about the performance, reliability and durability of unfamiliar products and systems. Independent assessments of performance, payback, etc. and online comparisons of manufacturers' specifications would assist customers to be more confident in their purchasing decisions. In recognition of the need for independent and trustworthy information and advice, manufacturers could liaise more closely with government energy efficiency and renewables advice schemes, such as the Green Homes Service launched in 2008 based on the UK's network of Energy Efficiency Advice Centres, to offer a 'one-stop-shop', to guide people through the details of technology choice, grant applications, planning permission, suitability, installation, use and maintenance.

Communications with customers could be also improved by providing more information on the technologies. It was clear, for example, from respondents' comments that many were unaware of improvements and innovations in the design and technology of energy efficiency products and renewables that have already taken place. Where products and systems are changing, consumers need to be kept informed of technical developments if they are not to reject technologies based on their outdated perceptions or experience, for example, that CFLs are still bulky, insufficiently bright and slow to warm-up, or that dimmable CFLs, and irritant-free, thin loft insulation materials are unavailable.

DISCUSSION AND CONCLUSIONS

This study surveyed consumer views on adoption, non-adoption and use of energy efficiency products and renewable energy systems by mainly 'green' householders. It identified ideas for improving the design of these technologies to be both more user-friendly and capable of delivering the expected reductions in fuel bills and carbon emissions, and therefore appeal to a wider group of consumers. The study suggests that feedback from actual and potential users can be useful for engineers, designers and manufacturers in guiding the R&D, specification and development, as well as the marketing, of these energy-saving technologies.

The questionnaire methodology employed in this project was helpful for contacting a large group of householders and users, although the findings may have some limitations associated with self reporting. Other methods, such as focus groups, video ethnography and user observation studies may be used to look at latent, non-rational or unstated user requirements. Such methods are of particular value if a design team or manufacturer wishes either to develop or test more innovative technological ideas, or to evaluate the influence of user behaviour in situ. A second methodological limitation of this research is the absence of a focus on specific, manufactured product brands. The results, a mixture of user-centred and usability improvements as well as innovative ideas, may be integrated with ecodesign methodologies, for example the Eco-Quality Function Deployment method that translates consumer requirements into technical and environmental design features to guide the development of prototype products and systems, before user testing (see Herrmann *et al*, 2007). Further research in our ongoing research programme will embrace some of these more detailed methodologies.

The main conclusions are discussed below:

User-centred research and consumer requirements

While the experience of adoption and use of the different energy efficiency products and renewable energy systems we surveyed is different, there are some common reasons for purchasing them, namely reducing fuel bills, saving energy and concern for the environment. More generally, the results on drivers for adoption highlight the consumers' pleasure associated with using renewable energy, as well as evidence of their association of renewable energy technologies with green status, morality and protectiveness towards future generations. Context and timing for adopting energy efficiency measures and renewables is also important since they are often installed when moving house, as part of other home improvements, or when purchasing additional energy efficiency measures.

User satisfaction with energy and carbon saving

The results suggest that respondents with experience of using energy efficiency and renewable energy technologies were less satisfied than they expected with the reductions in fuel bills and energy use, following installation. Many users, particularly of condensing boilers, solar water heating, micro-wind and solar PV also voiced concern about performance reliability and durability. This supports the importance of an engineering design focus on the functional efficiency and performance of these products, as well as a user-centred design approach. The mixed satisfaction of users of these technologies with the fuel savings based on their own estimates, may also reflect some rebound effects identified for several of these technologies, where benefits are taken in warmer homes, additional lighting or extra hot water, which consequently reduces both fuel and energy savings. New designs need to reflect the way people actually use these technologies, and satisfy their aims to save energy and the environment without sacrificing comfort and convenience.

Usability of energy efficiency and renewable energy technologies

A key challenge for designers and engineers is, therefore, to offer user-centred designs that offer efficiency, reliability and durability as well as achieving carbon reductions. Designers need to design for compatibility in the home, and consider the interconnection with existing systems and the building structure, for example overcoming problems such as a lack of compatibility between solar water heating systems and cold-fill appliances. Designers also have a role in creating aesthetic products and systems, overcoming the differences between people who dislike the visual impact of renewables, like solar panels and wind turbines, and those seeking a symbolic display of their environmental credentials.

Another challenge for design is to reduce ineffective use and rebound effects with better controls that are simple and easy to use, which warn when energy use is excessive, provide feedback on energy savings and influence good habits of energy use. For example, adopters of SWH, solar PV and micro-wind wanted control systems that indicated how best to use the system to minimize backup fossil fuel consumption. Users of wood-burning stoves wanted easier control and distribution of heat output.

The need for better designs of user-centred controls was highlighted in another study of consumer adoption and use of low carbon and renewable energy technologies, focusing on heating systems (Roy *et al*, 2008). The results, from surveys of 285 users, show that although householders who adopt low carbon and renewable heat systems, including solar water heating, heat pumps and wood-fuelled boilers are generally very satisfied with their purchase, they frequently do not understand how best to operate the controls to make the most efficient use of the system..

User sources of new product ideas and improvements

The study reported in this paper identified some improvement ideas that would encourage adoption, by mainly 'green' consumers who had adopted a range of energy efficiency products and renewable energy systems. However, in common with previous research (Holt, 1989: Luthje, 2004), our results found that relatively few of these users were able to provide genuinely innovative ideas. Holt (1989, p.167 states

'…the user…can indicate minor improvements, but is usually not able to suggest radically new products'.

Nevertheless, the experience of ordinary users, is a very helpful source of ideas for improvements to product and system usability. In addition to the mainly technical/design improvements discussed above, consumers had some non-technical ideas for improving these products and systems that together with the other findings of the project, suggest that promoting the widespread adoption and effective use of energy efficiency measures and household renewables requires both technical and non-technical design improvements by manufacturers, energy suppliers and retailers tailored to the specific markets and technologies.

Value of user-centred research for promoting more widespread diffusion

The reasons for non-adoption varied for each energy efficiency and renewable energy technology with cost emerging as a key deterrent, especially for renewables. The key problem limiting these emerging, niche markets is clearly financial, namely price, payback and operational costs tied to some concerns about product performance. Although these products and systems offer some desirable benefits, such as savings on fuel bills, helping the environment and the pleasure of using renewable energy, customers are more concerned, than for other household products, with financial issues such as payback. For example, high capital cost was the main reason for rejecting solar water heating, solar PV and micro-wind turbines, although concerns about reliability and durability, and hence payback, were also barriers.

The results also indicate that there are specific consumer requirements and user problems that are not fully appreciated by designers and manufacturers. For example, those who did not purchase loft insulation did so mainly because the difficulties in using a loft covered with thick mineral fibre insulation for storage; while a few were deterred by the health effects of these insulation materials. Visual intrusion, noise and vibration were deterrents for potential adopters of micro-wind turbines. Wood stoves were most often not purchased because of difficulties in controlling their output and the extra dirt and labour they involve.

This research supports the value of users' reflections on their experiences, as a source of ideas for design improvements to support product development and management processes, so that householders will widely adopt and use these products and systems effectively to reduce carbon emissions. The problem that users have with controls emerges as an important focus for future usability studies, particularly if energy efficiency products and renewable energy systems are adopted by the majority of consumers who are not especially 'green' or technically literate. The main issue for companies at this stage in these, emerging markets, however, may be to increase market share, with competitive pricing, although understanding user requirements for other non-price improvements may extend markets beyond the niche group of early adopters to promote more widespread diffusion

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Figure 1

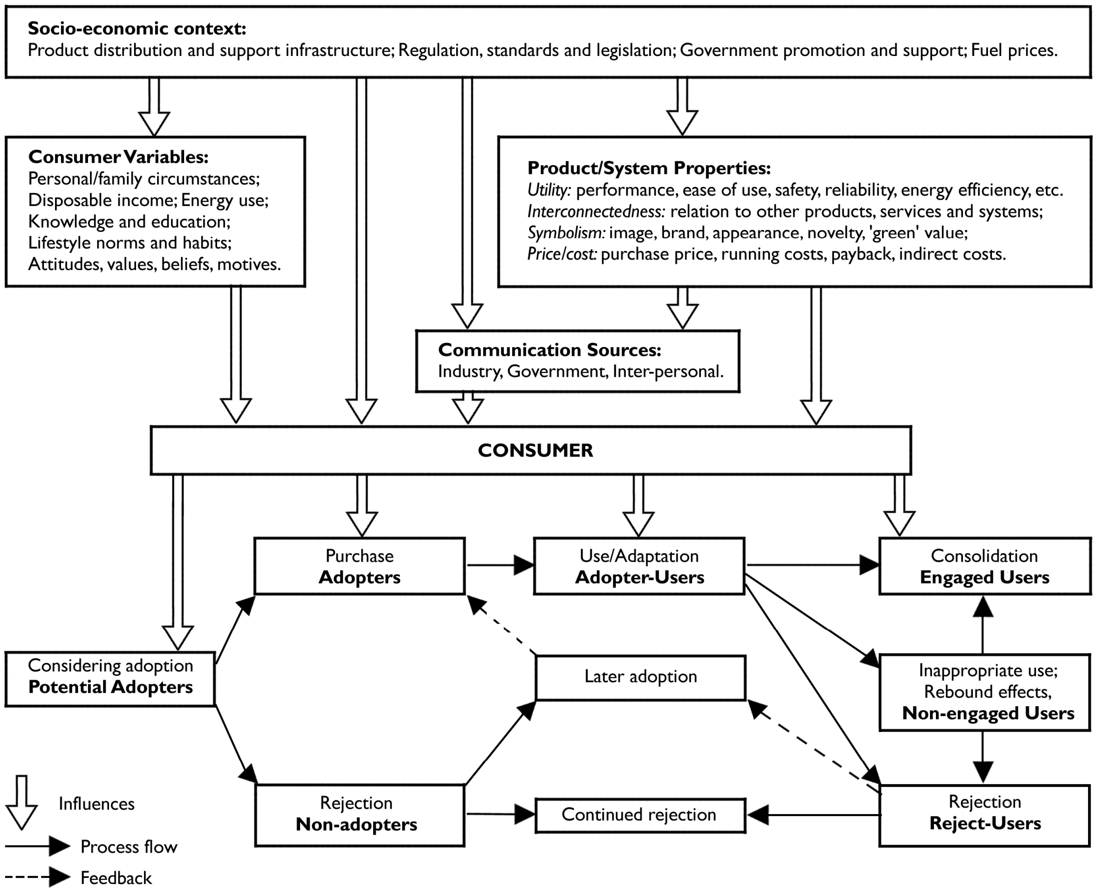

Fig. 1 Model of adoption and use of LZC products and systems (Roy, Caird and Potter, 2007, p. 51)