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Applied Energy (ISSN: 0306-2619)

Citation for the published paper:
Nilsson, A. ; Jakobsson Bergstad, C. ; Thuvander, L. (2014) "Effects of continuous feedback on households' electricity consumption: Potentials and barriers". Applied Energy, vol. 122 pp. 17-23.

Effects of continuous feedback on households' electricity consumption: potentials and barriers

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Abstract

Two field experiments were carried out to study (a) the effects on energy savings of continuous visual feedback via in-home displays, and (b) the motives for responding or not. In study 1, 40 participants living in separate or semi-detached houses in two different towns participated. All participants received a questionnaire and a list of possible energy saving measures. Households were then randomly assigned to an experimental condition (display) or a control condition (no display). In study 2, 32 households in rented apartments participated. No significant differences between the conditions were found for either of the studies. In study 2, semi-structured interviews were conducted among nine of the households. Through an analysis of interview transcripts barriers were identified explaining why the feedback intervention was not sufficient to change behaviour and reduce consumption. The barriers experienced indicate that there is a risk of overconfidence in IHDs. For the development of energy policies and more wide-scale implementation, it is important to be aware of the potential obstacles to success.

Key words: Electricity consumption, intervention, continuous feedback, in-home displays,

1. Introduction.

A large proportion of the world's energy is used by households. The direct energy use by households in the USA (including car transports) accounts for around 38% of total US carbon emissions [1]. In homes, the use of electricity accounts for more than half of the energy consumed, of which the major part concerns air conditioning. In Sweden, about 20% of the total annual consumption of electricity is related to private household electricity use (lighting, appliances, etc.) [2]. Over the past 30 years, the technical energy efficiency of appliances has improved substantially, while in the same period the domestic electricity demand increased. This can be attributed to an increase in electricity using equipment, for instance kitchen appliances, heat pumps and floor heating [3]. The potential to reduce energy use in most areas is however relatively good. For example, in a recent study [4] the behavioural plasticity (maximum potential for energy reduction through behavioural change) for the use of standby equipment and laundry behaviours is estimated at 35%. Many of these changes in behaviour are also relatively easy for individual households to achieve.

Household energy conservation has been an area of research for applied social and environmental psychology since the oil crises in the 1970s. The results so far have been reviewed a few times over the years [5-7]. This has revealed a picture varying from very positive, for example regarding the effectiveness of frequent feedback, to less clear, in terms of the lasting effects of behavioural changes [7]. However, some of these results and conclusions suffer from methodological shortcomings, such as the combining of different

types of interventions, making it difficult to discern the independent effect of a single strategy. Previous research is also deficient in terms of the attention to the influence of underlying psychological determinants of energy use and energy savings [7].

The overall aim of the present work is to study the influence of feedback on household electricity consumption and to understand the effects, potentials and barriers to electricity conservation. Several shortcomings from previous studies are addressed in these studies. In previous studies participants often take part as a consequence of their own interest, i.e. have a certain interest in energy issues. When preparing for the wider implementation of continuous feedback systems such as IHDs, It's important to investigate the effect of the feedback among households who do not actively seek to participate, and in that respect can be expected to be more similar to a normal population. Previous studies are also lacking in investigating apartments. Since apartments in general have lower electricity consumption, these households may experience lower motivation to conserve electricity compared to private homes. Another lack in previous studies is in depth interviews following interaction with the IHDs. It's important to investigate experienced barriers after the experimental period, especially if the results show small effects. This is investigated by carrying out two field experiments using continuous feedback intervention via in-home displays (IHDs), and a follow up interview study with participating households. Below a brief overview of central concepts and previous research in this area are presented.

Interventions aimed at encouraging households to reduce energy consumption can be divided into antecedence strategies (i.e. information, commitment, goals, modelling) and consequence strategies (i.e. feedback and rewards). It has been found that information alone tends to result in higher knowledge levels, but not necessarily in changes of behaviour or reduced energy consumption [7]. Instead, information in combination with commitment,

commitment alone, modelling (demonstration of the behaviour by others) and goal setting have been found to produce environmentally responsible behaviour [5].

A major obstacle to motivating these types of behavioural changes is that the consequences of the behaviour are delayed. As a result, it is difficult to know which types of behavioural change lead to reductions in energy consumption. In classical psychological learning theory [8], behaviour must be reinforced in order to lead to change. People continue with behaviours that are rewarded, and these rewards are essential to ensuring the repetition of desirable behaviour. The closer in time the consequences of the behaviour are recognised, the greater the impact they will have on the behaviour.

In most feedback intervention studies (see Abrahamse et al.[7] for a more comprehensive review), the feedback contains information about the energy consumption of the households in terms of energy units and/or monetary values. A distinction is made between continuous feedback, in most cases using a monitor or display showing the current consumption; and daily, weekly or monthly feedback, where participants are given information via mail or the internet. Studies using non-continuous feedback generally show rather weak effects on energy consumption [7, 9, 10]. For continuous feedback, most studies find a significant reduction of energy use. For instance, in a recent Danish study using in-home displays, the average reduction was around 8%, compared to less than 1% in the control group during the five-month trial [11]. A literature review by Darby from 2006 describes electricity reductions between 5%-15% for interested users of in-home displays showing both continuous and historic usage [12]. Other recent studies [13-15]have provided additional knowledge about household characteristics and different types of feedback devices, and resulted in a number of recommendations. They include that individual and specific feedback should be provided to the households instead of generalized tips and information applicable to all households [12], the information visualised should be simple and easily accessible; simple

diagrams and pregnant colour symbols are more important than the design concept itself; the distribution of consumption on each electrical appliance is important; and the information visualised on a display may be misleading if the user cannot distinguish between kilowatts and kilowatt-hours [16].

Feedback on electricity consumption in households might contribute to more sustainability in daily household life, yet according to [17] there is a need to know more about people's actual use of electricity and activity patterns in their everyday lives, especially if we are to develop sustainable guidelines and tools for these households. People's motivation to reduce their electricity consumption is also a vital factor to consider if display feedback to households is to be established [18]. The provision of improved and clear information about consumption data in general, and detailed information concerning the rent paid by tenants, are important initiatives that can complement technical interventions in buildings [19, 20].

In order to develop new and more effective ways of designing feedback information, it is important to understand people's motives. Psychological motives are rarely investigated in connection with behavioural change and energy conservation [7]. Most studies in the area report on the effectiveness of different experimental interventions without asking *why* people react to them or not. However, there are some valuable exceptions in terms of studies that use a combination of methods, including focus groups and interviews [11, 21, 22]. These studies show that positive environmental attitudes, as well as an interest in and understanding of the IHDs and the information they provide, appear to be important factors in motivating the households to use the IHDs to engage in electricity-saving behaviour. The aim of the present research is to further investigate this picture and to explore additional motives and perceived barriers.

Two field experiments were carried out to study (a) the effects on energy savings of continuous visual feedback via in-home displays, and (b) the motives for responding or not.

Two different types of housing were chosen. Study 1, a questionnaire survey, focuses on households in single-family and semi-detached houses, while study 2, an interview study, focuses on households in rented apartment blocks.

In both studies, the same type of in-home display (IHDs) was installed. The display provided the household with information on current electricity consumption, historical consumption (Day, Month, Year), as well as estimates of costs and CO_2 emissions from electricity consumption. In-depth information about the in-home display is presented in Appendix I. In order to understand the motives, potential and barriers of continuous feedback in relation to supporting electricity conservation in households, the participants in study 2 were interviewed.

2. Study 1

2.1. Method

2.1.1. Sample and procedures. The study was carried out in cooperation with two Swedish power companies (Alingsås Energi and Eon) and a Swedish construction company (NCC). Separate or semi-detached houses in two municipalities outside Gothenburg (Lindome and Alingsås) were chosen for the study. 100 households were selected randomly from customer registers and contacted by mail and telephone. In Alingsås 22 households chose to participate, while 20 of the households in Lindome chose to participate. Two questionnaires were sent out and after three reminders; a total of 40 households completed both. Out of these 40, one household reported a non-functional display and another household reported being away for parts of the research period.

Households were contacted via a request letter. The request letter provided participants with information about the duration and purpose of the study. On typing in a web address printed in the letter, participants were led to an Internet-based questionnaire. The request letter stressed that the survey participant had to be the person paying the electricity bill in the household. This was important, as respondents were asked to provide researchers with a letter of authority to obtain information concerning the household's electricity consumption from its utility provider. All respondents authorised this request. The households participating in the study did not receive any monetary compensation, but they were informed that they could participate in a lottery with a chance to win an energy saving device.

All participants received the first questionnaire and a list of potential energy savings. Households were then assigned randomly to an experimental versus a control condition, with 20 households in each group (see *Table 1*). Displays were then installed in the households in the experimental condition.

After the experimental period, participants received a concluding survey that reiterated some of the questions presented in the first questionnaire (electricity saving behaviour, intentions, social norms and perceived control), plus some additional questions regarding the display and the relative importance of the information given on the display.

PLEASE INSERT TABLE 1 ABOUT HERE

2.1.2. Participants. The average age was 46, which is somewhat lower than the average among home-owners in the region (M=50). 61% of the survey participants were men. (79%) of the participants lived with a partner and had children, while 17% lived with their partner and had no children. The average number of persons in each household was three. The level of education was above average, with 67% of the respondents holding a university degree.

The average size of houses included in the survey was 164 square metres, which is larger than the average private home in Sweden (147 square metres). All households in the survey were connected to the district heating system. Respondents in Lindome also had heat pumps, while only some of the separate houses in Alingsås featured heat pumps (visual inspections conducted when displays were installed).

2.1.3. Experimental measures. All households included in the survey were given a list with general information and tips on measures they could undertake to save energy in their homes. The list served the purpose of formally equalising any knowledge-based dissimilarities between the households in the survey.

Twenty IHDs were installed in randomly selected households from each municipality's test group. The IHDs were placed in the hallway or kitchen, making it a daily eye-catcher for the respondents. In-depth information about the display is presented in Appendix I.

The households' electricity consumption was measured before the experimental period in January and February 2010. The mean energy consumption for these two months formed the baseline value for comparison with the consumption during the experimental period from April to May 2010.

2.1.4. Questionnaire measures. The survey included 11 questions covering a variety of different electricity saving behaviours used in previous research [23]. Response alternatives ranged from "Always" to "Never" on a five-option scale (see Appendix II for the actual wording of the questions).

A number of background characteristics that had previously been shown to affect households' electricity consumption were included in the questionnaire. These were: age, sex,

living status (single/cohabiting; with/without children), number of persons living in the home, income, size of home, education and occupation.

2.2. Results

Firstly, the mean level of electricity consumption in the groups during the baseline period compared to the intervention period was investigated (Table 2). There were no statistical differences between the groups at $p<.05$ when tested by analyses of variance.

PLEASE INSERT TABLE 2 ABOUT HERE

The first focus of the study concerned the influence of feedback on energy consumption. To test the effect of condition controlling for the background factors, a hierarchical regression analysis was performed, with the baseline measure entered in the first step, and the display condition (dummy variable) entered in the second step. By including the condition city we were also able to control for potential differences due to differences in heating, but we found no differences between two the populations. As can be seen in Table 3, no significant effects were found for the experimental condition.

PLEASE INSERT TABLE 3 ABOUT HERE

Secondly, the question of whether the intervention increased the subjectively perceived motivation for the participants to conserve energy was investigated. An independent t-test showed a significant difference between the conditions t (1.25) = 2.19, $p < .05$, thus corroborating that continuous feedback is related to the motivation to save energy.

The self-reported energy behaviours (given in Appendix II) were compared before and after the intervention, in order to investigate whether there were any energy behaviours that changed during the intervention. Bonferroni-corrected paired-sample t-tests were conducted on all the 11 behaviours. The results showed an increase in all behaviours, except for taking shorter showers. However, only the question: "How often do you run the energy-saving programme (50-55 °) for the dishwasher, instead of the usual programme (65 °)?" showed a significant difference before (M= 3.26, SD= 1.67) and after (M=4.11, SD= 1.24) the intervention; t(18)=-2.92, p <.01.).

3. Study 2

3.1. Method

3.1.1. Sample and procedures. The study was carried out in cooperation with a public, municipally-owned housing association in Gothenburg. Two similar three-storey rental apartment blocks with 48 households, 24 in each block, were selected, in consultation with the housing manager. All apartments have sub-meters for household electricity consumption, i.e. individual metering and billing. A certain level of electricity consumption is included in the rent, depending on the size of the apartment. Tenants are charged extra if their usage exceeds this level, and given refunds if they use less. The extra payment or refund is displayed on the bill with a two-month delay. Households with low electricity consumption received up to 150 SEK (USD 24) in refund per month, while households with higher consumption paid up to 600 SEK (USD 95) extra per month on top of the rent.

Out of 24, a total of 17 displays were installed in the apartment block selected for the experimental group. The participants in one of the households moved out halfway into the experimental period and were removed from the study. Three households in the experimental group and five in the control group had recently moved into their apartments. Therefore no

baseline data (see below) could be calculated for these apartments, and they were subsequently removed from the quantitative part of the analysis. This left 13 households in the experimental condition, and 19 in the control condition, for the quantitative part of the analysis.

The tenants in the selected apartment blocks were informed about the research project in an introductory letter addressed to all individual households. Households from each block were then assigned to an experimental versus control condition, with 24 households in each condition. An employee from the housing company and an engineer from the company providing the displays knocked on the tenants' doors, and offered the households in the experimental condition the installation of a display at no cost. The households participating in the study did not receive any monetary compensation, but they were allowed to keep the display after the study.

The display intervention period in the experimental group lasted from October to December 2011 and was followed up by interviews in January 2012. Households in the experimental group were contacted by phone and asked to participate in an interview. Out of the 16 households that received the display, 13 could be reached, and of these, nine were willing to participate in an interview. The interviews were conducted either in a common meeting room for the apartment block, or in the homes of the participants, according to their preference. Only the interviewer and the participant(s) attended.

PLEASE INSERT TABLE 4 ABOUT HERE

3.1.2. Participants. Average age among survey participants was 50 years. 59% were women. Average monthly income was about 20 000 SEK (or about 3130 USD) before tax. The number of household members varied from one to nine per apartment. Seven of the

participants interviewed were men and six were women. Participants with a first language other than Swedish were over-represented in this study, as approximately 60% spoke Swedish as a second language. The apartment sizes are 80 square metres (3 rooms and kitchen) and 96 square metres (4 rooms and kitchen), respectively.

3.1.3. Experimental measures. A brief introduction to the display was given and two information leaflets were handed out. One gave instructions on how to operate the display, while the other gave recommendations on how to use the display to reduce electricity consumption.

Thirteen IHDs (the same as in Study 1) were installed in the selected households from the experimental condition.

The monthly electricity consumption was provided by the housing company for all apartments for the year of the study and the preceding year. A monthly mean value for the three-month experimental period was calculated, as well as a baseline value using the mean value of the consumption during the same three months of the previous year.

3.1.4. Interviews. The interviews were semi-structured and each interview lasted between 20 and 30 minutes. An interview guide with five topics was used (Table 4) and questions were explorative. The transcripts from the semi-structured interviews were analysed using a qualitative thematic analysis [24]. An inductive, data-driven, bottom-up approach was applied when searching for themes. The text was read and re-read several times, notes were taken, highlights made and themes created from topics appearing frequently.

PLEASE INSERT TABLE 5 ABOUT HERE

3.2. Results

3.2.1 Electricity consumption. The mean level of electricity consumption in the groups was investigated during the baseline period compared to the intervention period (Table 6).

PLEASE INSERT TABLE 6 ABOUT HERE

To identify any effect of continuous feedback on energy consumption, a hierarchical regression analysis was performed, with the baseline measure entered as a first step and the display condition (dummy variable) entered as a second step. As can be seen in Table 7, no significant effects were found for the experimental condition.

PLEASE INSERT TABLE 7 ABOUT HERE

3.2.2 Interviews. To understand the lack of any change in the electricity consumption behaviour, interviews were carried out in the experimental group. The qualitative analysis of the interview transcripts revealed how the participating households experienced the presence of the display, and how they reasoned about energy consumption. Two general themes emerged: barriers and motivational factors, which in turn consisted of several sub-themes (Table 8).

PLEASE INSERT TABLE 8 ABOUT HERE

The cluster of barrier factors can explain why the intervention did not accomplish its aim of helping participants to lower their energy consumption. Among the reasons stated were initially low levels of electricity consumption, established behaviour, difficulties in understanding the display and seeing a relationship between behaviour and consumption, and low awareness of how far the cost of electricity was included in the rent. The cluster of

motivational factors can explain some of the factors that motivated the use of the display. The participants stated different reasons for wanting to lower their electricity consumption. Economic considerations dominated among these reasons, but other, more altruistic and environmental considerations were also mentioned by several participants.

Barriers. Consuming low levels of electricity. Some participants indicated that they had been aware of their energy consumption before this intervention started. If consumption is already low, this will be a barrier to reducing it even further. *Habits*. The majority of participants reported that, despite receiving feedback on their energy consumption, little change in energy related behaviours had been made. This type of explanation came from households consuming more than the amount included in the rent, but also from households consuming less. Participants stated that despite receiving the continuous feedback, their everyday routines and habits had continued as before. The intervention with the display did not generate enough interest to break the established habits. *Difficulty in understanding the display.* Two participants expressed uncertainty about the functions on the display. If the display is not understood we can assume that this will inhibit the effectiveness of the feedback. *Difficulty in understanding the relationship between behaviour and consumption.* Two households expressed suspicion about the amount they had to pay extra, due to using too much energy. This illustrates the difficulty in grasping how much electricity is being consumed. During the interviews these households had computers and TVs on, in rooms where no one was using them. It seemed as though they used electricity without thinking about it, and then were surprised about having to pay extra for using more. *Low awareness of how much can be used without extra charge.* Only one participant expressed awareness of the number of kilowatt hours that was included in the rent.

Motivational factors. Even if actual energy consumption was not affected and participants confirmed that they had continued as before, some factors were found to motivate interaction

with the display and energy conservation behaviour. Different reasons for wanting to reduce consumption were stated by participants. Financial considerations dominated among these reasons, but other, more altruistic considerations were also mentioned by many. *Curiosity and interest.* This theme reflects a few participants' curiosity and interest in using the display to learn more about their energy consumption. *Cost considerations.* For most participants this seemed to be a driving force that made them careful with electricity-consuming appliances in their homes. *Altruistic/environmental concern.* Many participants, but not all, mentioned other reasons than financial considerations for keeping their energy consumption low. These reasons sometimes referred to the impact on the environment, as well as thoughts about not using too much electricity since others need it too.

4. Discussion and conclusion

This paper presents two feedback studies using IHDs that visualise the electricity use in households. No significant effects on electricity consumption were found for either of the studies. This means that the use of a display as such does not necessarily contribute to lower electricity consumption. The studies identified several barriers, but also motivational factors, from continuous feedback interventions using a qualitative approach. The barriers can be related to the use of the IHD and to energy conservation in general. IHD-related barriers are difficulties in understanding the display and the generation of insufficient interest in the display intervention to break established habits. This leads to barriers of a more general character, i.e. obstacles to successfully implementing conservation strategies. For people without an interest in saving energy it can be difficult to understand the relationship between behaviour and consumption; or behaviour, consumption and costs. There is a low awareness of how much energy can be used without extra charge, if it is included in the rent. This is an important issue in the Swedish context, where individual measurement and charging for the consumption of water, electricity and heating in rented apartments is a current topic of debate.

If energy consumption is already low this will be a barrier to reducing it even further. The potential for display feedback to stimulate energy conservation is closely related to the motivational factors, such as curiosity and interest, cost considerations and altruistic or environmental concerns. On the whole, the results support previous studies [11, 21, 22] showing that positive environmental attitudes, as well as an interest in and understanding of the IHDs and the information they provide, appear to be important factors in motivating the households to use the IHDs to engage in electricity-saving behaviour.

An important difference between the study 2 and other previous research is that participants were selected randomly by the housing manager. This differs from many other studies in which participants often take part as a consequence of their own interest, i.e. have a certain interest in energy issues. This is interesting when evaluating the results and preparing for the wider implementation of continuous feedback systems such as IHDs. The barriers experienced indicate that there is a risk of overconfidence in IHDs, especially for participants that have little initial interest in energy saving. Previous studies have focused on participants' actively seeking to take part of the study, thus guaranteeing some basic interest in energy saving. This group of people is likely to be the majority when considering a large-scale implementation of continuous feedback systems, and should therefore be more extensively studied. For the development of energy policies and more wide-scale implementation, it is important to be aware of the potential obstacles to success, especially for participants with low-interest. The interviews also indicate what could be improved concerning feedback strategies. Previous research [17] indicates the necessity of understanding the pattern of energy consumption, based on household members, in order to design the appropriate information for energy savings. Others point at the importance to provide customized information, to select appropriate feedback tools for specific household groups, and to pay special attention to increasing the energy consumption awareness in households with low

income levels [13]. The second study presented in this paper is carried out in rental apartments with mainly low-income households and people with a wide range of ethical backgrounds. In that way, the study contributes with specific knowledge for this group. IHDs have the potential to engage the whole household, including children, to be aware of and learn about the relationship between behaviours and electricity consumption [11]. In line with this, the present studies indicate the need to combine different types of feedback information, but also improved information, when introducing IHDs. These include a communicative introduction to the functionalities of the technical device, illustration of the connection between behaviour, energy consumption and related costs, and understanding what energy units mean, such as watts (W), kilowatt-hours (kWh), etc. Thus, tailored feedback is needed that is based on detailed documentation of the households' energy consumption and adapted to the household members' needs, and that combines different types of information in order to develop relevant strategies for energy savings.

An important area for future research is to continue to investigate the relationship between psychological motives and barriers and the information provided, in order to develop new and more effective ways of designing feedback information.

The limitation of the studies is the low sample size. Future studies should investigate the effects of more targeted and cohesive feedback information, and work together with governmental organisations and electricity companies on conducting studies with larger samples.

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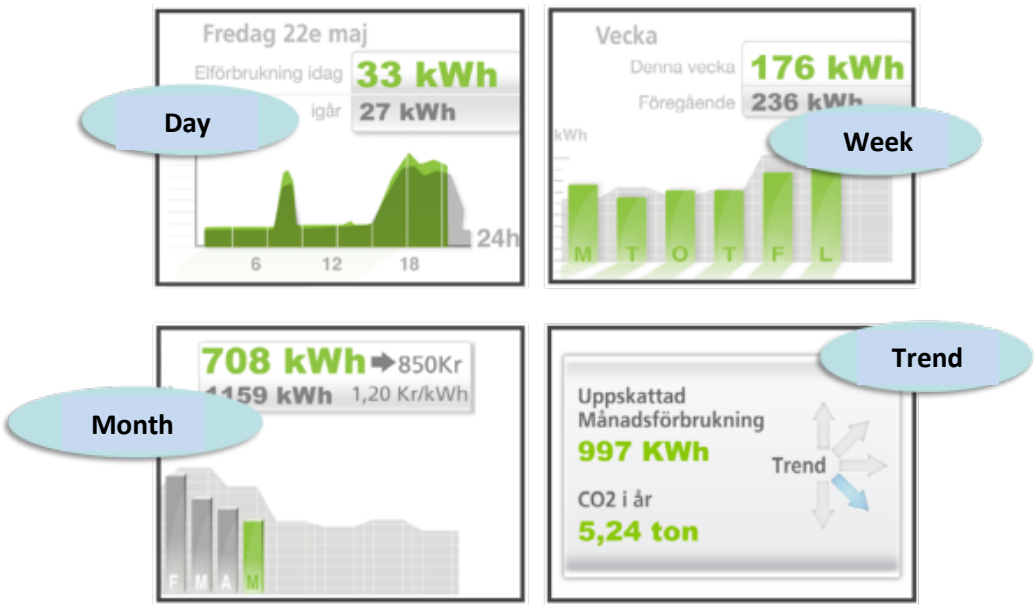
Appendix I

The IHD used in this experiment was a simple plug-and-play device that measures electricity consumption by attaching a transmitter to the electricity meter, allowing it to wirelessly communicate information to a receiver. The receiver presents the information on a screen, making it easy to see the instantaneous consumption, and developments throughout the day, week and month. The display also provides estimates of costs and carbon emissions (using values for marginal electricity, i.e. coal condensing emission intensities). To learn more about the specifics of the display, go to: www.exibea.se

Main view of Eliq display with real-time information. A wireless transmitter communicates with a touch screen display (3,5 tum).



Four other views of the Eliq display one can switch to: Daily, weekly, and monthly information about electricity use and trends.

Appendix II

Questions mapping the electricity saving behaviour of the household. Mean response before (B) and after (A) intervention in parenthesis, 1=Never, 5=Always):

1. How often do you turn off all the lights when you are the last person to leave a room? (B: 4,30 A: 4,48)
2. When you wash your whites, how often do you wash at 60°instead of 90°? (B: 4,59 A: 4,64)
3. How often do you run the washing machine when it is not full? (B: 2,29 A: 2,64)
4. How often do you turn off the standby mode on your electrical appliances when they are not in use? (B: 3,67 A: 4,05)
5. How often do you defrost frozen foods in the fridge? (B: 3,04 A: 3,48)
6. How often do you use the lid when cooking eggs or vegetables? (B: 3,61 A: 3,91)
7. How often do you run the dishwasher when it is not full? (B: 2,20 A: 2,40)
8. How often do you run the energy saving programme (50-55°) for the dishwasher instead of the usual programme (65°)? (B: 3,26 A: 4,11)
9. If possible, how often do you air-dry your laundry instead of tumble-drying it? (B: 3,83 A: 4,26)
10. How often do you check the temperature of the refrigerator and/or freezer? (B: 3,65 A: 3,75)

11. How often do you take a quick shower instead of a usual shower in order to save hot water? (B: 3,39 A: 3,35)