

RESEARCH PAPER

Home energy monitors: impact over the medium-term

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Home Energy Management Systems (HEMS), *e.g.* energy monitors, are intermediary products that can visualize, manage, and/or monitor the energy use of other products or whole households. HEMS increasingly receive attention for their role in energy conservation in households. A literature review and a case study examine the mid-term effectiveness (more than 4 months) of HEMS. The case study presents the results of a 15-month pilot with a domestic energy monitor in the Netherlands. It explores the extent to which participants manage to sustain their initial electricity savings over time, with a special focus on the development of habitual energy-saving behaviour. The results show that the initial savings in electricity consumption of 7.8% after 4 months could not be sustained in the medium- to long-term. A second finding is that certain groups of people seem more receptive to energy-saving interventions than others. These participants quickly develop new habits and exhibit larger savings than other participants. Obviously, a ‘one-size-fits-all’ approach for home energy monitors cannot be justified. For HEMS to be effective, a deeper understanding is needed that embraces social science, contextual factors, usability, and interaction design research.

Keywords: Captology, energy demand, energy management, energy monitor, Home Energy Management System (HEMS), housing, occupant behaviour, smart metering

Les Systèmes de Gestion Domotique de l'Énergie (HEMS), *par ex.* les contrôleurs d'énergie, sont des produits intermédiaires qui sont capables de visualiser, gérer et/ou suivre l'énergie consommée par d'autres produits ou un ménage dans son ensemble. Les HEMS bénéficient d'un intérêt croissant en raison de leur rôle en matière d'économies d'énergie dans les ménages. Une analyse bibliographique et une étude de cas examinent l'efficacité des HEMS à moyen terme (au-delà de 4 mois). L'étude de cas présente les résultats d'un projet pilote sur 15 mois utilisant un contrôleur d'énergie domestique aux Pays-Bas. Elle examine dans quelle mesure les participants parviennent à maintenir leurs économies d'électricité initiales au fil du temps, en mettant un accent particulier sur le développement de comportements habituels économes en énergie. Les résultats montrent que les économies initiales réalisées sur la consommation électrique, de 7,8% après quatre mois, ne pouvaient pas être maintenues sur le moyen et le long terme. Une seconde constatation est que certains groupes de personnes semblent plus réceptives que d'autres aux opérations d'économie d'énergie. Ces participants développent rapidement de nouvelles habitudes et affichent des économies plus importantes que les autres participants. À l'évidence, une approche unique pour tous concernant les contrôleurs d'énergie domestique ne peut se justifier. Pour que les HEMS soient efficaces, il est nécessaire d'avoir une compréhension plus profonde, englobant les sciences sociales, les facteurs contextuels, l'utilisabilité et les recherches en conception centrée utilisateurs (interaction design).

Mots clés: Captologie, demande énergétique, gestion de l'énergie, contrôleur d'énergie, Système de Gestion Domotique de l'Énergie (HEMS), logement, comportement des occupants, comptage intelligent

Introduction

Residential electricity consumption has been growing in all regions of the world at an average of 3.4% per year since 1990. Although some of this growth is a result of more people with access to electricity, the majority is caused by the increased consumption of electricity by individual households (International Energy Agency (IEA), 2009). Western households commonly own a growing number of appliances that currently range in number from 28 to 67 (Milieu Centraal, 2005; IEA, 2009). Also, the number of technical installations for space heating, cooling and ventilation is increasing. Technological solutions, such as switching to the most energy-efficient technologies available, could save up to 40% in residential electricity consumption (IEA, 2009). However, the focus on technology alone appears to have its limitations. With regard to energy, for instance, occupant behaviour was found to be the major contributor to the variance in domestic energy consumption (Brohus *et al.*, 2009; Crosbie and Baker, 2010). As Crosbie and Baker (2010) state:

It does not matter how much energy hypothetically could be saved by efficient technologies if no one wants to live in the properties, install or use efficient lighting and heating.

(p. 1)

In the endeavour to tackle this behavioural dimension, smart metering and Home Energy Management Systems (HEMS) are being given increasing attention both in academia and in commercial enterprises. HEMS are much advertised and promoted as ‘high potentials’ for domestic energy savings, with some (commercial) energy monitors claiming 10–20% savings. For the authors, this was the starting point for a critical examination of these seemingly optimistic claims.

HEMS are defined as intermediary devices that can visualize, monitor and/or manage domestic gas and/or electricity consumption. Their main purpose is to give users direct and accessible insight into their energy consumption. This makes them different from smart meters, which are predominantly intended to benefit the gas or electricity supplier and generally need a HEMS to give users the intended insight.

HEMS come in many shapes and sizes and they vary in six significant areas. The first is the type of energy for which they are intended: gas and/or electricity. Second, they differ at the level at which feedback is given. Some give feedback on overall household (utility) consumption, some provide detailed information for separate appliances (disaggregated), and yet others limit feedback to just one appliance. Third, they vary according to the type of feedback they provide, such as factual (*e.g.* showing real-time

consumption data as shown in Figure 1), social (*e.g.* using smiling/frowning faces, as shown in Figure 2), or comparative (*e.g.* current versus historical consumption data, as shown in Figure 3). A fourth characteristic is whether they only monitor or also manage energy consumption. The difference is that monitors only give feedback, leaving it to the user to decide whether or not to act on the feedback, while managers help users control if and when their appliances consume energy. Fifth, the type of interaction and physical location of HEMS varies from local appliance-specific solutions, such as standby-killers, to central in-home touch screens, to online web applications. Finally, their intended purpose can be energy saving or peak shaving (peak shifting of the grid load).

The type of HEMS that has been commercially available since the 1970s is the energy or electricity monitor, which solely gives inhabitants feedback on electricity consumption at the utility (household) level. This energy monitor has been dominating the market for years, and it is also the type of HEMS that has featured most in academic research. Recently, other kinds of HEMS have entered the marketplace and future studies will hopefully broaden their perspective to include these.

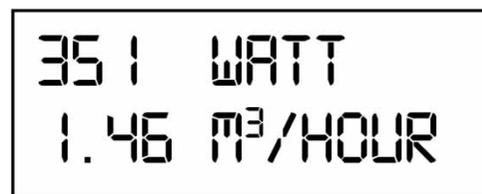


Figure 1 Factual feedback

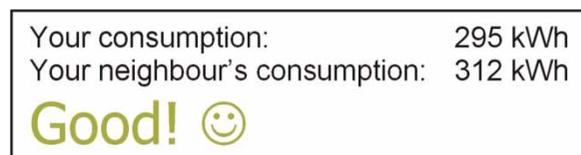


Figure 2 Social (comparative) feedback

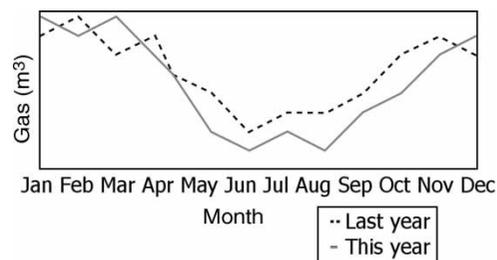


Figure 3 Historical comparative feedback

Research objectives and method

The general objective of this paper is to achieve a better understanding of the effectiveness of HEMS. A literature review will focus on HEMS in general, whereas the second part of this paper – the case study – will focus on energy monitors, considering their medium-term use and effectiveness (more than four months). Effectiveness is defined here as the extent to which users can maintain significant energy savings over these prolonged periods.

Most of the previous studies on HEMS have asked the same basic question: how effective are they in helping people save energy? Although this question has been answered many times and often with a positive result (for instance, Ueno *et al.*, 2006b; Midden and Ham, 2009), the majority of these studies have only assessed the use of energy monitors over relatively short periods (four months or less). The few studies that have taken a long(er) view show indecisive results (van Houwelingen and van Raaij, 1989). This uncertainty is the focus of this paper:

What are the medium- to long-term results of HEMS on energy savings?

What happens to the energy savings after the initial four months of HEMS usage?

What is the influence of the design quality and usability of HEMS?

Is there a relationship between the amount of HEMS usage and achieved energy savings, and what role does the development of habitual behaviour play?

This paper explores these questions through a literature review and a case study.

Literature review

Background relations

Background relations with technology are described from a philosophical point of view by Ihde (1990), who identifies products with an ‘absent presence’ in households. They operate in the ‘background’ either physically or in the back of our minds. Even more so, an increasing number of these background appliances, especially technical installations, function autonomously. They self-regulate their energy use, which is consequently imperceptible to users. While some products might drift into the background over time, most background products are intentionally designed to operate this way: there is deliberately little to no interaction with the end user. Borgmann (1995) describes this as disburdening but also disengaging technology. As a negative side-effect, these background products significantly contribute to the energy

consumption of households and the invisibility of energy flows in homes. More than half of carbon dioxide (CO₂) emissions of households are caused by background appliances and ‘imperceptible’ energy consumption like phantom loads (derived from Milieu Centraal, 2008).

While the disburdening effect also brings important beneficial aspects to users, it tends to undermine the direct cause-and-effect relationship between users, their behaviour and energy consumption. This is where HEMS come in: in their mediating role, they provide people with a (visual) representation of the energy consumption, and help them mentally interpret the actual energy (or monetary) figures and perceive the energy consumption of *other* products. Ihde (1990) calls this relationship between users and products a hermeneutic relationship. An alterity relationship between users and HEMS takes place when the HEMS *itself* is the continual focal point of attention. However, some instances have been recorded where HEMS slowly drift into the background of people’s attention, thus undermining their core purpose of giving recurrent feedback and ultimately becoming obsolete. When a HEMS drifts into the background, a shift from alterity relation to background relation takes place.

Several case studies have shown this change from alterity to background. The most detailed studies were performed by Ueno *et al.* (2006a, 2006b). These reported drastic reductions in the usage of a display giving disaggregated feedback during the first two to four weeks, after which stabilization took place. In the three-month pilot of the ‘PowerPlayer’ (interview with L. T. Fieret concerning PowerPlay pilot Nuon, SenterNovem and UCPartners, 29 June 2009) participants indicated that at a certain point in time they understood their gas and electricity usage patterns, and used the PowerPlayer less. Respondents did add that they would use the monitor again when buying new appliances. In a study on the use of an electricity monitor (PowerCost) by Mountain (2006), one-third of the participants indicated they would not use the monitor any more after the pilot. Lofstrom and Palm (2008) addressed the use of the Power-Aware Cord, which can visualize the electricity use of a single socket. They tested it for two months with six households and found that whereas in the beginning people were enlightened by the energy use of an appliance, after some time the Power-Aware Cord ‘just’ became a decorative element, likened by all participants to Christmas lights.

Although it is impossible to draw decisive conclusions based on these studies, the general trend seems to be that feedback devices slowly drift into the background. The exact cause of this finding has not been studied, although it is conceivable that people simply lose interest.

This raises the question how to prevent HEMS from drifting into the background. One possible answer lies in the increased interaction with HEMS, *e.g.* when people develop habits around them. Another possibility is the improved design of HEMS and their feedback, as several design strategies have been created to influence behaviour through products (Lockton *et al.*, 2008). A third option would be to view a background relation as a potential strength by implementing HEMS that not only monitor, but also manage energy. Energy managers operate more in the background, programmed (by users) to switch off appliances that are not in use. They are therefore less dependent on behavioural change for energy savings than monitors. Whereas monitors only give feedback, energy managers additionally give participants the ability to control their energy consumption. Perceived control is claimed to have a positive influence on users (Geller, 1995; Allen and Ferrand, 1999), although raising awareness through feedback still remains essential. However, there has been no scientific research into energy managers to validate their effectiveness (especially in comparison with energy monitors). This is therefore a potential area for future research. As past studies do give some insight into the possible role for design and habits, these will be discussed in the following sections, starting with habits.

Habits

Within psychology, habits are mainly approached as a barrier which prevent the development of new behavioural patterns and act as a cause of fallback. *Existing* habits, such as leaving the lights on, are seen as major obstructions to the development of new, sustainable behaviours. Even after months of trying to adopt a new pattern, users can still fall back into the old pattern. Habits take time to develop. Therefore, studies on feedback, intent on changing energy-related behaviour, need to have a long-term perspective. However, most of the studies on feedback were conducted over a period of less than four months and often without follow-up (for an extensive review, see Abrahamse *et al.*, 2005). In the rare cases that medium- to long-term studies have been conducted, the outcomes were indecisive (van Houwelingen and van Raaij, 1989; Mountain, 2006) or the studies failed to record long-term energy reduction results (Ueno *et al.*, 2006a).

A different approach to habit development is studying the development of *new* habits or rituals around HEMS so that users receive recurrent feedback. In this approach, habits are used as a strategy to prevent feedback devices from drifting into the background. While drifting into the background alludes to decreased use, to the point of abandonment, habitual use implies ingrained, regular use. Past research has

not given specific attention to the habitual use of HEMS, but it is apparent in some studies that under a limited group of users, regular usage does take place at any rate. In Mountain (2006), 38.9% of the participants in the case study indicated that they looked at the PowerCost monitor at least once a day. Kidd and Williams (2008) describe how participants develop certain habits around the energy monitor 'Efergy'. Matsukawa's (2004) study implies a relationship between amount of use of the energy monitor and energy saving. Though by no means a conclusive answer, it does warrant further research on the question if a relationship between (habitual) use of HEMS and savings exists.

While it can be left to chance whether users develop habits around HEMS, it can also be part of HEMS's design strategy. For their design to enable habits, they need to fit into people's daily lives and users should want to use them. Attention to design is not only beneficial to habit development, but also important for its influence on effectiveness.

Research on feedback and the design of HEMS

When considering the influence of design on the effectiveness of HEMS and prevention of non-use, it is important not only to focus on the physical appearance. Associated elements such as type of feedback, the architecture, the interface, the interaction between users and product, and the context in which it is used need to be included. As feedback is the core functionality and dominant 'behaviour intervention mechanism' in most HEMS, it poses a good starting point for the discussion. While feedback is approached by social scientists as strictly a behavioural intervention, it is inherently intertwined in the design of HEMS. A designer would consider certain aspects of feedback, *e.g.* presentation style, a smiley (emoticon) or the colour usage, as a means of making the interface understandable for the user.

Several researchers have reviewed studies on feedback. In their review, Abrahamse *et al.* (2005) conclude that feedback tends to be more effective when combined with other strategies, and also with increased frequency (*e.g.* real-time feedback instead of feedback at fixed points in time). Darby (2006), in reviewing the effectiveness of feedback, comes to the same conclusion: immediate direct feedback could be extremely valuable, as long as it is provided through a user-friendly display. Likewise, Fischer (2008) concludes that the most successful feedback should be given frequently and over a long time, that an appliance-specific breakdown is provided, and that it is presented in a clear and appealing manner using interactive tools. Mcalloy and Midden (2002), in much the same vein, conclude that product-integrated feedback,

when coupled with the possibility to set an energy-conservation goal, is a potentially highly successful means to save energy.

Some studies have found that people use feedback devices to track down a particular appliance at a specific point in time that is causing the rise in energy consumption (Kidd and Williams, 2008). One such study classified users accordingly as ‘seekers, detectives, and judges’ (Liikkanen, 2009). Knowing this, designing HEMS to give accurate and real-time feedback becomes essential. Likewise, considerations should be given whether to design portable or fixed HEMS, and if they should give disaggregated feedback. With energy monitors that only give feedback on overall household consumption, tracing back energy consumption to individual appliances can provoke a single-minded concentration on peaks by users (Kidd and Williams, 2008). The pitfall is that users consequently neglect continuous lower energy-consuming appliances that use more in the long run. Also, attention should be paid to delays or infrequent data transmission as this can lead to inexplicable peaks for users. Kidd and Williams (2008) noted, furthermore, that some participants switched types of energy being used, for instance heating water on the gas stove rather than using an electric kettle. Feedback on both gas and electricity consumption is therefore desirable, in particular given the fact that gas is responsible for a larger proportion of CO₂ emissions of households in the Netherlands (EnergieNed, 2008). In other words, these examples show that the design of the feedback given by HEMS should afford a certain type of use.

Feedback is one element in the design of HEMS. This section discusses to what extent researchers have taken into account other aspects of the design, in particular the design of the human–HEMS interaction. This human–product interaction concerns the ‘use, understanding and experience’ of products. This is broader than the straightforward use of a product as it includes the ‘physical, cultural, technological, and societal contexts’ in which they are used (Delft University of Technology, 2009).

The assumption is that using specific design strategies and design knowledge can help make HEMS more effective, particularly in the long run. Although some researchers acknowledge the importance of a user-friendly display (see above), few studies actually report implementing knowledge from the design of human–computer interaction field. Commercially available monitors have a predominantly ‘high-tech’ design, and studies regularly implement these monitors. This can lead to usability problems, as was documented for one participant with the use of the Efergy

monitor (Kidd and Williams, 2008): ‘I certainly haven’t used it. ... I certainly am not techno ...’.

One journal article on HEMS by Wood and Newborough (2006) does detail a number of human–computer interaction aspects to consider when designing what they call ‘energy consumption indicators’. In answering five questions concerning measurement units, categorisation and visualization of information, and the amount of possible interaction, Wood and Newborough emphasize the need for consideration of users and their use of HEMS to achieve energy savings. Outside the field of HEMS, in, for example, interaction design research, new strategies for influencing behaviour through design have also been developed in recent years. One such approach looks at ‘persuasive techniques’. There are numerous similarities in the way people interact with each other and the way they interact with (the interface of) a product. People talk to products, show affection, or get angry with them, just as they do with other people. The manner in which products are designed can effect peoples’ emotions and the manner in which they act. Knowing this, it is but a small step to reason that influence tactics could be integrated into products to persuade people into acting in a certain way. This has been coined ‘captology’ by Fogg (2003), who has also developed a behaviour change model (Fogg, 2009) to assist designers in creating persuasive products. Motivation, ability, and trigger are the three principal factors herein.

Merging persuasion theories and combining them with work from other (design) fields, Lockton is developing the Design with Intent (DwI) method (Lockton *et al.*, 2008; Lockton, 2009). DwI is defined as ‘design that’s intended to influence, or result in, certain user behaviour’ through six ‘lenses’ or strategies, that can motivate, enable or constrain a certain behaviour. Persuasive technology and DwI techniques are valuable for the design of the interface and architecture of HEMS. It can help strengthen habits, increase usage, and heighten effectiveness. Implementing Fogg’s line of thinking into HEMS, the first step would be to create the right triggers at the right moment. Another step could be to increase simplicity to heighten peoples’ ability to save energy. Like Fogg, Cialdini’s (1993) work teaches that the manner in which something is presented to a user is very significant, but has given particular attention to normative social influence (the importance of what other people do) in recent years (Goldstein *et al.*, 2008). HEMS are well suited to compare the consumption of a household with that of other households, and in doing so implement both descriptive and injunctive social norms through different visualization techniques. Knowing which strategy is the most effective

and which is preferred by different types of user is complicated, however, and needs to be studied in more detail.

Conclusions from the literature review

This review poses directions for future research. It highlights several focal points that deserve more attention and are key to creating effective HEMS and reducing energy consumption. Background appliances are an important factor in energy consumption, which makes accurate, traceable feedback valuable. Additionally, the usability, with instances of decreased use and non-use of feedback devices, needs to be addressed. Implementing insights from interaction design to develop user-friendly interfaces can help. But this needs to become a focal point in research, and research needs to study various types of HEMS, *e.g.* monitors as well as managers, to compare effectiveness. Finally, there is too little attention for medium- to long-term research. This is needed to see whether energy-saving behaviours become lasting habits and whether routine use can contribute to increased effectiveness. Not all can be studied within one research process, though, but the following case study will focus on one aspect, medium-term effectiveness, in relation to the habitual use of energy monitors.

Case study: a 15-month pilot with a home energy monitor

A 15-month pilot study occurred during 2008–2009 in the Netherlands. The pilot consisted of a four-month initial trial, instigated by several commercial parties, to assess the effectiveness of a newly developed home energy monitor, and a follow-up study by researchers from Delft University of Technology. The follow-up study took place 11 months after the initial trial ended, making the total trial period 15 months. The case study was anonymised due to sensitivities surrounding the commercialization of this newly developed product.

The energy monitor consists of a sensor, a sending unit, and a display. The sensor and sending unit are attached to the electricity meter. The sending unit sends a radio signal to the display unit. The display has three settings. In its standard setting, it shows the power consumption in watts (W) in real time (with a short delay of up to 10 seconds). It can also indicate daily consumption (over the past 24 hours), and can compare daily consumption with a personal savings target. The daily target was corrected to the individual's fluctuations in consumption throughout the week. The monitor was designed to be simple to use; and users acknowledged this as only 5% gave the monitor a 'negative' or 'very negative' score on ease of use after installation. A website with energy-saving

tips accompanies the monitor, as well as a voluntary e-mail service ('learn and save') with more tips.

The objectives of this case study were, firstly, to gain insight in the effectiveness of the energy monitor in the 11 months after the initial four-month pilot. Effectiveness was defined as the extent to which having the monitor at home contributed to sustained electricity savings. The second objective was to explore whether a habit of checking the monitor daily had a positive influence on sustaining the electricity savings over the trial period.

Based on results from previous studies (see the literature review), the research team had certain expectations and assumptions about the outcomes of this case study. The electricity savings were expected to be considerable after the four-month initial trial, consistent with other short-term research. However, over a longer period it was expected that some of the initial savings would be lost as a result of the monitor 'drifting into the background'. Also, it was expected that people who developed a habit around the monitor (checking it at least once a day at fixed times) would better manage to sustain their electricity savings, as opposed to those who did not develop habitual behaviour.

The resulting hypotheses are therefore:

- At the end of the initial four-month trial, participants have an overall mean electricity saving.
- Participants' initial (four-month) electricity savings are not expected to be sustained over the entire 15-month period. However, participants who kept the monitor at home after the four-month initial trial are expected to sustain better their electricity savings than those who returned the monitor.
- There is a positive relationship between having a daily habit of checking the monitor and sustaining the electricity savings over the 15-month period.

Method

Participation in the case study was on a voluntary basis. The initial four-month trial started in the last week of June 2008 and ran until the first week of November 2008. A total of 304 participants received an energy monitor with instructions for its use and installation. Most participants also filled out the three online surveys that were sent out at the beginning, halfway and at the end of the trial. As a reward for their participation, at the end of the four-month period people were given the option either to keep

the energy monitor or to return it and receive a gift certificate of €25 instead.

In September 2009, 11 months after the initial trial, 264 participants who had completed at least one of the surveys received an e-mail asking them to participate in an online follow-up questionnaire. Of the 189 respondents, 93 had kept the monitor after the four-months trial, and 96 had returned it. The electricity meter readings of the 189 respondents were checked for completeness and inconsistencies. All meter readings were self-reported at five different occasions approximately one year before and during the case study, which unfortunately introduced quite a large number of reporting errors and missing data. Participants with incomplete data were eliminated, as well as those with changes in family circumstances (*e.g.* moves, divorces, babies, children moving out). This left 54 participants for whom all meter readings were present and consistent. Of these, 26 had kept the monitor after the initial trial, and 28 had not. Within the group that had kept the monitor (group A), a distinction was made between those who had developed a daily habit after 15 months and those who had not (Tables 1 and 2).

The electricity consumption during baseline, initial trial and follow-up was corrected for seasonal influences and extrapolated to yearly consumption.

Findings

From the questionnaires and the meter data, a number of results were obtained. First, the main results from the questionnaires are discussed after which an analysis of the meter data is elaborated on.

Demographics

The demographics showed no exceptional data: the baseline consumption of 3614 kWh was the same as the Dutch average (which increased at an average rate of 1.1% per year between 1998 and 2008) (EnergieNed, 2008), while the household size of 2.4 was slightly above the Dutch average of 2.3. The large majority ($n = 43$) were homeowners. Household size, income, and tenure were spread evenly between groups A and B.

Habits

The responses to the questionnaires ($n = 189$) were analysed to understand the process of habit formation with the monitor. Of the 93 respondents who kept the monitor (Table 3), 80 indicated they still had a functional monitor in their homes, which was also in use. Seventeen of the 80 respondents indicated they used the monitor less than during the initial four-month trial, but 53 respondents said they checked it daily at a fixed moment in time.

If one looks specifically at the habits formed, then checking the monitor before going to bed was by far the most common routine. Second most popular was after getting up in the morning. Less common were before going out, or while using a specific appliance or space. It is interesting to note that the living room was by far the most common place to have the monitor, followed by the kitchen. None of the participants had chosen to place the monitor in the bedroom. Knowing that checking electricity consumption before going to bed is a common ritual can have design implications. Designers could consider fitting an 'energy check' into an existing bedtime ritual, such as turning down the thermostat, turning off the television or lights, locking up the house, or setting the alarm clock. This could influence the monitor's design and functionalities as well as its favoured location.

Savings

To understand the effects of the interventions with the energy monitor, the electricity savings were studied. A first observation is that household electricity savings varied widely (Figures 4 and 5). The household that saved the most (a family of three) saved 42.6% of electricity during the pilot and 30.4% during the follow-up. By contrast, the worst performer (a family of two) used 33.6% more electricity during the initial trial and 40.6% more during the follow-up.

The reasons for these extremes were quite straightforward. The 'high spender' (initial electricity consumption of 3985 kWh/year) had just purchased an air-conditioner, whereas the 'top saver' (initial electricity consumption of 2673 kWh/year) followed a strict regime: writing down the electricity meter data twice a day, recording how often the washing machine and dishwasher were used, replacing all incandescent

Table 1 Overview of the number of participants in the follow-up study (4–15 months)

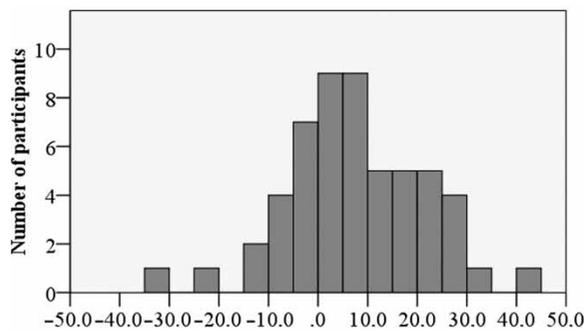
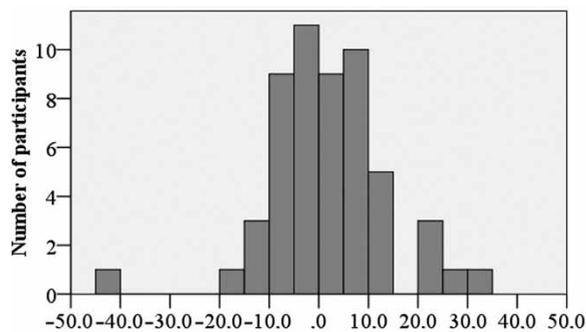
Follow-up study	Number of participants	Number who kept a monitor	Number who returned a monitor
Raw data	189	93	96
All electricity data available	54	26 (group A)	28 (group B)

Table 2 Subdivision of group A

Group A	Number of participants (total = 26)
With a daily habit (AH)	14
Without a daily habit (ANoH)	12

Table 3 Majority of participants developing a habitual behaviour

Participants with a functional energy monitor	80
Participants who use a monitor less during follow-up	17
Participants reporting a habitual behaviour	53

**Figure 4** Achieved savings (%) after four months (mean = 7.8, standard deviation (SD) = 13.8, $n = 54$)**Figure 5** Achieved savings (%) after 15 months (mean = 1.9, standard deviation (SD) = 11.8, $n = 54$)

bulbs, limiting the use of the tumble dryer to the bare necessity, decreasing the use of the dishwasher, and placing a timer on the pump of the garden pond. He made an extra note that he was 'very proud' of his achieved savings.

By far the most commonly noted responses for the expected savings with other participants were less use

of appliances and unnecessary lighting and switching appliances off rather than leaving them in standby. Compact fluorescent lights (CFLs) and light-emitting diodes (LED) were also an easy target. Buying new energy-saving appliances sometimes occurred, but this fact was mentioned less often and mainly consisted of new washing machines, fridges and freezers. One participant purposefully noted *not* buying a flat-screen television. In a couple of instances, a spillover effect to gas consumption could also be noted as a participant turned the heater down, adjusted the thermostat time schedule, or installed double-glazing. Whether this was directly caused by the interventions cannot be confirmed.

To analyse the data further, a mixed between-within subjects analysis of variance (ANOVA) was conducted to assess whether there was a difference in the percentage of electricity saved across two time periods (a four-month trial and an 11-month follow-up). The participants were split up in three groups:

- Group A consisted of participants who had kept the monitor after the initial trial, and was subdivided in two subgroups:
 - Participants who had developed a habit (AH).
 - Participants who had not developed a habit (ANoH).
- Group B consisted of participants who had returned the monitor after the initial four-month trial.

The electricity savings were corrected by using the baseline consumption as a covariate. This was done to correct for large variances in the individual electricity consumption of households.

There was no significant interaction effect between the three conditions and the time (Wilks' lambda = 0.97, $F(2, 50) = 0.67$, $p = 0.52$). This means that the savings of all three groups (AH, ANoH, and B) declined at the same rate during the course of the follow-up, in spite of the steeper decline that might seem apparent for AH from Figure 6. On the basis of the second hypothesis, it was expected that the fallback would be less for participants who had kept the monitor, and in particular for those who had formed a habit.

There was a marginally significant effect over time (Wilks' lambda = 0.94, $F(1, 50) = 3.30$, $p = 0.075$, partial eta squared (ϵ^2) = 0.06) with the savings of all groups decreasing over time.

All groups sustained savings during the initial trial (Table 4). However, this appears to be due to

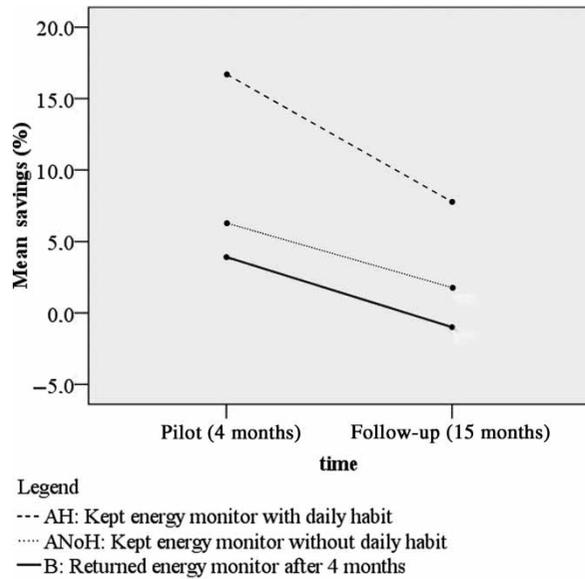


Figure 6 Mean savings (%) after 4 and 15 months

subgroup-specific characteristics as there is a significant between-subjects effect ($F(2, 50) = 4.63, p = 0.014$). As shown in Table 5, the difference in savings for households who had kept the monitor and developed a daily habit (AH) was already significantly different during the initial trial in comparison with households that handed back the monitor (B) ($p = 0.004$), but also in comparison with households who kept the monitor but did not develop a habit (ANoH) ($p = 0.050$). After the follow-up, the difference is only significant between B and AH ($p = 0.024$). The group that formed a habit still had significant savings after follow-up. Even though this cannot be conclusively attributed to the interventions with the energy monitor, it is highly likely that these contributed to the high savings of the receptive households that formed a daily habit; however, the effects are still relatively short-term as the same rate of fallback still occurs.

Table 4 Estimated marginal means (percentage energy savings)

Condition	Time	Mean	95% Confidence interval	
			Lower bound	Upper bound
ANoH: kept a monitor but no daily habit ($n = 12$)	Pilot	6.320 ^a	-1.198	13.838
	Follow-up	1.740 ^a	-4.985	8.464
B: handed the monitor back in ($n = 28$)	Pilot	3.910 ^a	-0.953	8.772
	Follow-up	-0.993 ^a	-5.342	3.356
AH: kept monitor with a daily habit ($n = 14$)	Pilot	16.713 ^a	9.747	23.679
	Follow-up	7.816 ^a	1.586	14.047

Notes: ^aCovariates appearing in the model are evaluated at the following values: baseline consumption = 3614.52 kWh. AH, Group A with a daily habit; ANoH, Group A without a daily habit; B, group B only possessed the energy monitor during the initial four-month trial.

Conclusions

The first hypothesis: ‘At the end of the initial four-month trial, participants have an overall mean electricity saving’, is confirmed. During the initial trial, the average savings that were achieved for all participants was 7.8% (standard deviation (SD) = 13.8). If the study had ended there, as most studies do, it would have been a sizeable outcome for the interventions. As stated in the Introduction, certain energy monitors advertise with similarly achieved figures.

A subgroup of highly motivated people (the same people that later reported the development of habitual behaviour with the monitor) even managed to reach an initial electricity saving of 16.7% in comparison with 6.3% and 3.9% for the other groups (Table 4).

The second hypothesis was: ‘Participants’ initial (four-month) electricity savings are not expected to be sustained over the entire 15-month period. However, participants who kept the monitor at home after the four-month initial trial are expected to better sustain their electricity savings than participants who returned the monitor.’ This hypothesis is falsified. None of the groups sustained their savings, and the fallback rates in electricity savings of the three groups (AH, ANoH, and B) do not differ significantly from each other. Participants who kept the monitor, though having liked it enough to retain it, did not manage to sustain their electricity savings any better than those without a monitor.

Finally, the third hypothesis: ‘There is a positive relationship between having a daily habit of checking the monitor and sustaining the electricity savings over the 15-month period’, could not be confirmed. Although the group that developed a habit (AH) still had significant savings after the 15-month period (compared with group B), this cannot be attributed to habitual behaviour, as this group (AH) already showed more than average savings during the initial

Table 5 Parameter estimates (percentage energy savings)

	Parameter	B	T	p	95% Confidence interval	
					Lower bound	Upper bound
Savings pilot	Intercept	22.061	3.963	0.000	10.880	33.241
	Baseline consumption	-0.001	-1.081	0.285	-0.004	0.001
	ANoH: kept a monitor without a daily habit	-10.393	-2.012	0.050	-20.769	-0.018
	B: handed the monitor back in	-12.804	-3.025	0.004	-21.306	-4.301
	AH: kept the monitor with a daily habit	0 ^a
Savings follow-up	Intercept	10.848	2.179	0.034	0.848	20.848
	Pre-pilot consumption	0.000	-0.686	0.496	-0.003	0.002
	ANoH: kept monitor without a daily habit	-6.077	-1.315	0.194	-15.357	3.203
	B: handed the monitor back in	-8.810	-2.327	0.024	-16.415	-1.204
	AH: kept monitor with habit	0 ^a

Notes: ^aThis parameter was set to zero because it was redundant.

AH, Group A with a daily habit; ANoH, Group A without a daily habit; B, group B only possessed the energy monitor during the initial four-month trial.

four-month trial. A more likely interpretation is that the savings were due to subgroup-specific characteristics (*i.e.* personality traits): these participants were probably predisposed and more receptive to the interventions with the energy monitor than the other participants.

It should be noted that other variables outside this study could have contributed to the participants' electricity savings, such as government campaigns, or the economic crisis. It is, however, highly likely that the energy monitor was an effective trigger for those who saved electricity. Although it is hard to generalize these findings to other household energy monitors, based on the results of this case study, the authors would like to draw the following tentative conclusions:

- Interventions that focus on energy monitors are mainly successful if they are targeted at a specific niche of users who are highly motivated to incorporate the use of the monitor into their daily lives. The exact personality traits of these users are yet to be determined.
- An energy monitor is not effective over a longer period (more than 4 months) for a majority of users. The participants involved in the case study could not sustain the initial reductions in electricity consumption over a period of 15 months.

Possible explanations for the lack of sustained savings may be one or a combination of the following:

- People revert to their old behaviour patterns.
- Over time, people add new appliances to their household. There is some evidence of this in the online surveys (reports of buying plasma screens,

air-conditioning, and electric heaters). Even if people have developed a habit of electricity-saving behaviour, these new products may lead to an overall increase in electricity consumption, as an energy monitor mainly curtails existing behaviour.

- The so-called rebound effect. People who replace inefficient products with more efficient ones sometimes increase the use of these more efficient products (Terpstra, 2008), thus negating the savings.

Discussion

Certain shortcomings in the design of the research could not be prevented within this study. The case study was conducted in joint cooperation with commercial parties, which has benefits for directly implementing research into practice, but it also posed some scientific limitations. For instance, it could not be ascertained, beyond probable cause, that the chosen intervention method (energy monitor) was completely responsible for the savings. As in many other studies, this case study also had to deal with convenience sampling. Participants' awareness that their electricity consumption was being monitored during the initial trial might have contributed to the higher savings (Hawthorne effect), although four months is a long time to register this consciously. In contrast, participants did not know that their electricity consumption would be monitored in the period after the initial trial (the follow-up). Furthermore, relying on questionnaires and self-reported meter data introduces a high error rate in the raw data. Tracking the real-time usage of energy monitors in future studies would give more reliable insights.

Overall conclusions

Both the literature review and the case study highlighted a number of focal points that have implications for future research. The case study confirms the need for longitudinal research, as it shows how the initial effectiveness of feedback tends to wear off over a longer period of time (more than four months). A second finding is that certain groups of people seem more receptive to energy-saving interventions than others. Obviously, a ‘one-size-fits-all’ approach for home energy monitors cannot be justified. In the development of energy monitors, their design should take into account the fact that users’ responses to a type of intervention are divergent.

However, the effectiveness of energy monitors could potentially be enhanced by using insights from interaction design research, such as persuasive technology (as discussed in the literature review) or by considering the night-time ritual of checking the monitor (as discussed in the case study) as part of the design strategy. The understanding of user habits that were formed can have design implications by, for example, fitting an ‘energy check’ into an existing bedtime ritual. The differences in savings between households are of such a magnitude that interventions tailored to individual households are also recommended.

Likewise, the differences in achieved – and sustained – savings between users indicates that a fuller understanding of the influence of contextual factors, design, usability, and users’ characteristics and/or ecological attitudes is highly desirable. Within social science, attention to a participant’s characteristics and attitudes is evident, but other factors receive too little attention. As Abrahamse *et al.* (2005) also concluded, demographics have repeatedly served as a classification, but other attributes are less well documented. The exchange of knowledge between designers, Home Energy Management Systems (HEMS) practitioners, and social scientists when instigating studies and campaigns therefore needs to be encouraged.

Further research should also consider the development and testing of HEMS that manage energy (rather than ‘just’ monitor it), as was introduced in the section on background relations. These allow users control when appliances and installations consume energy, while subtly correcting their undesired behaviours. This leads to the question: To what extent does more active control by users result in more persistent savings?

Finally, the case study did not allow for the testing of variations in the design of the energy monitor. However, this is definitely an avenue worth further exploration.

While several leads have been introduced both in the literature review as well as in the case study, the focus should be on testing and finding the right balance in the types of intervention and HEMS’s design strategy, coupled with a clear idea of the kind of user the monitor is serving.

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