Designing low & zero carbon products and systems – adoption, effective use and innovation

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Biographical information

Professor Robin Roy

Robin Roy is Professor of Design and Environment at the Open University with background in Mechanical Engineering and Design Technology.

His research has focused on: creativity in invention and design; design and innovation management; and design for the environment. His recent research includes Factor 10 Visions, which is investigating the potential for 60-90% reductions in the carbon emissions of higher education and housing and People-centred eco-design, the initial results of which are reported in this paper.

His recent teaching contributions include: Working with our environment (2000, 2006), Design and designing (2004) and Innovation: Designing for a Sustainable Future (2006).

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Sally Caird is a part-time Research Fellow at the Open University with a background in Innovation and Organisational Psychology.

Her research has focused on: innovators, innovating teams and networks in organisations; household ecological footprint and sustainable lifestyles; and enterprise and entrepreneurship. Her recent research reported here is people-centred eco-design, including the adoption and use of a wide range of energy efficient and renewable technologies.

She has also developed interactive web-based e-learning products for supporting education on achieving sustainable lifestyles.

Abstract

This paper summarises the aims, methods and some results of a study of the influences on consumer adoption – and non-adoption – of established energy efficient and innovative renewable energy products and systems; the problems and benefits experienced by users of these low and zero carbon (LZC) technologies; and improvement ideas to make the products/systems more desirable and effective at saving energy and carbon.

The influences on adoption and effective use vary for the different technologies and include the socio-economic context, consumer attitudes and values and communication sources. Product/system characteristics are also crucial, and include functional and ergonomic utility; interconnectedness with other systems, 'green' and aesthetic symbolism, and cost.

Technical, financial and other ideas for reducing the barriers to adoption and tackling the problems experienced by users are a step towards a more rapid and effective take-up of these LZC products and systems.

Introduction – adoption and use of LZC technologies

In order to address the problem of climate change the UK Government set a long-term target of reducing the nation's carbon emissions by 60% from their 1990 levels by 2050 and is expected to exceed its commitment under the Kyoto Protocol to reduce greenhouse gas emissions by 12.5% between 2008 and 2012 (DTI, 2006). The development and rapid adoption of 'low and zero carbon' (LZC) products and systems to reduce the 28% of all UK carbon dioxide emissions from homes are key elements of the Government's energy strategy. (HM Treasury, 2005).

Many domestic LZC products and systems are available. They range from products based on established technologies, such as home insulation, heating controls, compact fluorescent lamps (CFLs) and solar water heating, to more innovative technologies such as micro-combined heat and power (micro-CHP), micro-wind turbines and domestic photovoltaic systems. However, consumer adoption of most LZC technologies has been slow. One factor in the slow take-up is that often the products/systems are designed without taking sufficient account of user requirements – functional, economic and symbolic. Moreover, just persuading people to adopt LZC technologies does not guarantee reduced carbon emissions, as consumers often cancel out the benefits by trading up to larger, more powerful goods, increasing consumption, or by-passing their energy saving features.

The People-Centred Eco-Design project aims to address these issues by identifying what people want from these goods and how they choose and experience them, to help manufacturers design more desirable, carbon saving LZC products and systems and to help governments to develop more effective policies for household carbon reduction.

The people-centred eco-design project – aims and method

The research aims to identify:

- Key factors influencing consumer adoption, and non-adoption, of established and innovative LZC technologies;
- The problems and benefits which adopters of these technologies experience during installation and use; and whether they use the technologies in a way that reduces carbon emissions;
- Policies and actions to support the drivers and reduce the barriers to adoption, and address the problems of installation and use;
- Specifications, ideas and concepts for improvements to, or innovations in, the technologies that would make them more desirable to consumers and effective reducing carbon emissions.

The project comprises an exploratory study and a main phase. The exploratory study involved a literature review, pilot interviews with volunteer consumers and an on-line survey of energy professionals to develop the methodology for the main phase.

In the exploratory study a model of consumer adoption and use of LZC products and systems was developed (Figure 1). It includes four groups of variables that influence decisions and behaviour: the socio-economic context (e.g. fuel prices), communication sources (e.g. interpersonal), consumer variables (e.g. attitudes and values) and product/system properties (utility, interconnectedness, symbolism, and price).

The exploratory interviews and survey showed that the influences on the adoption and use of different LZC technologies varied, but all could be classified within our research model, giving confidence in its validity (see Roy, Caird and Potter, 2006).

The exploratory study also piloted questionnaires for the main surveys; carried out in two ways. First, by telephone interviews with clients of Milton Keynes Energy Agency, which provides advice on established energy efficiency measures, and of the National Energy Foundation that gives assistance on installing renewable energy technologies. Second, via a public on-line survey accessed mainly via websites of a BBC TV series 'Climate Chaos' and of the Energy Saving Trust, the official UK body promoting home energy efficiency.

To date we have conducted some 90 telephone interviews of people who adopted, or considered getting, one or more established technologies of loft insulation, heating controls, condensing boilers, energy efficient lighting and solar water heating. The on-line survey has produced 390 responses from people who had adopted, or considered but rejected, one or more of the established technologies and/or innovative micro-generation technologies such as micro-CHP, photovoltaic roofs and micro-wind turbines.

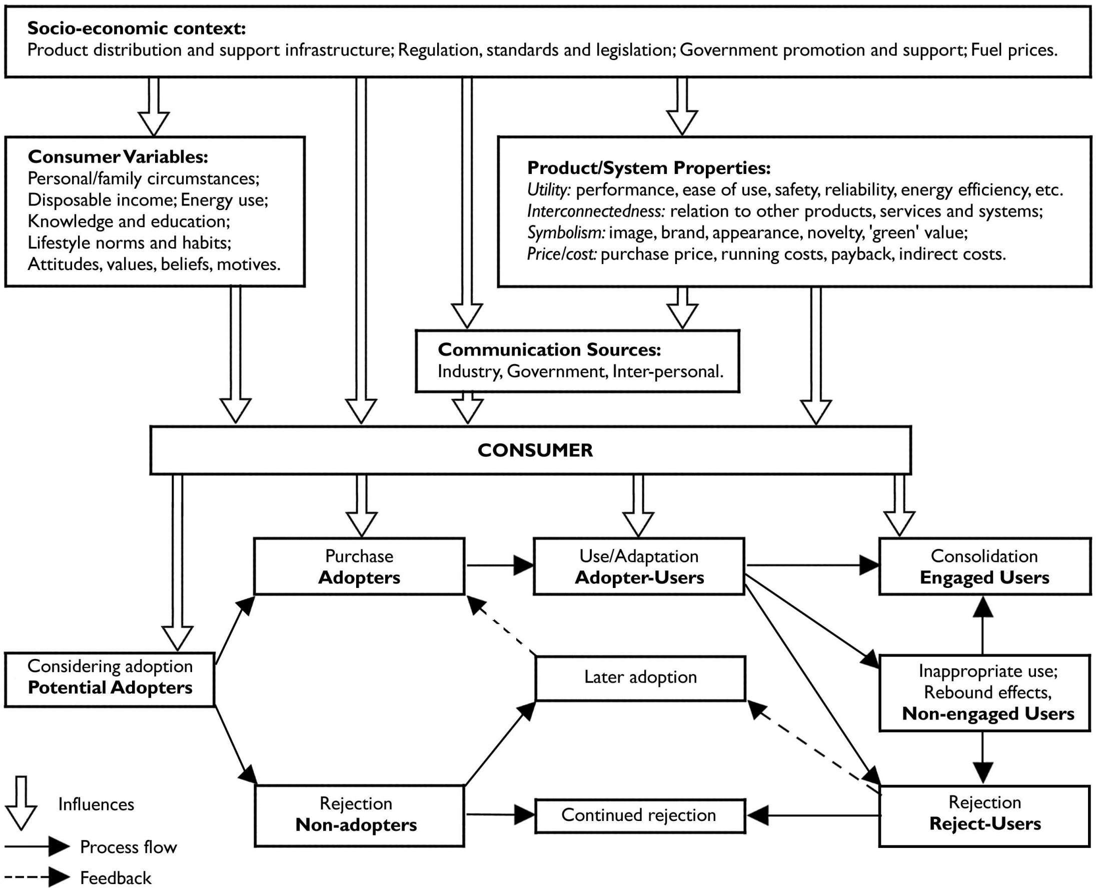

Figure 1 Model of the adoption and use of ecological products (Adapted from Roy, Caird and Potter, 2006)

Key results – main phase on-line consumer survey

This paper focuses on some key results from the on-line survey with some illustrative material from the in-depth telephone interviews. The respondents to the on-line survey were self-selected and not unexpectedly were 'greener' and from higher socio-economic groups than the UK population. This is therefore a purposive rather than a representative survey, necessary when investigating the early adopters of innovative products and systems such as micro-generation. Furthermore, as over 90% of the respondents said they were 'concerned' or 'very concerned' to reduce their environmental impacts their reasons for non-adoption represent significant barriers that need to be addressed before the less 'green' general population will even begin to consider adopting LZC technologies.

Adoption, use and improvement of established LZC technologies

Loft insulation

Loft insulation is one of the most cost-effective energy efficiency measures. Over 90% of UK homes have some loft insulation but bringing the 15m suitable UK homes to the recommended 300m of insulation is estimated could save 1.28m tonnes carbon, about 3% domestic emissions (Shorrock and Utley, 2003, DTI, 2005). New or top-up loft insulation is available via energy supplier and other subsidy schemes.

The majority of our on-line survey respondents installed loft insulation to save money and/or energy (84%) and/or to have a warmer home (77%) i.e. cost and utility were the key drivers. Over two thirds (68%) also responded that they installed the insulation to reduce environmental impacts; a driver dependent on this group's greener attitudes.

A minority (15%) seriously considered but decided against loft insulation, mainly because of the need to clear the loft (33% of non-adopters) and/or suffering a loss of loft storage space (37%) Nearly a fifth (19%) of adopters also said clearing loft was a problem. These are barriers to do with the interconnectedness of insulation with other building elements.

In the open comments several 7 adopters and 3 non-adopters mentioned they were deterred by the irritant effects of, the glass or lava fibre normally used for loft insulation, some mentioning their preference for eco-friendly materials such as recycled paper – barriers concerned with utility and consumer attitudes.

The majority (58%) of adopters said the main benefit of loft insulation was a warmer house, while nearly a third said they also had lower fuel bills (29%) and/or energy consumption(31%). *'We reduced the temperature of the upstairs radiators and turned down the central heating thermostat by 2 degrees to 19 degrees C.' said one adopter.* However, there is some evidence of a rebound effect of loft insulation, with at least 4% adopters taking the benefit in higher room temperatures, heating more of the house or heating the house for longer periods rather than lower energy consumption. Three respondents (1%) mentioned that loft insulation also helped keep their home cooler in summer, a benefit likely to become increasingly important with climate change, but not generally mentioned in insulation programmes.

These drivers, barriers, problems and benefits suggest several improvement ideas and design challenges (see the Appendix Table 1).

The loft storage issue clearly needs a better solution than those currently available; a professional task of raising the joists and boarding or individual 'bodged' solutions. Nearly a third (31%) of non-adopters would have installed given a better method of providing post-insulation storage.

Loft insulation also offers challenges for materials innovation. Three quarters (76%) of adopters said they felt that non-irritant, eco-friendly insulation materials would be a good idea, while 60% said they would like less bulky materials that provided the same insulation. Over half of the non-adopters said one or both of these improvements would have encouraged them to install. Existing eco-friendly or high performance insulation materials are not available in UK subsidised insulation schemes, so lower cost alternatives would be a worthwhile innovation. One simple idea was that rolls of mineral fibre insulation should be encased.

Heating controls

Over 90% of UK homes have central heating, mainly from a gas-fired boiler and radiators equipped with one or more heating controls; thermostat(s), plus a timer/programmer and/or thermostatic radiator valves (TRVs). Under 2005 UK Building Regulations new or replacement boilers must be energy efficient condensing designs, so good controls are becoming increasingly important. Getting consumers to use existing controls properly is estimated could save about 3% UK heating energy consumption (MTP, 2004), while installing improved controls could save about 0.5m tonnes carbon or 1% total (DTI, 2005).

About three-quarters of our respondents installed timer/programmers and/or TRVs to reduce their fuel bills (74%) and/or energy consumption (78%), a cost driver. 57% claimed that they installed controls to reduce environmental impacts; again a driver linked to the greenness of these consumers.

Some respondents seem to be referring to controls they already possessed; our surveys indicate that many people keep old controls when upgrading their heating system. There appears to be a barrier, probably due to perceived utility and cost, to installing modern controls.

Most respondents said using their timer/programmer (71%) and TRVs (50%) was fairly or very easy. However, a minority (under 10%) responded that using controls was difficult or very difficult; with some complaining about over-complex programmer instructions, buttons and displays that are too small; and the fact that TRVs need setting by trial and error. For example, one user of a timer/programmer commented *'they are more complicated to set up than the system we had in our old house... Too many options mean it is easier just to leave the damn thing on'*. Such adopters rejected their programmers or TRVs, switching their central heating on and off using the thermostat. Sometimes this was due to installation of the controls in inaccessible places, programmers hidden in cupboards or integral with combination boilers installed in the loft. Others were unsure how best to use their controls to minimise energy consumption and maintain comfort; and a third (36%) of adopters agreed it was good idea to have better information/instructions on how to use controls effectively.

When people used their programmer to control heating times and/or TRVs to control room temperature about a third said this saved them money (33%) and/or energy (40%) and provided a warmer house (32%). Used effectively, controls have little rebound effect.

These drivers, barriers, problems and benefits suggest some improvement ideas and design challenges.

Over 50% of adopters said the following were good ideas: controls that automatically optimise comfort and energy use; provide feedback on energy consumption,are designed for all users; display room-based set heating times and temperatures; and detect where heating is required in relation to room use.. Over a quarter (27%-43%) of non-adopters said these improvements would encourage them to install new controls. (Appendix Table 2)

Such responses suggest that there could be a demand for 'inclusively' designed, intelligent heating controls that provide feedback and operate automatically with manual over-ride. Other ideas are for controls with radio controlled clock settings that can be adjusted via a portable device or over the telephone or internet, or TRVs that can be calibrated for set temperatures, perhaps with child locks. There is also a potential demand for better information, maybe 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.

Energy efficient lighting

Energy efficient lighting includes established compact fluorescent lamps (CFLs) and emerging technologies such as Light Emitting Diodes (LEDs). Widespread adoption of CFLs is estimated could immediately save 0.6m tonnes carbon, about 1.5% of the UK household total (DTI, 2005).

Most respondents had installed at least one CFL to reduce fuel bills (82%) and/or save energy (91%) and/or for environmental reasons (82%). Adopters liked CFLs' long life but 15% felt dissatisfied beacuse a lamp failed after one to three rather than the advertised 8 to 10 years. The life of CFLs thus acted as a driver but also a barrier if it failed early.

6% had considered CFLs but decided against getting any. The biggest deterrent was their size and perceived ugliness (42% of non-adopters), followed by their cost, incompatibility with existing fittings and/or dimmers and/or their light quality (all 33%) – barriers of interconnectedness and symbolism. These barriers also stopped adopters from installing additional CFLs, especially since many didn't realise that CFL design and technology had improved considerably since their first lamp. *'I was very surprised at how pleasant the light is – my preconceptions based on the unpleasantly cold light of the early models had prejudiced me against them before'* said one respondent.

The improvements respondents' most often wanted were CFLs compatible with existing fittings, especially halogen spotlights and dimmer switches, and with a less harsh light quality (Appendix Table 3). Manufacturers have introduced many of these improvements, but consumers do not seem to be aware that they exist, a barrier of poor communication from manufacturers.

A few respondents had installed (7%), or considered but rejected (16%), LEDs. The main improvements desired by about half of both groups were for more information and for LEDS suitable for general lighting.

Solar water heating

Domestic solar water heating (SWH) may be considered an established or an innovative technology. SWH systems using flat plate solar collectors are commonplace in many countries. More recent systems using evacuated tube collectors are more efficient and expensive. Despite being the most popular domestic renewable energy technology, accounting for 96% of the UK's 82,000 micro-generation installations (DTI, 2006), SWH is still relatively rare in Britain the industry is small and fragmented and adopters generally feel that they are installing an innovative system.

A typical flat plate or evacuated tube system will provide about 50% of a UK household's hot water and an installation programme is estimated could save about 2.2m tonnes carbon, or 5.3% UK household energy, by 2020 (DTI, 2005).

In our sample SWH was the most commonly adopted renewable energy system with 39 installations (10% of the sample, compared to approximately 0.3% of UK households with SWH).

The main reasons for installing SWH were to save energy, reduce environmental impacts and reduce fuel bills (all around 80% of adopters). Another frequent reason was having the funds to invest (42%) – SWH adopters were often retired (18%) and were willing to spend some retirement capital on a 'green', money-saving system. The reasons were thus a combination of utility, cost and consumer attitudes.

Nearly half (48%) who installed SWH responded that the system met their expectations very well and 19% fairly well. *'Fantastic – every home should have one – Government regulations should incorporate solar water heating in all new homes'* said one satisfied user. 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, and half the users tried to use solar hot water when it was available, e.g. showering in the afternoon. There was some evidence of a rebound effect – 21% SWH adopters were less concerned about using hot water and 8% said they used more, but the extra could be mainly solar heated. The most frequent disappointment was not being able to use solar heated water in their dishwasher or washing machine (31%); due to plumbing constraints or because most new appliances are cold fill only; problems of interconnectedness. Another complaint (12%) was of insufficient solar hot water, usually because of a too small storage tank and/or rapid cooling of the water, especially overnight. There were also problems of overheating, breakdowns and insufficient solar hot water storage capacity on sunny days and difficulties of understanding the controls and how best to use the system to minimise back-up water heating.

151 (39%) of our on-line respondents had seriously considered SWH but decided against. The overwhelming reason was capital cost (73%). Other reasons were also mainly cost related; namely likely fuel savings and payback given uncertain reliability and system life (up to 36% non-adopters), but difficulties in finding a good installer was another deterrent (25%).

As before, these drivers, barriers, problems and benefits suggest some improvement ideas and design challenges. Both adopters and non-adopters agreed with similar improvement ideas to SWH, although the percentages differ (Appendix Table 4)

Not surprisingly, both groups would like lower cost systems, perhaps using simpler technology e.g. a 'solar lilo' was mentioned and one respondent suggested a concept comprising black hose coils on the roof. Both groups liked the idea of having SWH financed by an energy supplier and paid back via their fuel bills. *'The finance idea is new to me and very attractive'* observed one non-adopter.

More adopters than non-adopters, having experienced SWH, felt that systems integrated with the roof and/or involving installation from inside the house and/or which give feedback on money and energy saved were good ideas. The feedback idea reinforces the demand for more informative and easier to understand SWH controls. More adopters than non-adopters would like to see integrated systems, e.g. a SWH and condensing boiler package such as offered by one major manufacturer. 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.

Innovative micro-generation/renewable systems

Innovative technologies in the on-line survey included micro-CHP (domestic combined heat and power units that generate heat and electricity); solar photovoltaic (PV) roofs and micro-wind turbines to generate electricity for direct household use, with any surplus fed into the National Grid. There are only about 3000 such installations in the UK (DTI, 2006), so there were too few adopted by our respondents to make generalisations (3 micro-CHP, 12 PV and 7 micro-wind). However, a surprising number of respondents (59 for micro-CHP and about 130 each for PV and micro-wind) claimed to have seriously considered one or more of these technologies but decided against.

Not unexpectedly, the main barrier to installation was cost (about 50% for micro-CHP and wind), rising to 85% for PV, a very expensive technology. But other important barriers were the uncertain performance and reliability of these technologies, no suitable location for the unit, especially micro-wind turbines, and interconnectedness issues of integrating with existing electricity and/or heating systems. Potential noise and vibration, visual intrusion and planning objections were additional deterrents for micro-wind. *'I live in a suburban area: imagine if everyone had one! Chaotic visual impacts and noise pollution'* said one non-adopter.

There were similarities and differences in improvement ideas for these systems. Apart from lower cost designs, a popular idea was for the system to be financed by an energy supplier, with an agreed feed in price for surplus electricity, and paid back via energy bills. PV and micro-wind systems integrated into buildings were also popular ideas.

Many respondents said that they need more independent information about the technology, performance and economics of micro-generation; the information provided by existing bodies seems too generalised with the details left up to the installers. A proper one-stop shop offering advice, planning permission, and installation and servicing, was a solution suggested by some respondents.

Conclusions

This project provides several lessons for the design and marketing of 'green' technologies. First it shows how important it is to research user requirements when developing such products and systems. LZC products and systems are often designed as purely functional goods without considering the many factors that influence consumer adoption. These factors include other aspects of utility such as health impacts (e.g. irritant insulation fibres) and ergonomics (e.g. harsh CFL lighting); interconnectedness with existing buildings and systems (e.g. solar water heating incompatibility with combination boilers and cold fill appliances), and symbolism (e.g. the perceived ugliness of CFLs).

Price is an obvious barrier to adoption of these technologies, becoming increasingly significant as their cost increases from a £5 CFL or a £100 loft insulation job to a £4000 SHW system or a £15,000 PV roof. Subsidies have had a significant effect on adoption of lower cost systems, but in the UK are insufficient to stimulate the market take-off of costly micro-generation systems; where the ability and willingness to adopt still relies on 'green' households with disposable wealth. Wider adoption of such systems probably requires innovative financing schemes e.g. council tax rebates, repayment loans through energy suppliers.

The research also shows how the problems and benefits consumers experience during installation and use of LZC technologies provides information for their marketing and design e.g. difficulties in setting controls, the disappointing life of some CFLs, the benefits of insulation in both cold and hot weather, the pleasure of showering in solar heated water. The experience of the early adopters provide a useful indications of whether widespread adoption of LZC technologies can be achieved.

Good communications are an obvious stimulus to adoption and effective use; but despite existing schemes consumers still want more independent information and advice, especially on innovative micro-generation technologies. A single body to guide people through all the details of choice, installation and use, or integrated systems from a single supplier are suggested ways of promoting adoption. Where design and technology is changing consumers need to be kept abreast of developments if they are not to reject technologies based on outdated perceptions or experience (e.g. CFLs that are bulky, insufficiently bright and slow to warm up).

Finally, while this paper analyses the factors influencing the market success of these green goods in terms of drivers and barriers to adoption, and problems and benefits in use, our research recognises that consumers' attitudes and motivations are complex and socially embedded (Guy and Shove, 2004) and changing behaviour is often not simply a matter of supporting drivers and benefits or removing barriers and problems but understanding people's lifestyles. Doing so via technical, financing and other improvements that, as far as possible, take lifestyles into account is the first step.

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Appendix: LZC product and system improvement ideas

Table 1 Loft insulation – improvements considered good ideas/would encourage adoption

Improvement idea	Adopters (%) N=237	Non-adopters (%) N=59
Materials that provide the same insulation but are thinner/less bulky	143 (60%)	29 (54%)
More user and environmentally friendly loft insulation materials	180 (76%)	31 (57%)
Systems to provide storage space above the insulation	93 (39%)	17 (31%)
Loft clearance and storage service as part of the installation process	58 (24%)	11 (20%)

Table 2 Heating controls – improvements considered good ideas/would encourage adoption

Improvement idea	Adopters (%) N=282	Non-adopters (%) N=30
Better information/instructions on how to use the controls effectively	102(36%)	8 (27%)
Controls designed for all users (including elderly/disabled)	158 (56%)	10 (33%)
Controls that operate automatically to optimise comfort and save energy	144 (51%)	12 (40%)
Controls that display set heating times and temperature for each room	148 (52%)	10 (33%)
Controls that provide feedback on money and energy used/saved	150 (53%)	11 (37%)
Systems that respond to room use and detect where heating is most required	154 (55%)	13 (43%)

Table 3 CFLs – improvements considered good ideas/would encourage adoption

Improvement idea	Adopters (%) N=266	Non-adopters (%) N=24
CFLs that fit existing light fittings e.g. standard light bulb, spot lamp and candle bulb sizes	191 (72%)	11 (45%)
Different colour rendering e.g. less harsh light quality	111 (42%)	11 (45%)
CFLs that can be dimmed.	147 (55%)	10 (42%)
More powerful CFLs (e.g. 150 watt equivalent)	108 (41%)	6 (25%)
Wider range of lamp fittings for CFLs	106 (40%)	8 (33%)
Even higher energy efficiency	171 (64%)	7 (29%)
Wider availability, in shops, etc.	118 (44%)	7 (29%)

Table 4 Solar water heating – improvements considered good ideas/would encourage adoption

Improvement idea	Adopters (%) N=52	Non-adopters (%) N=149
Lower cost SWH systems	23 (44%)	89 (60%)
Solar panels integrated with the roof	36 (69%)	72 (48%)
Packaged systems e.g. solar water heating plus condensing boiler	25 (48%)	64 (43%)
System financed by energy supplier paid back via fuel bills	23 (44%)	84 (56%)
Installation of solar panels from inside the house	23 (44%)	44 (30%)
SWH systems designed for installation without scaffolding	18 (35%)	39 (26%)
System designed to give user feedback on money and energy saved	29 (56%)	61 (41%)
Guaranteed reliability, durability and payback	25 (48%)	70 (47%)