Journal of Cleaner Production 48 (2013) 250–259

Contents lists available at SciVerse ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Objectives, barriers and occasions for energy efficient refurbishment by private homeowners

Immanuel Stieß [a,*], Elisa Dunkelberg [b]

[a] Institute for Social-ecological Research, ISOE, Hamburger Allee 45, D-60486 Frankfurt/Main, Hessen, Germany
[b] Institute for Ecological Economy Research, IOEW, Potsdamer Str. 105, D-10785 Berlin, Germany

ARTICLE INFO

Article history:
Received 22 April 2011
Received in revised form
24 September 2012
Accepted 30 September 2012
Available online 16 October 2012

Keywords:
Energy efficiency
Low and zero carbon technologies
Private homeowner
Information instruments
Germany

ABSTRACT

By retrofitting their homes to meet stricter energy efficiency standards, private homeowners can reduce home energy use significantly, thus taking a significant step towards achieving a low carbon lifestyle. Although the adoption of low and zero carbon (LZC) technologies can play a key role in achieving significant reductions of CO_2 emissions, current practices are rather disappointing. In Germany, for example, homeowners are moving very slowly when it comes to achieving significant reductions in personal energy use and carbon emissions. In many cases, the maintenance and repair activities being undertaken are those resulting in only subtle improvements in energy efficiency and far less than what would appear to be technically viable. With this in mind, we present the results from a standardized empirical survey of 1000 homeowners in Germany that focuses on homeowner maintenance and refurbishment decision-making. A comparison of homeowners applying LZC technologies vs. those carrying out standard refurbishment measures allows us to consider homeowner objectives and barriers to energy-efficient refurbishment and examine the critical role that the dissemination of information and transfer of knowledge play in achieving energy-efficient refurbishment measures. We further discuss the ways that stakeholder collaboration can improve energy efficiency knowledge transfers and enhance the willingness of private homeowners to adopt LZC technologies.

1. Introduction

The provision of heating and hot water in private households is still responsible for more than 40% of the total energy consumption and greenhouse gas (GHG) emissions in Europe (Lechtenböhmer and Schüring, 2011). Residential building stock is the biggest factor, responsible for an EU-wide average of 30% of total final energy consumption (Itard et al., 2008), with detached and semi-detached housing offering the greatest potential for reductions in energy use (Weiβ and Dunkelberg, 2010). By adopting low and zero carbon (LZC) technologies such as loft insulation, high-efficiency condensing boilers, or renewable heating systems, homeowners can significantly reduce energy demand and related GHG emissions. Recent estimates suggest that an 80% reduction in energy consumption is possible for buildings in Europe (Lechtenböhmer and Schüring, 2011).

During the past decade many EU countries have launched political initiatives to tap this potential and improve home energy efficiency. In 2002 the Energy Performance of Buildings Directive (EPBD) established the political framework for the EU countries' national policies on energy efficiency. In 2010 the directive was relaunched and the German government adopted an energy efficiency program with the ambitious goal of an 80% reduction in primary energy demand (PED) in its building stock by 2050 (BMWI and BMU, 2010). The measures to increase energy efficiency in Germany are codified in the Energy Conservation Act (Energieeinsparverordnung; EnEV) and the Renewable Energies Heating Act (Erneuerbare-Energien-Wärmegesetz; EEWärmeG). In addition to these two regulatory instruments, financial incentives and subsidies provided by the German state-owned development bank the KfW Group are intended to further encourage homeowners to implement energy-efficient refurbishment measures.

Despite these efforts, roughly 80% of the housing stock in Germany still is found lacking with respect to state-of-the-art technology, and energy efficiency improvements are increasing at a very slow pace. The annual rate of energy efficient refurbishment in the entire building stock has only gradually increased, from 1.6% in 1994 to 2.2% in 2006 (BMVBS, 2007), and growth in the annual

* Corresponding author. Tel.: +49 69 7176919 19; fax: +49 69 7176919 11.
E-mail addresses: stiess@isoe.de (I. Stieß), elisa.dunkelberg@ioew.de (E. Dunkelberg).

0959-6526/$ – see front matter
http://dx.doi.org/10.1016/j.jclepro.2012.09.041

rate for detached and semi-detached homes is even weaker (Weiβ and Dunkelberg, 2010). Projections show that if these rates continue unchanged, complete facade insulation of the entire building stock will not be achieved until roughly the end of the century (Weiβ et al., 2012; Weiβ and Dunkelberg, 2010).

With this background in mind, we examine the driving forces, motivational factors, and barriers that influence the adoption of LZC technologies among private homeowners in Germany. Our guiding assumption is that the decision to undertake an energy-efficient refurbishment emerges from a complex interplay of socio-cultural, economic and contextual factors (Stieβ et al., 2009; Zundel and Stieβ, 2011); such a decision furthermore requires specialized information and technical knowledge (cf. Coltrane et al., 1986; Mahapatra et al., 2011), which obligates homeowners to interact with various professionals in order to gather, select and evaluate information about the installation, use and potential impacts of innovative LZC technologies.

By drawing on an empirical survey of 1008 homeowners who retrofitted their homes, it is possible to examine how expectations and attitudes towards refurbishment and technology can promote or hamper energy efficient refurbishment. Particular emphasis is given to the means by which homeowners deal with the need for expert knowledge to overcome uncertainties related to such measures.

2. Conceptual framework

The installation of LZC technologies can improve a building's energy performance and transform the daily energy use options of its occupants. Such technical interventions have to be carefully planned given the substantial investments required and the necessary planning horizon of years or even decades. Unlike routine energy use practices, the implementation of such measures is the result of purposeful planning and strategic long-term decisions concerning energy consumption – decisions that are made only a few times in a person's life.

Social scientists stress that the adoption of LZC technologies is not guided by economic considerations alone, but is socially embedded in and shaped by personal and contextual aspects; socioeconomic factors such as age, education and income are often found to influence our decisions about energy conservation measures (Scott, 1997; Martinsson et al., 2011; Herring et al., 2007). Based on a brief review of recent studies, Nair et al. (2010a,b) identify a specific set of personal and contextual factors that may influence the adoption of energy efficiency measures. The relevant personal factors include in particular education, income, age, and gender, as well as attitudes towards energy saving and awareness of energy efficiency measures. Building age, thermal comfort, perceived energy costs and past investment form important contextual factors (Nair et al., 2010a). Drawing on approaches from cultural sociology and technology studies, other authors argue that the perception and acceptance of energy-efficiency measures is socio-technically constructed. Gram-Hanssen et al. (2007) demonstrated that socio-cultural factors shaping consumption practices in everyday life, such as comfort and convenience, aesthetics, fashion or an interest in new products, may also play an important role for the adoption or rejection of LZC technologies. They thus argue that the influence of housing practices and related attitudes towards the home, its maintenance, upkeep, and improvement must be taken more closely into consideration.

Fig. 1 shows a refurbishment decision model that was developed as a conceptual framework for the empirical survey (Stieβ et al., 2009). The model includes personal factors in the form of socio-demographic situation (age, education), and resources (income, assets and technical skills – resources II); it gives particular emphasis to attitudes towards energy efficiency, refurbishment, housing and life-styles.

Contextual factors are another important aspect of the model. In addition to the age and the technical condition of a building, the model accounts for particular situations or "occasions". Such situations are associated with a building's condition, but at the same time are linked to an activity of the homeowner; for example, the decision to carry out a larger refurbishment may be more probable in a situation where a homeowner has to replace defective technical equipment or appliances or refurbish worn or damaged parts of a building. In such situations the installation of LZC technologies is more feasible given that only the so-called additional costs need be compensated by energy cost savings within the customary refurbishment cycle. In the example of facade insulation, homeowners refurbishing a building exterior have to pay for expenses such as scaffolding and painting no matter what; thus only the materials and labour expenses directly related to insulation measures lead to additional costs (Weiβ et al., 2012). Against this background, the adoption of LZC technologies presumably occurs more often when a building component reaches the end of its refurbishment cycle. Another relevant occasion might be at the time of change of ownership given that new owners are more likely to invest in modernization measures.

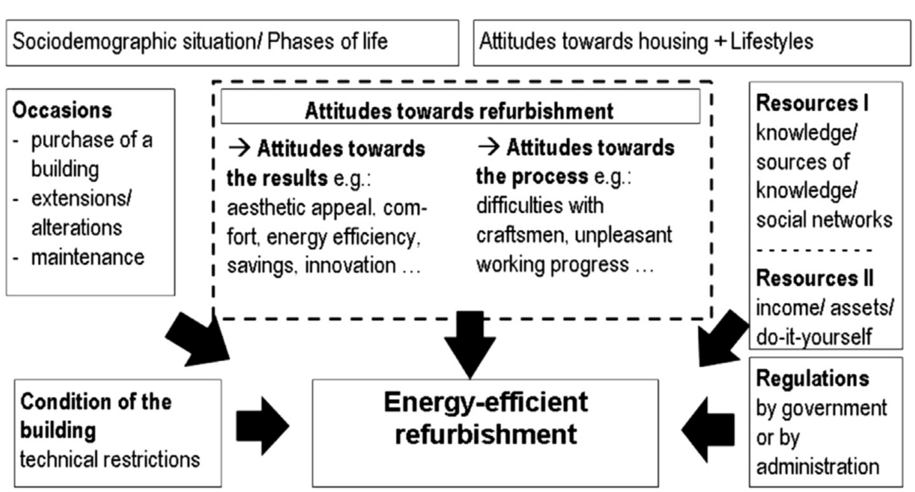

Fig. 1. Model of the refurbishment decision (adapted from Stieβ et al., 2009).

Access to information is also an important factor in the model within the wider decision-making context. Refurbishment is a complex activity requiring specialized information and skills (Resources I). Homeowners are not usually trained in construction and technology and thus must find ways to cope with the need for expert knowledge. While this is true for all refurbishment activities in general, Nair et al. (2010b) argue that an appropriation of expert knowledge is particularly important in the context of LZC technologies. The adoption of LZC technologies, they suggest, should be viewed as an innovation process consisting of several stages: First, homeowners must recognize the need for innovation; second, they have to collect information about the possible choices; and third, they have to select the most appropriate innovation based on an evaluation of the alternatives. Homeowners who want to make energy efficiency improvements during refurbishment face a complex set of questions concerning performance of the various technical options, reliability, benefits and risks, and compatibility with existing electrical and plumbing systems. Communication and transfer of knowledge from external sources is thus a crucial prerequisite for the successful adoption of LZC technologies.

There exists a broad debate in the social sciences on the diffusion of knowledge about energy efficiency, the essence being that information is not simply passed on from the expert to the user, but rather needs to be contextualized and socially embedded (Guy and Shove, 2007). In this process, expert knowledge has to be actively translated, evaluated against the views and opinions of other experts and laypersons, and adapted to the context of everyday life (Bartiaux, 2008; Desmedt et al., 2009). This requires that the expert knowledge be considered trustworthy and consistent with the view of other persons in the homeowner's social network (Coltrane et al., 1986; Gram Hansen et al., 2007; Hobson, 2003). From this perspective, one could presume that homeowners adopting LZC technologies are relying on information sources different from those chosen by homeowners undertaking conventional refurbishment measures.

Finally, legal regulations are another contextual factor in the refurbishment decision; this factor, however, has only limited importance for the scope of this study, as most regulations specifically address new construction and only a few requirements are applicable to the refurbishment of existing buildings (Weiβ et al., 2012).

Based on this model and an exploratory survey, we formulated several hypotheses concerning personal and contextual factors:

1. The potential adoption of LZC technologies is the result of an alliance of economic and non-economic considerations and motivations.
2. Adoption of LZC technologies is more likely at the time of change of ownership.
3. Investments in LZC occur more frequently in conjunction with the replacement of broken, defective or worn components and are thus closely linked to the life or refurbishment cycle of technical devices and building components.
4. Consultation with an energy advisor leads to an investment in more energy-efficient measures and qualitatively more ambitious measures.
5. Homeowners often believe that their home's energy performance is better than it actually is; a lack of accurate information about actual energy performance is thus an obstacle to LZC investment.

3. Data and methodology

Our paper is based on an empirical survey of homeowners of single and semi-detached homes that explores the key factors influencing the decisions of private homeowners with regard to energy-efficient refurbishments (Stieβ et al., 2010).

As the first step, an exploratory, largely qualitative, in-depth study of 44 homeowners was conducted. The study included homeowners who had adopted LZC technologies as well as those who had carried out standard refurbishments (no specific emphasis on energy efficiency). The main goals of this explorative study were to identify the main objectives and barriers regarding energy efficient refurbishment, refine the conceptual model, and develop hypotheses on the adoption of LZC technologies (Stieβ et al., 2009); the results led to the set of hypotheses presented in the preceding chapter.

In a second step, an empirical survey of 1008 owners of single and semi-detached homes in Germany was conducted. The sample included homeowners who had renovated or modernised some or all of the exterior structural envelope (walls, roof, or windows) or the heating system in the period 2005–2008. The sample consisted of two groups:

- STANDARD group: Homeowners who conducted a standard refurbishment using technology meeting relatively low efficiency standards (e.g. painting the facade, installing a low temperature boiler or conventional double-glazed windows).
- ENERGY group: Homeowners who carried out energy-efficient refurbishment measures using LZC technologies having a high energy efficiency potential or utilising renewable energies (facade insulation, roof insulation, basement ceiling insulation, triple-glazed windows, installation of wood pellet or wood chip heating systems, solar heating collectors, heat pumps, condensing boilers, insulation of heating pipes).

Classification into these two groups was based on the outcome of the refurbishment decision and does not necessarily reflect the respondents' intentions or objectives.

The survey was conducted using computer-aided personal interviews (CAPI) in spring 2009. Potential participants were chosen from a random selection of homeowners in Germany and contacted by phone using a brief screening questionnaire asking whether they had retrofitted their home in the past four years and what kind of measures had been applied. Homeowners who had carried out conventional measures were assigned to the standard refurbishment subset; those who had carried out at least one measure meeting at least one of the predefined criteria for energy-efficiency effectiveness were assigned to the energy-efficient subset. The sampling protocol called for the two subsets to be equally represented; the final sample thus contained 541 homeowners having done energy-efficient refurbishment and 467 homeowners standard refurbishment.

The questionnaire included a comprehensive set of questions regarding technical aspects of each building's condition and the measures undertaken; this allowed us to calculate the pre- and post-refurbishment energy standard for each residential structure using a freely available spread sheet tool ('Kurzverfahren Energieprofil', KVEP) developed by the German Institut für Wohnen und Umwelt (IWU, 2006). The calculations are based on the guidelines of the German Energy Conservation Regulations (EnEV), and the spread sheet includes typical default thermal transmittance values for building components of various materials and years of construction.

4. Results

In this paper we will focus on the results from the descriptive statistical analysis, comparing the ENERGY and the STANDARD groups. The two groups share a similar socio-demographic structure and income levels; however, they differ considerably regarding their attitudes and refurbishment objectives and access to information.

4.1. Refurbishment situation and objectives

With respect to personal factors, homeowners' attitudes towards refurbishment are clearly shaped by a number of motives and/or objectives (see Table 1), and the two groups differ in the reasons they give for their decision to refurbish. STANDARD group members are mainly driven by aesthetic or functional concerns, their goals being to embellish their home, do necessary maintenance work, or maintain or increase the value of their home. The small range of objectives suggests that many homeowners in this group see refurbishment from a pragmatic or functional point of view: retrofitting is done as required to maintain a functional home.

Members of the ENERGY group, in contrast, show another, more comprehensive, set of motives for refurbishment. The most important motives and objectives stated by the ENERGY group are to save heating energy and reduce energy and operating costs. Improvement of indoor climate is a strong motive for refurbishment in both groups, but it is particularly important for the ENERGY group. Other motives and goals stated more frequently in the ENERGY group are a wish to contribute to climate protection or to become less dependent on fossil fuels. Interest in the newest technology turns out to play a vital role for energy-efficient refurbishment given that there is a huge difference between the two groups in terms of interest in technology. The majority of the ENERGY group (77%) stated that they strongly or somewhat agree with the motive to "install up-to-date technology in their homes" compared to only 28% of the STANDARD group.

These findings confirm Hypothesis 1 that the adoption of LZC technologies is not driven by economic concerns alone, but results from an alliance of economic and non-economic motives and objectives. Obviously, the desire to consume less energy and to reduce energy costs is a key driver for energy-efficient refurbishment. But homeowners' refurbishment decisions are shaped by a rationality differing from that of conventional investment calculations. The majority of homeowners do not expect an immediate return on investment; they associate the economic benefits of LZC technologies with a medium or long-term perspective and a desire to become more independent from the vicissitudes of fluctuating energy markets (Zundel and Stieβ, 2011). But these gains have to be in line with other non-economic benefits such as an increase in (thermal) living comfort, the adoption of advanced and/or prestigious technology, or support of a low-carbon lifestyle.

The close association between refurbishment and change of ownership is supported by the empirical findings. Table 2 shows that more than 40% of the homeowners in the ENERGY and the STANDARD groups acquired their home in the year 2000 or after. The associated refurbishment activities were carried out between 2005 and 2008, thus demonstrating a relatively close connection between acquisition and refurbishment for these respondents. There was, however, no indication of a correspondence between the timing of these two events and one or the other of the two subset groups. A considerable proportion of the homeowners who retrofitted their relatively newly acquired homes did not improve energy performance significantly (see Table 1); Hypothesis 2 can thus only be partially confirmed.

Maintenance and more substantial renovation projects represent particularly suitable opportunities for installing LZC technologies; approx. two-thirds of the homeowners agreed strongly or somewhat that refurbishment was carried out because of necessary maintenance work (Table 1); only slight differences, however, could be found between the two homeowner groups. This finding supports Hypothesis 3, that the implementation of LZC technologies is likely to occur in the course of replacing broken, defective or worn components and that it is linked to the life cycle of the building's technical components. But major retrofits are nonetheless frequently carried out without substantial improvements in energy efficiency, and many homeowners thus miss this opportunity for feasible energy efficient refurbishment.

4.2. Information sources used for refurbishment

Members of the ENERGY group used a broader range of information sources and informed themselves more comprehensively than the STANDARD group, but in both groups the information sources ranged widely (see Table 3).

Both groups consulted experts for advice on refurbishment; however, they chose different professionals for their information. Tradesmen and building centres are the only experts that are more often consulted by STANDARD group members than by ENERGY group members. The ENERGY group more often turned to a broader range of specialists instead, including heating installers,

Table 1
Objectives of homeowners with energy-efficient vs. standard refurbishments (adapted from Zundel and Stieβ, 2011).

"A house can mean various things to its owners and this often influences our plans for the future. Which statements apply to you?"
Scale with four values: strongly agree (1), agree somewhat (2), disagree somewhat (3), strongly disagree (4)
Energy-efficient refurbishment: $n = 541$; standard refurbishment: $n = 467$

	Mean		*t*-Test
	ENERGY	STANDARD	Sig.
Embellish the home	2.50	1.80	.000*
Save heating energy	1.62	3.14	.000*
Reduce energy costs as far as possible in the long run	1.69	3.17	.000*
Reduce operating costs	1.81	3.16	.000*
Create a better and more comfortable indoor climate	2.08	2.63	.000*
Maintain the home's value	2.07	2.42	.000*
Increase the home's value	2.09	2.39	.000*
Install up-to-date technology	2.04	3.14	.000*
Make a contribution to climate protection	2.27	3.44	.000*
Become less dependent on fossil fuels	2.69	3.54	.000*
Perform necessary maintenance	2.19	2.34	.037*
Replace a defect or broken building component	2.60	2.82	.003
Respond quickly to a problem or defect	2.78	2.85	.294
Remedy a structural defect	3.03	3.00	.692
Create more living space in the house	3.22	3.17	.490

*Significant at 5% level.

Table 2
Date of home acquisition of homeowners with standard vs. energy-efficient refurbishments (adapted from Stieβ et al., 2010: 29).

"What year did you acquire the house?"
Energy-efficient refurbishment: $n = 541$; standard refurbishment: $n = 467$

	Percentage	
	ENERGY	STANDARD
1979 and before	5	6
1980–1989	15	15
1990–1999	33	35
2000–2008	47	44

Table 3
Sources of information for refurbishment (adapted from Stieβ et al., 2010, p. 38).

"There are many different sources of information and ways to get advice on refurbishment. Which information sources did you use?"
Energy-efficient refurbishment: $n = 541$; standard refurbishment: $n = 467$

	Percentage	
	ENERGY	STANDARD
Tradesman/craftsman (other than heating installer)	71	81
Colleagues and/or friends	59	55
Family and/or relatives	51	42
Building centre/home-improvement market	39	45
Internet	49	32
Heating installer	52	17
Leaflets, guidebooks or other literature	38	24
Chimney sweeper	34	20
Journals/periodicals	31	18
Manufacturer	27	15
Architect	24	13
On-site energy assessment by energy advisor	22	3
Energy advice from municipality	14	2
Energy advice from consumer advice centre	11	3
Energy advice on telephone	9	2

chimney sweeps, architects, and manufacturers. The ENERGY group was also more likely to draw on the Internet, handbooks, and journals as sources of information on refurbishment; they also were more likely to seek professional energy advice. This is in line with Nair et al. (2010a), who identified material suppliers and energy advisors as the most important external information sources in making a decision to proceed with energy efficiency measures.

The fact that homeowners in the STANDARD group consulted fewer sources of information than the ENERGY group members can be seen as an outcome of the large investment costs associated with an energy-efficient refurbishment. The decision to reduce heating costs and save energy opens up a number of options, most which require a substantial financial investment. This is confirmed by Nair et al. (2010a), who note that investment-intensive decisions, in particular, lead to a greater search for external information sources; thus the ENERGY group's greater demand for information resources is not surprising.

In both groups the homeowners' own social network plays a vital role in obtaining information on refurbishment. Colleagues, friends, relatives and neighbours are important sources of information for both groups. Unlike professional experts or companies, these persons are viewed as impartial sources of information having no financial self-interest and are thus regarded as more trustworthy. Coltrane et al. (1986) found that the credibility of information sources as a function of trustworthiness and expertise was an important factor for the success of energy conservation programs. The trustworthiness of an information source, however, does not guarantee an increase in energy efficiency; as our results indicate, many discussions with neighbours or relatives only lead to a STANDARD level of renovation. It is therefore important to generate community awareness about the importance and usefulness of energy conservation. The process of learning begins with individuals seeking to increase their tacit knowledge – their own level of familiarity with the subject; this involves the acquisition of information from the mass media, friends, neighbours and energy suppliers (Darby, 2006). In this process, there is a vivid exchange of knowledge between multiple and heterogeneous sources and actors, including experts as well as members of one's own social network. Energy agencies can support this learning process by fostering interaction between early adopters of LZC technologies and other homeowners in social networks or through local neighbourhood initiatives.

4.3. Barriers to a comprehensive energy-efficient refurbishment

An analysis of the barriers facing homeowners who are considering energy efficiency improvements underlines the crucial importance of communication to the successful adoption of LZC technologies. Homeowners give various reasons for not carrying out a comprehensive energy-efficient retrofit (see Table 4), and although significant differences regarding specific barriers are found between the two groups, both show a similar tendency with respect to perceived barriers.

The main barriers to the adoption of LZC technologies in both groups were related to a lack of personal involvement in the issue and/or economic reasons. Furthermore, 62% of the STANDARD and 60% of the ENERGY group agreed either fully or somewhat that their home already was in good condition and that there was no reason for further energy-efficient refurbishment measures. This finding is in line with results of Nair et al. (2010a), who found that the majority of Swedish homeowners were satisfied with the existing thermal performance. Section 4.5 deals with the question of how closely (or not) this view corresponds to actual performance values.

The unwillingness to borrow money was the main barrier for both groups, but was particularly important to the STANDARD group, with agreement from roughly two-thirds of the respondents. A lack of financial resources for an energy efficient refurbishment was cited by roughly half of the respondents. Given that those measures with the highest energy-saving potential (renewable-energy heating systems and thermal insulation) are associated with substantial investment costs (see Weiβ et al., 2012), the lack of financial resources and the unwillingness to take out a loan present serious hindrances to achieving high energy efficiency levels. The substantial upfront costs of conservation measures and a lack of access to financial means were also identified as important barriers in Levine et al. (2007) and Huber et al. (2011).

Uncertainty as to whether investments in LZC technologies will pay off or have the desired impact is another reason homeowners shrink back from energy efficient refurbishment. Although most of such measures are economically viable when carried out within the customary refurbishment cycle (Weiβ et al., 2012), many homeowners stated that they were uncertain about whether

Table 4
Main barriers to energy-efficient refurbishment – homeowners having undertaken energy-efficient vs. standard refurbishments (adapted from Zundel and Stieβ, 2011).

"There are various reasons for not undertaking an energy-efficient refurbishment. Which of these statements apply to you?"
Scale with four values: strongly agree (1), agree somewhat (2), disagree somewhat (3), strongly disagree (4)
Energy-efficient refurbishment: $n = 541$; standard refurbishment: $n = 467$

	Mean		*t*-Test
	ENERGY	STANDARD	Sig.
I am unwilling to take out a (further) loan	2.25	2.07	.003*
My home is in a good condition, and does not need further refurbishment	2.31	2.36	.343
I am not interested in doing more upkeep than necessary	2.57	2.26	.000*
I am not sure whether the investment will pay off	2.66	2.33	.000*
No time to deal with the topic	2.70	2.50	.002*
I worry that this would entail too much dirt or stress	2.72	2.50	.001*
I lack the necessary financial resources	2.64	2.53	.077
The credit line for the house is exhausted	2.84	2.93	.170
The technology is not yet fully developed	3.23	3.28	.348
I worry about damage to the structure (e.g. mildew)	3.46	3.33	.013*

*Significant at 5% level.

refurbishment measures will be profitable, with homeowners in the STANDARD group being more likely to agree with the statement "I am not sure whether the investment will pay off". Anxieties about the difficulties of installation (the mess, the added stress, potential for things to go wrong) may also lead homeowners to avoid LZC technologies. Members of the STANDARD group, in particular, expressed concern that energy-efficient refurbishment would bring too much "mess and stress" into their lives.

4.4. Energy advice and the adoption of LZC technologies

Professional advice plays a vital role in the decision process in the run up to refurbishment. The survey's results indicate that the STANDARD group and the ENERGY group show differing attitudes towards professional advice Table 5. Members of the STANDARD group more often stated that they were familiar with refurbishing and therefore did not need any professional advice; mistrust of such professionals is also more common in the STANDARD group. A majority in both groups disagreed somewhat or strongly with the statement that professional advice is not needed as it is available from personal contacts and acquaintances. This is remarkable as many homeowners asserted that they relied on discussions with family, friends, or colleagues as a source of information on refurbishment. Consulting those from one's own social environment thus contributes another perspective, but does not seem to replace the need for professional advice.

Homeowners in the ENERGY group made more frequent use of professional energy-efficiency advice or assessments than those in the STANDARD group (24% vs. 7%), but the overall low figure is an indicator that many homeowners are not aware of such services. According to Mahapatra et al. (2011), 43% of Swedish energy efficiency consultants believed that less than 50% of the homeowners were aware of such services.

In Germany, homeowners can choose from a broad range of energy assessment options and professional consulting services offered by various suppliers. Energy assessments are available from consumer advice centres, local municipalities, and energy suppliers and in numerous forms, with varying types of interaction between users and experts. Advisory services can be provided in person, on site, via the Internet or even on the telephone. Services provided via telephone are usually free of charge, while on-site offers are generally provided for a fee. One of the most comprehensive energy assessments in Germany is the so-called "BAfA-Vor-Ort-Beratung", a standardized on-site assessment. The German government offers a roughly €300 subsidy for the service, but homeowners have to pay the remaining €300–400 themselves. After calculation of a building's energy performance using certified computer software, consultants recommend specific measures as well as a general package of energy-efficient refurbishment measures (BAfA, 2009).

Homeowners seem to prefer services that are provided on-site. More than half of the homeowners asking for an energy consultation used this type of assessment. A broad and detailed on-site assessment is particularly appreciated by homeowners carrying out comprehensive refurbishment measures. The share of homeowners using this type of assessment increases with the size of the investment and the building's age; thus it is greatest among homeowners with an investment sum of more than €50,000 and a pre-1948 building structure. The average number of implemented measures also differs significantly between those utilising energy advisors and those not (2.4 vs. 1.2, 5% significance level). Homeowners relying on energy advisors are in particular more likely to invest in insulation, replacement windows, condensing boilers, and renewable energies (see Table 6). Still, in both groups only a few homeowners have implemented renewable energy technologies such as heat pumps and solar collectors. An extensive database of more than 7500 houses representing residential building stock in Germany also showed that only 9% of the residential buildings had a solar collector in 2010; in 3% biomass was the main energy source, and in 2% heat pumps were used (Diefenbach et al., 2010). High investment costs are probably the main obstacle to widespread use of renewable energies: a high efficiency boiler, for example, currently entails roughly €6000; for a heat pump system, procurement and installation costs of €17–25 thousand must be anticipated (cf. Weiβ et al., 2012).

A majority of homeowners who contacted an energy expert appreciated the relevance of such services; 49% considered the energy advice to be very important and 40% important for the decision-making process; 25% indicated that they modified their original refurbishment plans as a result of the energy assessment or advice received and 18% implemented additional energy-saving measures. There are several reasons for these relatively low figures. Many homeowners planning a comprehensive refurbishment utilising innovative LZC technologies may only be consulting an independent energy expert for the purpose of avoiding potential mistakes. Or a consultation with an energy expert may be

Table 5
Attitudes towards professional advice – homeowners with standard vs. energy-efficient refurbishment adapted from Stieβ et al., (2010).

"Attitudes towards professional advice on home refurbishment vary. Which statements apply to you?"
Scale with four values: strongly agree (1), agree somewhat (2), disagree somewhat (3), strongly disagree (4)
Energy-efficient refurbishment: $n = 541$; standard refurbishment: $n = 467$

	Mean		*t*-Test
	ENERGY	STANDARD	Sig.
I do not need paid professional advice as I am familiar with refurbishing.	2.84	2.65	.001*
I always seek professional advice so as to avoid mistakes.	1.93	2.28	.000*
If I plan to carry out any refurbishments, I will ask for professional advice.	2.06	2.37	.000*
I can always get advice from friends and other people I know; I do not need professional advice.	2.73	2.70	.521
I do not trust professional consultants.	3.12	3.01	.035*

*Significant at 5% level.

Table 6
Implemented refurbishment measures – homeowners with vs. without using energy advices.

No energy advisor: $n = 768$; with energy advisor: $n = 240$

	Percentage	
	No energy advisory services	With energy advisory services
Painting and mending facade	43	27
Replacement door	23	18
Replacement windows	36	57
Installation of low temperature boiler (gas/oil)	6	8
Installation of condensing boiler (gas/oil)	16	28
Installation of biomass heating system	2	10
Installation of heat pump	2	6
Installation of solar collector	1	15
Heating pipe isolation	6	17
Insulation of facade wall	8	30
Insulation of roof or upper ceiling	8	23
Insulation of basement ceiling	4	12

required as a condition of the energy efficiency funding or loan agreement – funding from the KfW Bank Group, for instance, is linked to an obligatory BAfA on-site consultation.

Hypothesis 4 is thus corroborated by the findings. The scope of the positive effect of energy advising services overall, however, is rather limited given that their use is restricted to those already determined to improve the energetic performance of their homes. The majority of homeowners in the STANDARD group will probably not actively seek out professional energy advice.

4.5. Energy performance before and after refurbishing

Pre- and post-refurbishment primary energy demand (PED) was calculated based on the empirical data from the survey. Before refurbishment the mean PED in the sample was 281 kWh m^{-2} a^{-1}. Following refurbishment it dropped to 231 kWh m^{-2} a^{-1}. Prior to retrofitting, the STANDARD group showed a lower mean PED than the ENERGY group; after refurbishment this was reversed (see Table 7); both differences are statistically significant at the 5% level. Buildings of homeowners who used energy assessments or advisors also showed a higher PED before retrofitting compared to those not utilising such services. Since a small number of STANDARD group members did rely on an energy advisor ($n = 33$), not all differences are statistically significant.

Refurbishments in the STANDARD group led to small energy reductions, averaging only 6%; in the ENERGY group an average reduction of 22% was realized. Insulation of facade walls, roof insulation, and deployment of renewable energy heating systems were in particular responsible for large reductions in the PED (Weiβ et al., 2012). Still, the reduction in the ENERGY group is low compared to the estimate of 80% potential energy savings in the residential building stock (Lechtenböhmer and Schüring, 2011).

A reason for the relatively small reduction in PED is that even homeowners in the ENERGY group rarely carried out comprehensive energy-efficient refurbishments; less than 25% implemented more than two such measures in the period 2005 to 2008. These results suggest that in both groups potential energy savings remain untapped. Similar results can be found when comparing those relying on energy consultants to those not (Table 7): Those who consulted an energy advisor achieved greater energy savings – whereby greater energy savings are linked to both larger pre-refurbishment PEDs as well as larger numbers of LZC measures (see Table 6). Comprehensive energy-efficient refurbishment, however, remains the exception.

Given that informed homeowners – those knowledgeable about the true state of their building's structure and thermal condition – are more likely to undertake energy-efficient refurbishments than those not, accurate information about a building's energy performance is a crucial prerequisite for the adoption of LZC (cf. Nair et al., 2010a). As shown in Section 4.3, many homeowners considered their homes to be in good condition after refurbishment and therefore planned no (further) energy efficient refurbishment. The data in our survey show a correlation between homeowner statements about a building's energy performance and the actual PED (see Fig. 2); however, one should keep in mind that the standard deviation is quite high.

As shown in Table 7 and Fig. 2, buildings belonging to homeowners in the STANDARD group had a lower average PED before refurbishment and a higher average PED after refurbishment than did those of the ENERGY group, and only 13% of the structures in the STANDARD group included at least one insulated component (facade, roof, upper ceiling, or basement ceiling) *after* refurbishment. In the ENERGY group a considerably higher percentage of 50% of all structures was insulated. In both groups the percentage of insulated structures is slightly lower for those respondents who fully disagreed that their home is in good condition.

These results allow two remarkable conclusions: Although they do not have detailed information, many homeowners can assess their home's energy performance reasonably well. At the same time it seems that members of the STANDARD group are more likely to believe their home to be in good condition than members of the ENERGY group, even though their structures exhibit higher energy demands. The small proportion of insulated building components in the STANDARD group indicates a large untapped potential for additional energy savings – particularly in this group. Thus, in spite of reasonable knowledge about a building's energy performance, homeowners, especially those in the STANDARD group probably underestimate the current energy saving potentials. Hypothesis 5 (homeowners often misjudge their home's energy performance; lack of accurate information is thus an obstacle to LZC investments) can therefore neither be verified nor falsified.

4.6. Recommendations for improving policy instruments

The findings presented in this paper prove that the refurbishment activities of homeowners in Germany are far below what is needed to meet the German government's ambitious goal of reducing PED in the German building stock by 80%. Drawing on our refurbishment decision model and the findings from the empirical survey, it is possible to discuss some implications for improving homeowner adoption of LZC technologies.

Starting with personal factors, we find a broad array of attitudes and motives supporting the adoption of LZC technologies, including economic, ecological and technical concerns as well as the desire for greater thermal comfort. These motives are widespread among homeowners and our empirical data suggest that they are shared by a majority of them. There is, however, a small contingent of

Table 7
Mean PED before and after retrofitting – STANDARD vs. ENERGY group (standard deviation).

	Mean PED (kWh m^{-2} a^{-1})	
	Pre-retrofit	Post-retrofit
STANDARD		
As a whole	268 (109)	252 (92)
With energy advisor or assessment	322 (133)	272 (84)
No advising services	263 (106)	249 (92)
ENERGY		
As a whole	294 (128)	214 (84)
With energy advisor or assessment	305 (132)	200 (83)
No advising services	287 (125)	223 (84)

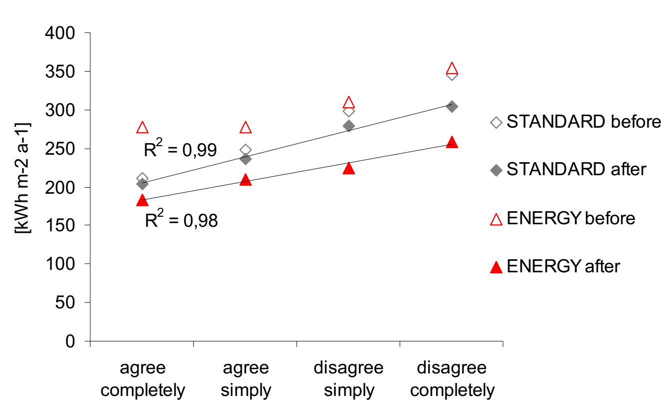

Fig. 2. PED before and after retrofitting linked to the statement: "My home is in good condition, and does not need further refurbishment" – STANDARD vs. ENERGY group.

homeowners who are not willing to improve the energy efficiency of their homes and who will only be induced to act by applying stricter legal standards to the existing building stock.

At the same time, our study shows the crucial importance of contextual factors for the successful adoption of LZC technologies. In particular, knowledge, both as expert knowledge about refurbishment measures and accurate information about the energy performance of one's own home are necessary decision-making resources. As the empirical results show, homeowners have a general idea of their buildings' energy performance, but tend to underestimate the potential for energy savings. Information and feedback tools can support homeowners in gaining knowledge about their own building's energy performance and current energy consumption. These instruments can motivate homeowners to improve the energy performance of their homes and to modify their energy consumption behaviour.

The impact of existing informative instruments such as energy performance certificates (EPC) and interactive online tools, however, is known to be very limited. In Germany such performance certificates are only mandatory for rental housing or change of ownership; hence, they are not applicable to the majority of homeowners, who live in single-family homes. Another reason for the minimal impact of EPCs may be that homeowners often do not trust such energy labels (Amecke, 2011; Gram-Hanssen et al., 2007; Gram-Hanssen and Christensen, 2010). Interactive online tools for residential energy-efficient retrofits (e.g. "Heizcheck" and the "Modernisierungsratgeber" in Germany) are a popular source of information (Novikova et al., 2011), but the use of these tools seems to be limited to those who are already confirmed energy savers.

In stakeholder group discussions by Svenfelt et al. (2011) feedback tools such as energy meters and informative billing were suggested by several stakeholders as innovative instruments that help to modify homeowner behaviour and investment will (Svenfelt et al., 2011). Detailed energy use billing statements, providing information on electricity, heat, gas or oil demand, can also function as a feedback tool (Henryson et al., 2000; Novikova et al., 2011). With regard to homeowners the potential of such measures, however, is limited to those relying on gas or district heating (Novikova et al., 2011). More advanced energy meters like those suggested by stakeholder group "residents" (Svenfelt et al., 2011) could also be applied to other types of heating systems, but even if such advanced instruments were broadly implemented, they would only have a limited potential to overcome the main barriers identified above. Feedback instruments provide information about actual energy consumption and thus offer a general motivation to reduce energy demand; however, they do not provide homeowners with useful advice as to how to do so.

Personalised communication has been found particularly effective in conveying information about energy efficiency measures to homeowners (Nair et a. 2010b; Bartiaux et al., 2006; Coltrane et al., 1986), but it should be more consistently and systematically linked to appropriate situations and opportunities such as a change of ownership or replacement of defective parts, when the adoption of LZC technologies is more likely. In each of these situations homeowners usually are in contact with various professionals; in the case of a sale or purchase this might include bank employees, the registry of deeds, or an architectural firm. In the case of renovation or repairs typical contact persons would include tradesmen or building centre employees. Such key personnel should be supplied with informational materials or tools and trained to inform homeowners about opportunities to invest in energy conservation or renewable energies, as well as legal requirements. They should also receive training in communication skills so that they are able to address the specific motivations for and barriers against energy efficient refurbishment.

Although change of ownership represents a particularly suitable occasion for energy-efficient refurbishment, there are nonetheless homeowners who do not even comply (unintentionally, perhaps) with the minimum legally required measures, e.g. renovation of the façade without insulation. Compliance with existing regulations (in particular the EPBD) should thus be enhanced. Weiβ et al. (2012) suggest adopting random audits in order to better utilise the potential of existing law. At the same time, it is clear that the communication between authorities and homeowners is insufficient. The above-mentioned third-party agents such as registry office agents should therefore serve as an intermediary by providing expert advice and emphasising the benefits of timely investments in LZC technology in specific situations.

In Germany, innovative social marketing campaigns have been established at the regional level; they demonstrate how communication of energy efficiency can be targeted to specific refurbishment situations. One example is the campaign "Gut beraten starten" ("a well-advised start"), prepared by the Climate Protection Agency in the Hannover region, which involves the collaboration of energy advisers, tradesmen, local mayors, and the local press. Once the campaign has been announced by local media and in a letter from the local mayor, energy agencies offer homeowners an initial appraisal of their buildings' energy performance. Evaluations show that this type of campaign is a very successful and effective communication tool (Stieβ and Birzle-Harder, 2010).

Thus local energy agencies, climate centres, and consumer organisations can play an important role in accelerating the adoption of LZC technologies, but to do so they have to go beyond their traditional roles of providing technical expertise (knowledge) and information about legal requirements (regulation) and adopt a new role, actively engaging with homeowners and serving as an intermediary and multiplier for energy efficiency among stakeholders and the local public. As independent institutions, such local agencies are well-suited to address specific situations through local public relations work (occasions) and initiate networks among suppliers, energy consultants, tradesmen, and building centres at the local and regional level. From this perspective, energy agencies have the potential to be important agents in fostering collaboration, communication, and interaction between the various stakeholders, much as Svenfelt et al. (2011) call for.

The actual and potential role of such innovative communicative approaches and networks in the refurbishment process has to be analysed and perhaps refined with the help of further research. To the extent that the success of these approaches can be confirmed, such measures should be broadly implemented and supported by the authorities. A broader network similarly involving the various stakeholders, but also including those involved in technical development as well as builders might additionally be necessary on a national scale in order to develop an effective long-term plan for achieving the stated goals (see Svenfelt et al., 2011).

5. Conclusions

Our objectives were to investigate the expectations and attitudes homeowners have towards refurbishment and technology and to analyse the degree to which these promote or hamper the implementation of energy efficient refurbishment. Particular emphasis was given to how homeowners deal with the need for expert knowledge. Drawing on the results of an empirical survey of 1008 homeowners who retrofitted their homes, several hypotheses could be proven.

The empirical results show that the decision to install LZC technologies usually is the result of a combination of personal and contextual factors and is shaped by our wants and everyday needs, including comfort, convenience, social status and belonging, concern for the environment, and of course economic aspects. Homeowners primarily adopt LZC technologies to reduce energy consumption and costs. A majority of homeowners has a positive attitude towards professional energy advisors; such consultations generally lead to an investment in more ambitious and qualitatively better energy efficiency measures.

Such professional consultations and advising, however, are usually limited to those homeowners who are already convinced of the benefits and prepared to adopt innovative LZC technologies. A main challenge is to reach those not yet aware of the benefits of such energy efficiency improvements, who tend to overestimate the energy performance of their homes and therefore underrate the energy saving potential of LZC technologies. Feedback tools that provide information about personal energy consumption such as informative energy bills or an energy meter can help motivate and support homeowners' decision-making, but such measures need to be supplemented by personalized communication and consultations.

The adoption of LZC technologies is also closely linked to specific occasions such as when major renovations or a retrofit are to be undertaken and such energy efficiency investments are more profitable; this would also include change of ownership, as well as other maintenance or refurbishment measures. Unfortunately, the empirical results demonstrate that homeowners often miss such occasions and frequently undertake such projects without investing in LZC technologies. If we are to increase the rate of energy efficiency improvements in the housing stock, a more systematic approach to these situational opportunities is necessary. One potential instrument is the implementation of coordinated campaigns at the local level with participating energy agencies, consultants, tradesmen, the local authorities, and the local press. Such collaborative efforts at the local level as proposed by Svenfelt et al. (2011) already exist in some regions in Germany and are also useful for the efficient compilation of accurate and non-conflicting information.

Additional funding can further promote energy efficient refurbishments by providing the financial resources for more comprehensive improvements. As the empirical results reveal, many homeowners are reluctant to take on additional home loans; thus, financial incentives in the form of subsidies or tax reduction would help. Finally, stricter regulation would support the implementation of more ambitious targets. Legal regulations with a long-term perspective would serve as a roadmap and provide orientation over a greater time frame, making it easier for homeowners to make refurbishment decisions involving time horizons of a decade or more.

Achievement of the ambitious objective established by the German government will further require networking at the national level of experts, intermediate organisations, tradesmen, builders, homeowners, technical developers and the authorities (Svenfelt et al., 2011); coordinated planning and a collaborative approach are required if we are to reach this overall energy reduction target.

Acknowledgements

The authors owe thanks to the ENEF-Haus research team, namely Tanja Albrecht, Barbara Birzle-Harder, Jutta Deffner, Victoria van der Land, Thomas Vogelpohl, Julika Weiβ, and Stefan Zundel. We also thank Annalena Lahav, who contributed to the work with her statistical knowledge, and we are grateful to the German Ministry of Education and Research (BMBF) for funding the ENEF-Haus project (www.enef-haus.de) as part of the Social-Ecological Research Funding (SOEF) programme.

References

Amecke H., 2011. The Relevance of the European Energy Performance Certificate for Purchasing Decisions. CPI Report. Climate Policy Initiative.
BAfA [Bundesamt für Wirtschaft und Ausfuhrkontrolle], 2009. Richtlinie über die Förderung der Beratung zur sparsamen und rationellen Energieverwendung in Wohngebäuden vor Ort – Vor-Ort-Beratung – vom 10. September 2009. Retrieved on 25.5.2010 from. www.bafa.de.
Bartiaux, F., 2008. Does environmental information overcome practice compartmentalisation and change consumers' behaviours? Journal of Cleaner Production 11, 1170–1180.
Bartiaux, F., Vekemans, G., Gram-Hansen, K., 2006. Socio-technical Factors Influencing Residential Energy Consumption SEREC. Final Report.
BMVBS [Bundesministerium für Verkehr, Bau und Stadtentwicklung], 2007. CO2-Gebäudereport 2007. Retreived on 18.03.2010 from. http://www.bmvbs.de.
BMWI, and BMU [Bundesministerium für Wirtschaft und Technologie, Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit], 2010. Energiekonzept für eine umweltschonende, zuverlässige und bezahlbare Energieversorgung.
Coltrane, S., Archer, D., Aronson, E., 1986. The social-psychological foundations of successful energy conservation programmes. Energy Policy, 133–148.
Darby, S., 2006. Social learning and public policy: lessons from an energy-conscious village. Energy Policy 34, 2929–2940.
Desmedt, J., Vekemans, G., Maes, D., 2009. Ensuring effectiveness of information to influence household behaviour. Journal of Cleaner Production 4, 455–462.
Diefenbach, N., Cischinsky, H., Rodenfels, M., Clausnitzer, K.-D., 2010. Datenbasis Gebäudebestand. Datenerhebung zur energetischen Qualität und zu den Modernisiserungstrends im deutschen Wohngebäudebestand.
Gram-Hanssen, K., Christensen, T.H., 2010. Energy Efficiency in Existing Detached Housing—Danish Experiences with Different Instruments.
Gram-Hanssen, K., Bartiaux, F., Jensen, O., Cantaert, M., 2007. Do homeowners use energy labels? A comparison between Denmark and Belgium. Energy Policy 35, 2879–2888.
Guy, S., Shove, E., 2007. The Sociology of Energy, Buildings and the Environment: Constructing Knowledge, Designing Practice. Taylor & Francis Ltd.
Henryson, J., Hakansson, T., Pyrko, J., 2000. Energy efficiency in buildings through information – Swedish perspective. Energy Policy 28, 169–180.
Herring, H., Caird, S., Roy, R., 2007. Can Consumers Save Energy? Results from Surveys of Consumer Adoption and Use of Low and Zero Carbon Technologies. Paper for eceee 2007 Summer Study. Retrieved on 17.8. 2010 from. http://www.eceee.org/conference_proceedings/eceee/2007/Panel_9/9.146/.
Hobson, K., 2003. Thinking habits into action: the role of knowledge and process in questioning household consumption practices. Local Environment 8, 95–112.
Huber, A., Mayer, I., Beillan, V., Goater, A., Trotignon, R., Battaglini, E., 2011. Refurbishing Residential Buildings: A Socio-economic Analysis of Retrofitting Projects in Five European Countries (consulted November 2011). http://www.fedarene.org/documents/projects/EEW2/WSED2011/Huber.pdfS.
Itard, L., Meijer, F., Vrins, E., Hoiting, H., 2008. Building Renovation and Modernization in Europe: State of the Art Review. OTB, Delft Technical University, The Netherlands. Retrieved 30.05.2010 from. www.eracobuild.eu.
IWU [Institut für Wohnen und Umwelt], 2006. Kurzverfahren Energieprofil. Exceltool. Retrieved on 18.3.2010 from. http://www.iwu.de.
Lechtenböhmer, S., Schüring, A., 2011. The potential for large-scale savings from insulating residential buildings in the EU. Energy Efficiency 4, 257–270.
Levine, M., Uerge-Vorsatz, D., Blok, K., Geng, L., Harvey, D., Lang, S., Levermore, G., Mongameli Mehlwana, A., Mirasgedis, S., Novikova, A., Rilling, J., Yoshino, H., 2007. Residential and commercial buildings. In: Metz, B., Davidson, O.R., Bosch, P.R., Dave, R., Meyer, L.A. (Eds.), Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom, New York, NY, USA.
Mahapatra, K., Nair, G., Gustavsson, L., 2011. Swedish energy advisers' perceptions regarding and suggestions to fulfill homeowners expectations. Energy Policy 39, 4264–4273.
Martinsson, J., Lundqvist, L.J., Sundström, A., 2011. Energy saving in Swedish households. The (relative) importance of environmental attitudes. Energy Policy 39, 5182–5191.
Nair, G., Gustavsson, L., Mahapatra, K., 2010a. Owners perception on the adoption of building envelope energy efficiency measures in Swedish detached houses. Applied Energy 87, 2411–2419.
Nair, G., Gustavsson, L., Mahapatra, K., 2010b. Factors influencing energy efficiency investments in existing Swedish residential buildings. Energy Policy 38, 2956–2963.
Novikova, A., Amecke, H., Neuhoff, K., Stelmakh, K., Kiss, B., Rohde, C., Dunkelberg, E., Weiß, J., Matschoss, K., Darby, S., 2011. Information Tools for Energy Demand Reduction in Existing Residential Buildings. CPI Report.
Scott, S., 1997. Household energy efficiency in Ireland: a replication study of ownership of energy saving items. Energy Economics 19, 187–208.
Stieß, I., Birzle-Harder, B., 2010. Evaluation der Kampagne "Gut beraten starten. Im Auftrag der Klimaschutzagentur Hannover und proKlima – Der enercity – Fonds (Frankfurt am Main).

Stieß, I., Zundel, S., Deffner, J., 2009. Making the Home Consume Less - Putting Energy Efficiency on the Refurbishment Agenda. In: Proceedings of the 9th Eceee Summer Study.

Stieß, I., van der Land, V., Birzle-Harder, B., Deffner, J., 2010. Handlungsmotive, -hemmnisse und Zielgruppen für eine energetische Gebäudesanierung. Ergebnisse einer standardisierten Befragung von Eigenheimsanierern (Frankfurt am Main).

Svenfelt, Å., Engström, R., Svane, Ö., 2011. Decreasing energy use in buildings by 50% by 2050 — a backcasting study using stakeholder groups. Technological Forecasting & Social Change 78, 785–796.

Weiß, J., Dunkelberg, E., 2010. Erschließbare Energieeinsparpotenziale im Ein- und Zweifamilienhausbestand. Institut für ökologische Wirtschaftsforschung, Berlin. Retrieved on 01.09.2010 from. http://www.enef-haus.de.

Weiß, J., Dunkelberg, E., Vogelpohl, T., 2012. Improving policy instruments to better tap into homeowner refurbishment potential: lessons learned from a case study in Germany. Energy Policy 44, 406–415.

Zundel, S., Stieß, I., 2011. Beyond profitability of energy saving measures — attitudes towards energy saving. Journal of Consumer Policy 34 (1), 91–105.