Architecture and the Built environment

Smart Energy Management for Households

A practical guide for designers, HEMS developers, energy providers, and the building industry

Sonja van Dam

Smart Energy Management for Households

A practical guide for designers, HEMS developers, energy providers, and the building industry

Sonja van Dam
Delft University of Technology, Faculty of Architecture and The Built Environment, Real Estate and Housing Department

Architecture and the Built environment

abe.tudelft.nl

Design: Sirene Ontwerpers, Rotterdam

ISBN 978-1492764779

Contents

Reason for this research

A family retrofitted their recently bought home with high-tech installations that had the potential to achieve significant energy reductions. However, after several years, the reductions had still not been achieved. The owners were struggling to understand why their energy consumption was higher than expected, and so they called in experts. Several attempts were made to gain control over their consumption, but to no avail. To measure and receive feedback on their energy consumption, smart meters and a device giving feedback were experimented with, but without success. The owners therefore remained in the dark as to whether their technical installations were not living up to expectations, or whether it was down to their own habits, practices and use of the installations.

This is just one of a range of experiences from practice that gave rise to this research. Had a simple device that gives easily accessible insight into and control over a household's energy consumption been available to the above family, it might have helped them to understand the cause of their higher than expected energy consumption and to achieve the energy savings potential.

There has been research on such devices – namely home energy management systems (HEMS) – but why they are not always used or effective in practice, remains uncertain. The aim of the research presented in the thesis was to explore how HEMS might, not only in theory but also in practice, better contribute to achieving long-term energy reductions in households. This was done by evaluating the longitudinal effectiveness of HEMS and exploring factors that influence their use and effectiveness. The aim was to infer design-related strategies to improve the use and effectiveness of HEMS.

1 Introduction

This publication is an extended version of the summary and conclusions of the doctoral thesis 'Smart Energy Management for Households' (van Dam, 2013). It is specifically intended to give practitioners dealing with HEMS in their day to day profession practical tools to strive to improve the use and effectiveness of HEMS. This booklet gives a concise summation of the insights and guidelines formulated in the thesis concerning the design use and implementation of HEMS, coupled with citations from users, and practical examples of the applicability of the insights and guidelines. In doing so it aims to let industry benefit from the findings of the research without needing to directly read the thesis

This booklet has the following setup. First the general setup of the research is explained, along with the framework used to structure the findings of the research. Next, the various findings related to the different elements within the framework are discussed along with the design related guidelines following from these findings. Where possible, these findings are supplemented with citations or practical examples along with references to where the findings are explained in the thesis, in case the reader is particularly interested in a certain topic. This booklet consecutively provides a reflection on the research as a whole and on its setup, as well as on current industry developments. Finally recommendation for the domains merged within this research – namely housing, the building industry and the HEMS industry – as well as for future research are presented.

The resulting knowledge can be employed to inspire these domains. For the HEMS industry: in striving to designing HEMS that are capable of influencing users, effective in reducing energy consumption, and easily usable and implementable in everyday life. For the building industry this research illustrates the benefits of considering the behaviour of inhabitants in achieving sustainable housing transformation. Furthermore, lessons are presented in how the building industry can contribute to increasing the ease of implementation of HEMS. HEMS researchers may assimilate knowledge for setting up and conducting future research well and to deepen the knowledge on ways of increasing the effectiveness of HEMS.

2 Research setup

§ 2.1 Research aims

The aim of the research was to infer design-related insights and guidelines to improve the use and effectiveness of home energy management systems (HEMS). This was done through an empirical evaluation of the longitudinal effectiveness of these devices and an exploration of factors that influence their use and effectiveness. Four main goals were stated:

- An empirical evaluation of the mid- to long-term effectiveness of HEMS.
- Exploring and identifying factors that may influence the use effectiveness of HEMS.
- Inferring design-related insights and guidelines to improve the use and effectiveness of HEMS.
- Reflecting on the implications for housing transformation, HEMS practitioners and researchers and their goal to reduce the energy consumption of households.

Three case studies executed with three different HEMS in households, a life cycle assessment (LCA) on those three HEMS, as well as a reflection on the challenges of both researching and implementing HEMS in existing housing gave a comprehensive picture of the opportunities and barriers for HEMS and their potential for achieving behaviour change and energy reductions. The research revealed five typical use patterns that emerged amongst households. It also revealed average energy savings of 7.8%, which however decreased in the follow-up that was conducted, and factors that may influence the use and effectiveness of HEMS. Nonetheless, the LCA calculations divulged that the HEMS can achieve net energy savings when taking their embedded energy into account.

§ 2.2 Problem statement

Reducing the energy consumption of existing households formed the starting point for this research. There are many facets to this energy consumption, including the size, quality and age of the home, its appliances and technical installations (which

increasingly run autonomously or in the background), and its inhabitants, including their demographic characteristics, practices and behaviours. Because of this complexity, addressing only one of these facets is not effective in substantially reducing the overall energy consumption of households. This called for an interdisciplinary approach, merging the domains of design for sustainability, sustainable housing transformation and environmental psychology.
In this research, HEMS were chosen as the intervention to address the various elements that contribute to household energy consumption, thereby functioning as a pivot. This was done because HEMS can be implemented in existing households with existing appliances and technical installations. By giving feedback and/or helping households to manage their energy consumption they can, in theory, assist them in changing their behaviours and practices and thus reduce their energy consumption. The capability of HEMS to visualize background energy consumption was also seen as an essential component.

However, in analysing literature on HEMS, four critique points were encountered. Past research tends to be limited in the types of HEMS and energy sources studied. Furthermore, limited knowledge was available on the longitudinal effectiveness of HEMS, the large variances in achieved energy savings and use of HEMS, and factors influencing their use and effectiveness.

§ 2.3 Conceptual framework

To address these critique points and explore the influence of the factors: user, other people, other products, context, and time; the human-computer interaction framework of Wever et al. (2008) and van Kuijk (2010) was proposed. HEMS were positioned within the framework (Figure 1), postulating the pivotal role of HEMS: how they influence and relate to the other elements in the diagram and household energy consumption, thereby implying that these elements in turn influence the use and effectiveness of HEMS. This framework visualized the interdependence of the different elements and structured the findings of the research.

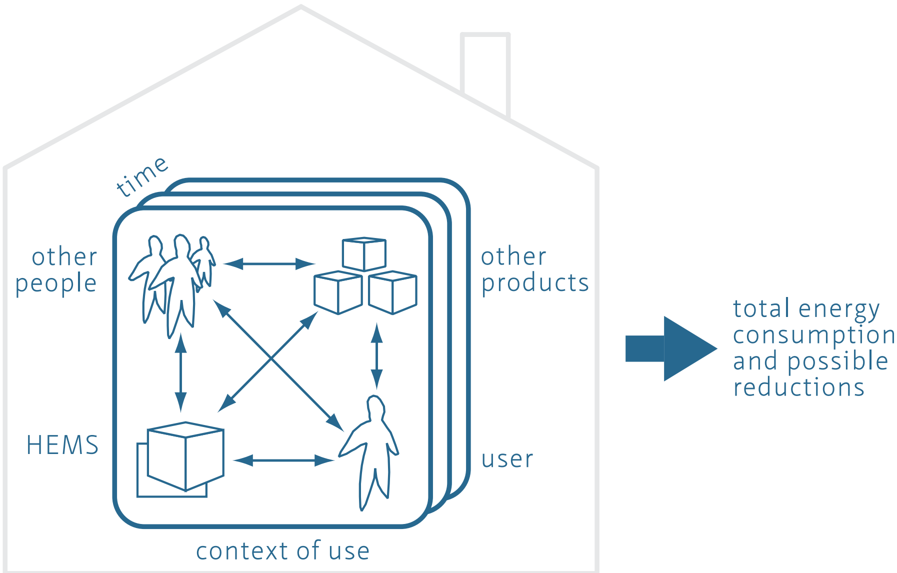


Figure 1
Factors influencing the use and effectiveness of HEMS. Adapted from Wever et al. (2008) and van Kuijk (2010)

§ 2.4 Case studies:

In past research, the specific influence of the various relational lines and elements within the framework was given limited or no attention, due to the predominant singular focus on savings, and therefore their influence remained unapparent. To explore these factors, three case studies, each with a distinctly different type of HEMS, were conducted. The three HEMS were an electricity monitor, an energy management device, and a multifunctional HEMS. Figure 2 gives a short overview of the time line of the three case studies.

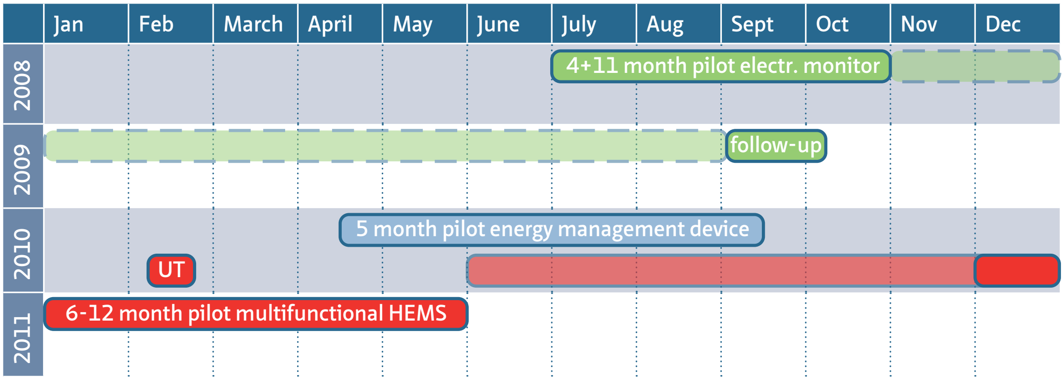


Figure 2
Time line of the three case studies

The first case study evaluated the longitudinal effectiveness of the energy monitor (Figure 3, picture 1) in 189 households during a 4-month period and at an 11-month follow-up. The energy monitor gave real-time and cumulative/24-hour feedback on overall electricity consumption. The quantitative data for this first case study were gathered by means of meter readings and four online questionnaires.

In the second study, an energy management device (Figure 3, picture 2) was implemented that gave real-time and historical feedback for individual appliances and helped manage whether and, if so, when appliances consumed electricity. This study lasted five months. The data were gathered by means of qualitative, semi-structured in-depth interviews through house visits with 10 households.

The third case study implemented a multifunctional HEMS (Figure 3, picture 3 and 4) that gave historical feedback, and for half the participants real-time feedback, on gas and electricity consumption and lasted 6–12 months, depending on time of installation in households. The data in this case study were gathered by means of focus groups, usability studies and interviews amongst 54 participants of which 40 were unique.

1

2

3

4

Figure 3

Picture 1: the 'Wattcher' energy monitor used in case study one.
Picture 2: the 'Plugwise' energy management device used in case study two.
Picture 3&4: Multifunctional HEMS used in case study three (picture 3 displays the start screen for the 'dumb' meter, picture 4 displays the start screen for the 'smart' meter).

§ 2.4.1 Coding

A coding system was used in this booklet to identify the citations from individual participants of the second and third case study. Each participant received a unique number (1–50). After the number, letters indicated which HEMS the participant had used, which research group he or she was in, and what type of qualitative research he or she had participated in[1].

Participants in the second trial using the energy management device have the letters (EM) and an additional letter indicating they were in the group with only plugs (P) or in the group that also had the Eee top (E). Interviewees are indicated by an (i). The bold letter indicates from which data the citation came. In the cases where two adults were interviewed within one household, an "(M)" or "(F)" indicates whether the comment is from the male or the female.

In the third case study with the multifunctional HEMS, the letters that were used indicate, in order of use, the multifunctional HEMS (MF), whether they were in the smart meter (S) group, analogue meter (A) group or used the HEMS only in a lab setting (blank), and whether they participated in the usability study (u), one or two focus groups (f or ff), the concept test (c) and/or the interview (i).

Participants from the first case study were not uniquely coded due to the quantitative nature of this research. In the few cases that a comment from one of the participants in one of the four questionnaires is cited, reference is only made to the first case study.

1 For a full explanation of the setup of the case studies and further demographics of the participants see §5.2.3, §5.3.3, §5.4.2, and Appendix A V of the thesis.

3 Findings

Five sub-questions were formulated in order fulfil the goals mentioned in § 2.1 and to derive design-related insights and guidelines. These insights and guidelines relate to the issues surrounding HEMS, as visualized in Figure 1, and are intended to improve the use and effectiveness of HEMS.

The five research sub-questions that were explored were:

- What are the medium- to long-term results of HEMS on energy savings?
- What typical use patterns emerge when households have a HEMS in their homes over a prolonged period of time?
- What factors might influence the use and effectiveness of HEMS?
- What is the overall effectiveness of HEMS when taking their lifecycle and embedded energy into account?
- What can industry and researchers learn from implementing HEMS and conducting research with HEMS in existing households?

This section in split into 5 paragraphs that each address one of these questions . After answering each question and presenting supporting citations from participants or examples, the design-related guidelines that can be inferred from the answer are formulated in text boxes. Quotations are in blue between quotation marks and examples are presented as second level bullets in blue. The findings are structured according to the framework in Figure 1. Finally, a closing remark on the design-related insights and guidelines is given.

§ 3.1 The medium- to long-term results of HEMS on energy savings

The first question on what the medium- to long-term results of HEMS on energy savings are was mainly addressed in the first case study which will be discussed here.

§ 3.1.1 Conclusions on the element of time in Figure 1

The first case study, of 189 households that used an electricity monitor for 4–15 months, addressed the element of time. The conclusion was that the effectiveness of HEMS tends to decrease over time. The initial savings in electricity consumption of, on average, 7.8% (for 54 participants) after four months were not sustained over a period of 15 months.

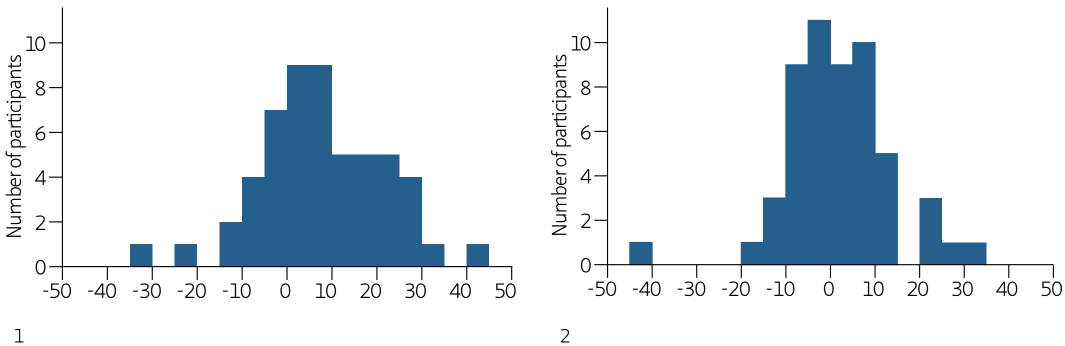


Figure 4
Histograms of achieved savings (%). Picture 1: after 4 months (Mean=7.8 SD=13.8, N=54), Picture 2 after 15 months (Mean=1.9 SD=11.8, N=54).

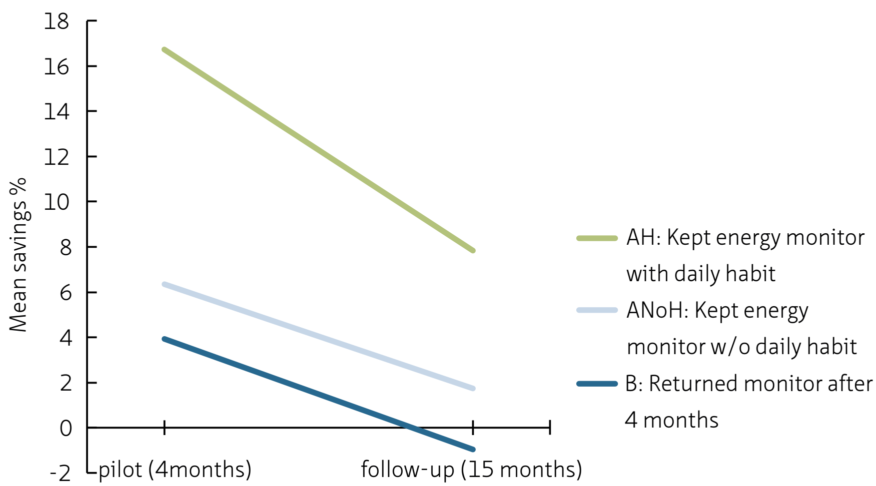


Figure 5
Mean Savings (%) after 4 and after 15 months

- The participants were divided into three groups. The group that had developed a daily habit after 15 months of checking the monitor at a fixed time, achieved the largest initial savings in comparison to the groups that did not have a daily habit after 15 months or that returned the monitor after four months. Both the savings and the development of the habit were likely caused by the household's predisposition (Figure 5) (Ch. 4).

- All three groups had the same rate of fall-back (Figure 5), even though the line of group AH looks steeper (Ch. 4).

- Households' responses to the interventions were divergent, with large differences between households in positive and negative energy savings (Figure 3) (Ch. 4).
  - 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 'high spender' (initial electricity consumption of 3985 kWh/year) had purchased an airconditioner, 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 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.

- An electricity monitor might not be an effective strategy in the long run if it is implemented as a standalone measure (Figure 5) (Ch. 4).

- Interviews during the second and third case studies revealed that HEMS do sometimes facilitate engagement in a process of change, helping users to reduce their energy consumption. (Ch. 7)

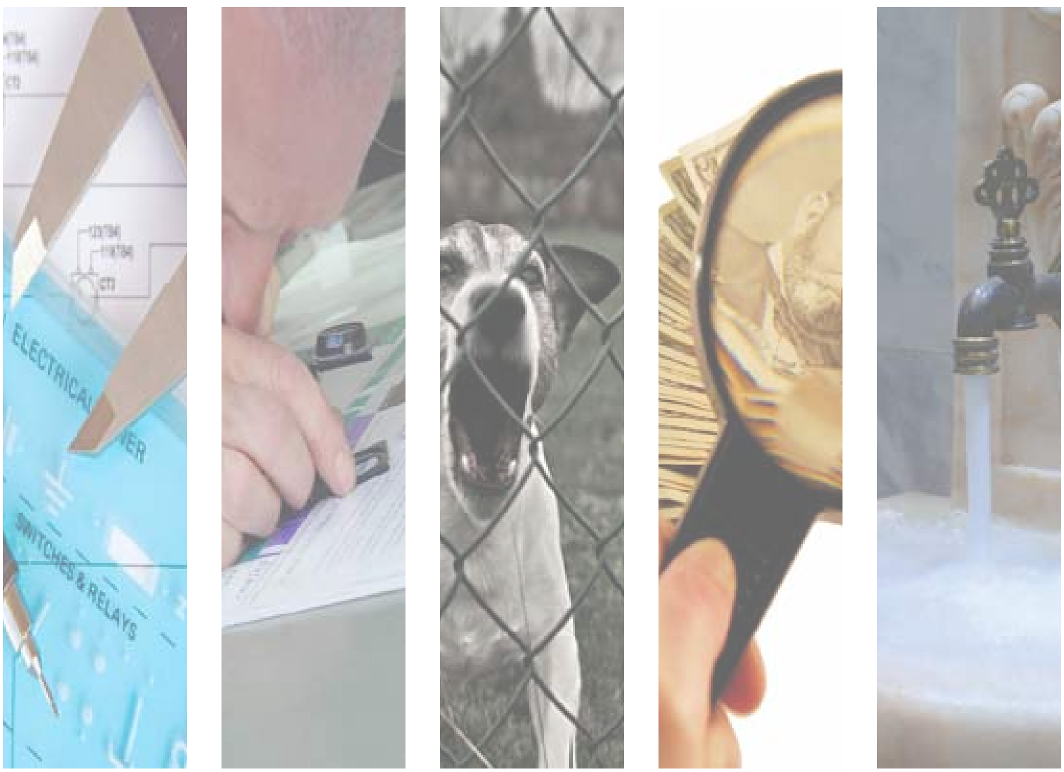
50EMPi: "In the last electricity bill [half a year before] it turned out that we used about one and a half or two times the national average". He continued: "In first instance I messed around a bit with energy meters and that sort of thing" after which he signed up for the case study. Two months into the study he purchased solar panels. Coincidentally there was a price incentive offered by his municipality that influenced his decision.

Design-related guidelines and insights related to the longitudinal effectiveness of HEMS

- HEMS should not be developed as standalone interventions but should be incorporated as part of a broader, overarching change strategy.
  - Consideration should be given to implementing them alongside other interventions, (financial) incentives, campaigns, and policy regulations.
- Interventions that utilize current 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. Therefore the 'en masse' implementation and target audience of HEMS should be given careful consideration.
- To increase savings across the board, and to counter the difference in measured effectiveness between different users, interventions should be tailored to individual households.

§ 3.2 Typical use patterns that emerge when households have a HEMS in their homes over a prolonged period of time

Strong differences between users and the way they used and applied HEMS were found amongst the participants in the second and third case studies. The patterns that emerged in the use and application of HEMS cannot be seen in isolation from the user who brought them about. To be able to present the findings in a manner that gives a coherent description of the context of use and the strong differences between users and their use of HEMS, the findings were translated into a classification of types of users and their use of HEMS:



The techie | The one-off user | The manager | The thrifty spender | The joie de vivre

Figure 6
Five types of users and their use of HEMS

- The ‘techies’ used HEMS to analyse and keep track of their (overall an dissaggregated) energy consumption and production over time, which was seen as a hobby. For some techies, it was also a challenge to reduce their (baseline) consumption as far as possible, mainly through technical solutions such as efficient lighting, timers, hot-fills and energy-saving software. They would also sometimes browse forums for more unorthodox solutions. They had kept track of energy consumption in the past and they enjoyed the gadget appeal of HEMS and having a variety of types of feedback.

50EMPi: " I just like watching it [the energy management device]." 41EMEi: "The way in which I go about it is that I now, I used to do it weekly but now monthly, write down my meter readings… And at the same time, the readings of the solar panels… I put that in an Excel spreadsheet where I can view the consumption over a period and I can make a prognosis" 16MFSf: "I wrote the meter readings down on Sunday evenings…before or after studio sport… easy to remember… It was just interest, hobby, a bit of fun. Playing around in excel to accomplish that, adding those graphs."

- The ‘one-off users’ had characteristics that overlapped those of the ‘techies’. However, they used a HEMS as an informative but short-term tool to discover which appliances they could reduce energy consumption on and, where possible, to be able to implement technical solutions or, to a lesser extent, adapt their behaviour on the basis thereof. The one-off user’s motivation to switch off appliances when not in use may be as much (or more) for fire prevention as for energy savings.

46EMEi: "We both though it [the energy management device] seemed like fun. So then we ran through the whole house together placing plugs in everything… Like two kids in a toy shop." 44EMEi: "If I'm into it, in the ‘vibe’, then I enjoy being occupied with it, then I enjoy adjusting the settings, then I enjoy knowing ‘small facts’, to click on something for ‘did you know that?’, then I will read it all. But the rest of the time. I have other things on my mind, then I am busy… with all sorts of other stuff. 42EMEi(M): "Like with that NAS, I therefore learned that the program indicates that itself, a kind of on/off at fixed times, and I now use that, and it's programmed once and I'll probably never touch it again."

- The ‘managers’ used the HEMS to keep tabs on the consumption of appliances and other household members, using it as a ‘badgering tool’ or ‘evidence’ to address their behaviour. Showering habits and unnecessary consumption (e.g. with regard to their baseline) were a particular focal point. Family dynamics played a key role in this type of use.

7MFufc: "Sometimes they [kids] take long showers, and then the door is locked, so then I have to knock on the door once in a while. Like: ‘hurry up a bit!’. How much that costs, I don't know exactly. But now I could quickly run down the stairs to look. And then I can also show it." 17MFSfc: "when those girls of mine were under the shower, I just turned the warm-water tap on [downstairs] and then hooo!" and "But my husband and my son, when they have been in a room the light remain on, and that has been annoying me my whole life. So I hope that through the display that the rest of my family will start *to become more aware of the electricity consumption." 43EMPi(F): "I can also just get really furious if someone forgets to turn the washing machine on during the cheap tariff."*

- The 'thrifty spenders' were characterized by their thriftiness. A HEMS was appealing because of its money saving attributes, but also because it was supplied free of charge. Their perceived thriftiness is based more on their perceived attitude and upbringing than on hard facts or knowledge. While even small potential savings are interesting to them and they are keen on receiving advice, they tended to have difficulty applying the HEMS to achieve savings.

48EMEi: "Still I saw that, despite the small…, it is still €30 that I can cut back per year."38MFAi "It's not the case that I cannot pay for it otherwise or something, but it is just, well… That's from my childhood, also from my parents" and "I have friends who… have to go along with all the latest things. And not I. I will only throw something away if it is rather worn-out." 48EMEi: "No, I'll just wait till it [her second-hand fridge of unknown vintage] is worn out. I'm not going to buy a new one anyways" and "If you think 'I can be more thrifty', then you will engross yourself in it [energy bill], but I think, well, actually, I can't be any more thrifty."

- The 'joie de vivres' used HEMS as means of keeping a global but intermittent overview of how their money was being spent, and possibly to verify whether their bills were correct. They disliked being confronted too often with their consumption, disliked details and tended to have difficulty understanding energy data and HEMS in general. They are dissimilar in their characteristics to the 'managers', being more relaxed and not striving for control. Comfort and convenience are valued

20MFAfi "It caught my attention that my consumption increased so substantially and it was more my frustration that I did not know where it was going. Not that I couldn't pay it, but then you get these ideas, like, yes but isn't any energy leaking away? And that is because I have a renovation behind me, and that was actually the background. And actually I haven't got an insight into it, and I thought, now it's structural again, it's placid again, well, that's fine then" and "Right now that [consumption figures] doesn't mean anything to me, because I don't know what the norm is." 29MFc: "No, whether someone showers for three or four minutes… I know, look, it's not wrong to keep paying attention, but I just want to shower comfortably. No, no, no, I am not that type."

Commonly, not all household members used the HEMS, and in particular the feedback it gave. Reasons that were stated were, for instance, disinterest in energy consumption, the feeling that saving is too much effort or has too little benefit, the HEMS is too technical, or that there were technical problems with the feedback.

Design-related guidelines and insights related to the typical use patterns that emerged

- In the design of HEMS, consideration should be given to users' desired use, practices and goals. Particular attention should be paid to those aspects that seem beneficial to a HEMS' effectiveness,
  - Examples addressed in the thesis were a desire to receive feedback on shower use (e.g. duration of showers, amount of energy or water used) as well as the practice to use the HEMS to monitor baseline consumption. A HEMS could be better equipped for example to visualize past and current baseline consumptions and persuade households to reduce it.
- The effectiveness of HEMS could potentially be enhanced through the application of insights from interaction design research to target the different types of users and their use of HEMS.
  - Various options are available. Three potential avenues are given as examples:
  - Fogg (2003, 2011) suggests approaches for creating persuasive technology, for example by focusing on motivation, ability or creating a trigger.
  - Cialdini (1993) addresses seven influence strategies, such as social comparative feedback: showing with smilies how you are doing in comparison to neighbours.
  - Lockton (2012) merges various disciplines in his design with intent toolkit: a practical tool suggesting eight different lenses through which to design for behaviour change
- Designers should strive to support the creation of positive dialogues between household members through the HEMS.
  - Possibilities could be social games or paying attention to positive achievements.

§ 3.3 Factors that may influence the use and effectiveness of HEMS

This paragraph addresses the question on factors that might influence the use and effectiveness of HEMS. It addressed the ways in which the HEMS, the user, other household members, and existing technical installations and appliances interplay and potentially influence whether and, if so, how households use HEMS, which can have a domino effect on their effectiveness. The factors are discussed below by systematically addressing each of the interactions in Figure 1, drawing from the findings of the three case studies.

§ 3.3.1 Regarding the interaction between a HEMS and its user(s) in Figure 1, the following factors may influence the use and effectiveness of HEMS

- Number of persons using a HEMS in a household: there was often one main user of the feedback given through HEMS, and this user was often male. This means that there was usually only one person in a household who received feedback and could potentially act on it (Chs 6 and 7)

41EMEi: "Yes, I'm the user [of the energy management device]. Yes, that is even not 99% but 100%."

- Mismatch between HEMS and user: users have distinctly different capabilities, needs, desires and usage related to HEMS, for which HEMS are not always appropriate. Different types of feedback (e.g. real-time, disaggregated, historical, comparative) fit different desires and applications (e.g. tracking consumption of individual devices, oversight, badgering tool) (Chs 6 and 7).

19MFAff: At first I saw kilowatts [current consumption] and cubic meters [per hour]. Now I only see euro's [per day], well that means completely nothing to me, you know. 6MFu: "It is all numbers; it doesn't mean anything to me" and "So then those numbers are sort of meaningless... I think colours more. More than numbers".

- (In)ability, (dis)interest or (un)willingness: not all users want or are able to save energy with a HEMS (Chs 4 and 7).

"The electricity monitor confirms that we are doing well. Further savings would barely be possible in our household." (first case study). 29MFc: "that makes me panicky, that's not healthy". saying that consumption is "only to be viewed on my own initiative"

  - Users had difficulty understanding what energy figures such as kWh's and m^3 mean and indicated a need for a point of reference in order to be able to act on the information.

6MFu: "what does 'm' '3' mean?" 20MFAfi: "Right now that [consumption figures] doesn't mean anything to me, because I don't know what the norm is."

- Managing the energy management device was challenging for some participants.

47EMEi(F): "I don't understand anything at all about it [the HEMS], but I am also not technical for the rest."

- User's goals and energy saving approaches differ. This influences the duration and intensity of the use of a HEMS (Ch. 6).

Goals: 46EMEi: "Well, to get insight into the consumption, really. Not the overall consumption, but the consumption of an appliance or group of appliances." 41EMEi: "...view the consumption over a period and I can make a prognosis of, say, what the consumption will be towards the end of the year." 48EMEi: "To see if I could be more thrifty than I already was.

- The quality of the technique: current HEMS that are on the market and/or are being researched are still an emerging technology, and as such they quite often still have start-up problems (Chs 6 and 7).

23MFAf: "If you get inexplicable peaks of 180 euros for gas and 150 euros for electricity per day it is hard to believe the rest. You can't steer on it... All these numbers, measurements, they don't mean anything anymore."

- A HEMS integration in a household's everyday life and practices:
  - Energy management devices do not always fit well with the rhythms and practices of everyday life (Chs 6 and 7).

48EMEi: "I believe my husband has pulled the plug [of the device] out again...so then I thought; I'm really giving up".

  - For some users, a HEMS becomes engrained in daily life with a daily habit of checking the HEMS, which was reported by over 25% of participants in the first study. To put things into perspective, however, over half opted to return the HEMS after four months (Ch. 4).
  - A common ritual that occurs around HEMS checking it before going to bed, in example for a baseline check whereby households check to see whether their consumption drops at night (Chs 6 and 7).

"There were times sitting in bed, turned the light out and then try to get the little light (on the monitor) to come on so we could read it in the dark – 'yea, we've dropped! Night night, darling!" (Kidd and Williams 2008)

§ 3.3.2 Regarding the interaction between user and other people, and HEMS and other people in Figure 1, the following factors may influence the use and effectiveness of HEMS

- Unappealing design or nature of HEMS: current HEMS do not appeal to the majority of members of households, although non-energy related HEMS functionalities might interest other household members more than feedback or control (Chs 6 and 7).

50EMPi: "I look at it [the energy management device], yes, yes, yes. My girlfriend doesn't look at it, no, no, no. No, she doesn't look at it…"

- Family dynamics (Chs 6 and 7):
  – HEMS may help open lines of communication between household members to reflect on behaviours.

"Consumption had become easier to discuss with the family members." (first case study)

  – HEMS are sometimes used as 'evidence' or a 'badgering tool' to try to influence the behaviour of other household members, which may be beneficial for energy savings but can lead to conflicts.

"I mean some nights I can come home from work and the whole house is lit up like Blackpool Tower – the computer's on, the telly is on, the radio's on in here and there's nobody in the house! That used to drive me up the wall but they are now starting to think. I've been badgering them and I've been flashing that meter in their faces!" (Kidd and Williams, 2008)

- The capability of, success at, or inclination to influencing the behaviour of other household members: HEMS users indicated that they were not always capable of or successful at influencing others, or were not inclined to do so (Ch. 6).

21MFAfi: "See, and that was of course also a bit my intention, to make them, um, more conscious… but I have not yet been able to achieve that completely… Well, children in puberty, it doesn't interest them that much. Other things keep them occupied." 48EMEi: "So it has not achieved behaviour change with my household members."

§ 3.3.3 Regarding the interaction between HEMS and other products in Figure 1, the following factors may influence the use and effectiveness of HEMS

- Cause-effect relationship: one application of HEMS is to trace overall consumption back to individual appliances. However, the cause–effect relationship between overall consumption and individual appliances based on aggregated feedback may be easy, challenging or frustrating, depending on the characteristics of the user.

HEMS that give disaggregated feedback on individual appliances were preferred by certain users but disliked by others (Chs 6 and 7).

17MFSfc: "I don't need to know all of that. Look she [15MFSf] wants to know everything, what everything uses and so forth, but I don't need to know that. I think this is totally unnecessary. I like to see those peaks and that you have a blue line and a red line, and I just want a good line, but I don't need to know what those appliances..."

- Match and compatibility with appliances and users knowledge of appliances: current energy management devices are not always an optimal solution to reducing the standby energy consumption of appliances (Chs 6 and 7):
  - Some appliances – such as HD recorders, network attached storage, digital set-top boxes and other appliances with clocks – are ill adapted to being switched off externally (manually unplugging or with an energy management device).

42EMEi(M): "When you actually just pull the plug [of the NAS], which is what you actually do with the energy management device... then it actually uses more energy than when you let it turn off by itself."

  - User knowledge of the workings of their appliances and the most efficient energy settings was regularly inadequate. This resulted in the suboptimal use of the energy management device and energy.

47EMEi(M): "But your modem works with an IP address and if you turn it off then a new IP address is assigned to you... I had it a while ago and then you get an IP address that was blacklisted. So I do not turn it off any more"

- Both technical installations and HEMS are currently poorly equipped to measure the production of renewable energy (e.g. via solar panels), while interactions with participants indicate that HEMS are particularly appealing for households that produce their own energy (Chs 6 and 9).

50EMPi: "Well, of course, I will, um, sit in front of the meter closet for a week to see how much the solar panels produce [when they arrive]."

§ 3.3.4 Regarding the interaction between users and other products, and other people and other products in Figure 1, the following factors may influence the use and effectiveness of HEMS

- Energy savings approaches and motives differ: certain types of users prefer either a behavioural or technical approach to energy reduction, while others do not strive for reductions (Ch. 6). Users may have an additional or alternative motive for turning appliances off, for example to reduce the risk of fire.
  - Users who favour technical solutions to energy reduction prefer to implement technical solutions, change products or adjust their energy settings.

42EMEi(M): "Like with that NAS, I therefore learned that the program indicates that itself, a kind of on/off at fixed times, and I now use that, and it's programmed once and I'll probably never touch it again."

  - Users who favour a behavioural approach are predominantly geared towards reducing unnecessary consumption and the duration of use of, for example, lights, showers and appliances, by paying attention to the behaviour of different household members.

One household thought they had saved because of "non use, switching off and tighter control over the kids (ADHD)." (first case study)

  - Some users or household members just won't change.

39MFAi "No, I'm not going to take the plugs of my TV out" and laughs.

- Lock-in: Busy lifestyles, lack of knowledge of how and when to turn off their products, and choices from the past can hinder changes in energy consumption behaviour. Certain participants indicated that they found themselves 'locked-in' by past choices. Even highly motivated people may find it hard to change (Ch. 7).

23MFAf: "Had I known then what I know now... I should say that I would have carried through further with insulating... But well, the house has been renovated and then you don't really start again that quickly."

§ 3.3.5 Regarding the element of context in Figure 1, the following factors may influence the use and effectiveness of HEMS

- Organisational aspects such as tenure, type of installation (e,.g. fitter, DIY), (lack of) accompanying services, and data transmission with external parties can hinder the successful implementation of HEMS (Ch. 9).

19MFAff: "I have had the fitter come over four times... But it functions now, except the statistics don't work. But I am not going to call anymore."

- The location, the structure of the home and the embedded housing technology – especially the type of gas and electricity meters – can have a negative impact on data transmission and the implementation of HEMS (Ch. 9).
  - Examples of issues given in the thesis are the distribution of housing technology throughout the home with too large distances, reinforced concrete, unsuitable meters, irregularities on meters, incorrectly read or unclear C-value of meters.

- These elements may furthermore lead to the HEMS not functioning properly or to households receiving intermittent, erratically fluctuating or incorrect feedback (Chs 7 and 9).

§ 3.3.6 Main factors

In summary, the main factors that can be derived from the above-mentioned bullets are:

- The characteristics of the user and other household members (their knowledge, capabilities, motivations, interests and desires).
- The design of the HEMS (its specifications and functionalities, the type of feedback, the quality of the technique, its usability, applicability and relevance, and its integration and implementability in household daily life and practices).
- The design and functioning of appliances.
- The design of the dwelling.
- The match/mismatch or compatibility/incompatibility between HEMS, users, appliances and the dwelling, and the adoption of the HEMS by household members.
- Family dynamics.
- The complexity of reducing energy consumption and users' preferred type of reduction approach.

Design-related guidelines and insights inferred from the factors that may influence the use and effectiveness of HEMS

- One size does not fit all. To increase the audience of HEMS, they should be diversified using a user-centred design approach,
  - Examples of diversification are the application of different types of feedback given at different levels, persuasion techniques and different architectures.
- Consideration should be given to the differences between users and the developments of users over time with regard to their capabilities, manners of cognitively processing information (e.g. visually oriented, preferences for colours or numbers), interests, levels of energy- and appliances-related knowledge, and technical know-how,
  - Ways in which HEMS can accommodate these differences are by creating a layered design in the interface (e.g. giving basic information up-front and more in-depth information in following screens), by using a combination of methods and graphical elements to relay energy consumption data (e.g. size, colour and numbers, see figure 7), and making comparisons (e.g. between different time periods, energy sources, and households) easy.

- HEMS should strive to make energy reduction opportunities easy and apparent.
  - e.g. through visualising potential savings in (baseline) consumption or suggesting automated saving opportunities.
- In order to create recurrent awareness of energy reduction amongst HEMS users, designers should consider not developing HEMS as a one-off design, but rather devise a longitudinal design strategy to continue stimulating their users over time.
  - Longitudinal design strategies may vary in complexity. They may, for example, give consideration to adjusting the interface and its information based on seasonal influences or shifting consumption, assisting households in a learning process, or including more intelligent systems that perceive changes in household's environment or behaviours and make adjustments on the basis thereof.
- HEMS should stimulate users to begin a search process that leads to other media or people for further analysis and in-depth (energy-saving) information, because only a limited number of functionalities and amount of information can fit on the HEMS platform.
  - Ways in which this could be stimulated is e.g. by accommodating easy transitions (or export functionalities) between different platforms and information sources but also creating more possibilities for extracting useful analyses from the consumption data, such as interactive graphs or correlations between energy consumption data, weather, and indoor temperature as performance indicator of the home.
- HEMS should support users who have limited knowledge of energy and of the functioning of their homes, technical installations and appliances. This is particularly relevant for removing the confusion as to what current 'best practices' for energy reduction of energy-using products are.
  - Examples are tailored information or (semi-)automation
- Attention should be paid to the possibility to develop daily habits around HEMS, particularly the baseline-check or night-time ritual of checking the HEMS.
  - Both the architecture of the HEMS as well as its interface can accommodate the development of habits, e.g. through portability of the HEMS, specific information on baseline consumption (incl. the use of colours) or notifications at certain times.
- Attention should be paid to the ability of HEMS, particularly energy management devices, to function according to households' daily practices.
  - For instance by evaluating their architecture and location with regard to the vicinity to a given activity and integration in other products.
- Ways of making HEMS more appealing to other household members who do not use the HEMS should be explored.
  - Engaging children should be considered as well as gaining a better understanding of why HEMS are not appealing to other household members
- The proper function and usability of HEMS should be given the highest priority.
- Feedback on the production of energy, such as PV cells, should be considered and promoted.

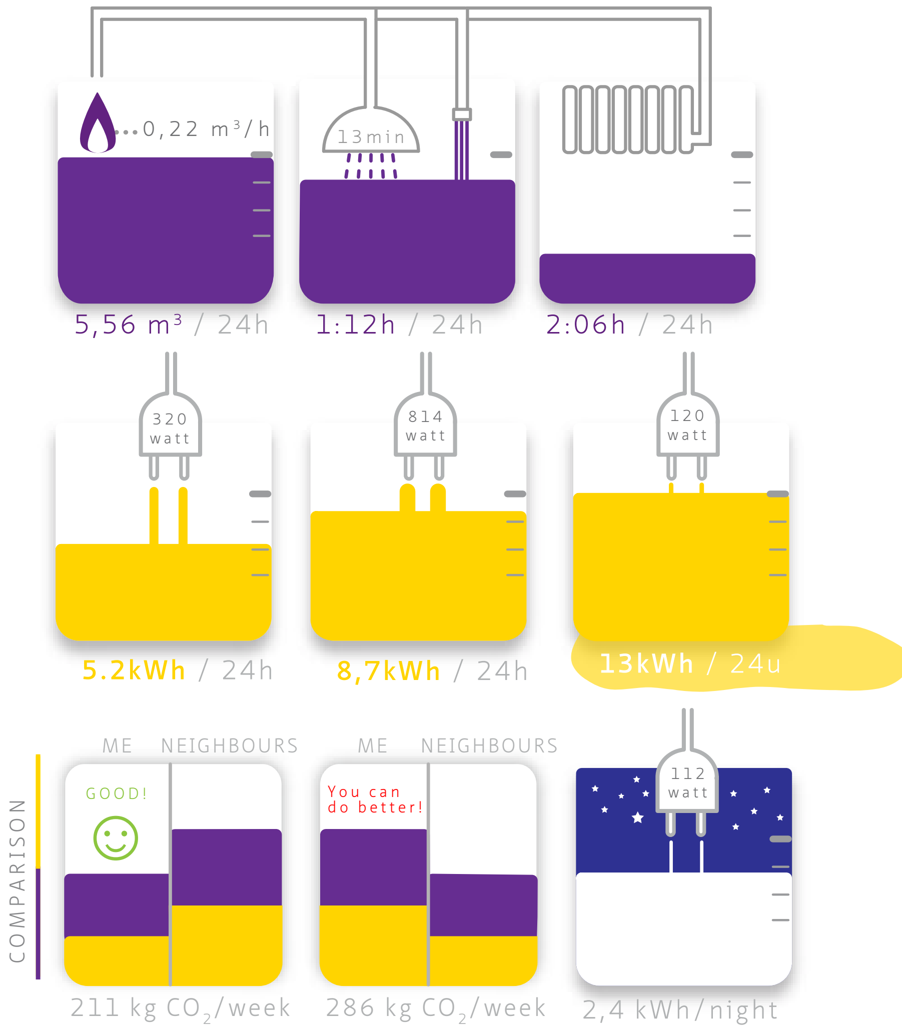


Figure 7

Designs used in the concept testing during the third case study. Designed by Enrica Masi.
The first row portrays widgets of gas consumption broken down for hot water heating and space heating. It visualizes both current consumption (m3 per hour or amount of minutes) and consumption over a given time period (e.g. 24 hours). An animation of hot water traveling through the pipes visualized whether gas was being consumed for hot water heating or space heating at a given point in time.
The second row portrays widgets of overall electricity consumption, visualizing both real-time consumption and consumption over a specified time period (e.g. 24 hours) in relation to the norm or a goal.
The third row portrays widgets of comparisons to other households over a specified time period (e.g. one week) and of baseline consumption, visualizing both real-time consumption and cumulative consumption of the night.
More in-depth information, such as graphs, could be found when a widget was pressed.

§ 3.4 Assessing the overall effectiveness of HEMS when taking their lifecycle and embedded energy into account.

The positive result of the lifecycle assessment is that all three types of HEMS studied can theoretically achieve net energy savings (where $e_{saved} > e_{invested}$) over the course of five years (Ch. 8 thesis and Table 1). To reach this conclusion, the cumulative energy demand (CED), eco-costs and economic payback were calculated for the three HEMS used in the case studies, and the new hardware of the multifunctional HEMS. The net energy savings were calculated using the CED indicator and six energy savings scenarios. In five scenarios, the savings were fixed and ranged between 2% and 10%, with an additional 'fall-back scenario' based on the first case study.

	'fall-back'	2%	4%	6%	8%	10%	'fall-back'	2%	4%	6%	8%	10%	'fall-back'	2%	4%	6%	8%	10%	'fall-back'	2%	4%	6%	8%	10%
0y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
½y	+	+	+	+	+	+	+	-	+	+	+	+	+	-	+	+	+	+	+	-	-	-	+	+
1y	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+	+	+	-	-	+	+	+
1½y	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+	+	+	+
2y	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
2½y	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
3y	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Energy monitor						Multifunctional HEMS (old)						Multifunctional HEMS (new)						Energy management device					

Table 1
Break-even point for the CED of the three HEMS calculated for the six scenarios

However, there are a number of significant nuances:

- The electricity monitor is the simplest HEMS and, on paper, it becomes effective sooner than the other HEMS: it achieves positive net energy savings within 6 months in all scenarios (Table 1).
- On paper, the multifunctional HEMS has the greatest potential because it addresses the household's total energy consumption (i.e. both its gas and its electricity consumption).
- Within the given scenarios, it can take up to 18 months for the multifunctional HEMS and up to 24 months for the energy management device to achieve net energy savings, as they have more hardware and higher electricity consumption than the energy monitor (Table 1).
- If the electricity consumption of the HEMS itself is too high, the net energy savings may become negative again within the course of five years. This was illustrated in a fall-back scenario with the energy management device (§ 8.4.2 thesis).
- For all three HEMS, the economic payback time was more than five years in between one and three of the scenarios (Table 2).

	'Fall-back'	2%	4%	6%	8%	10%
Energy monitor	-€5	€81	€158	€235	€312	€389
Multifunctional HEMS	-€237	-€131	€50	€231	€412	€593
Multifunctional HEMS new	-€186	-€80	€101	€282	€463	€644
Energy management device	-€239	-€153	-€76	€1	€78	€155

Table 2
Economic profit in euros after 5 years for the 3 (+1) HEMS for the six scenarios

Design-related guidelines and insights related to the lifecycle assessment

- Reported savings by means of a HEMS should be rectified to account for the embedded energy in the HEMS itself and the resources needed to produce the HEMS.
- Overall, it may be argued that HEMS should not be developed as standalone, dedicated products, but should be integrated into existing products. However, care should be taken to maintain the simplicity and accessibility of the feedback.
- Design strategies towards reducing the number and size of parts and the HEMS' energy consumption have positive effects on the CED and eco-costs.
  - The eco-costs and CED of the new multifunctional HEMS were reduced by around 40–45% in comparison to the old one. The reduction in energy consumption was the most significant contributor, followed by the size of the display.
- Careful trade-offs needs to be made with regard to the architecture of the HEMS.
  - While the small size of the display of the electricity monitor is positive for the cumulative energy demand (CED), it could limit the potential to achieve net energy savings through behaviour change, due to the limited interface design opportunities.
- It is recommended that energy management devices should be implemented only into 'high potential' appliances or by combining a very modest number of plugs from the energy management device with an energy monitor.
  - Examples of 'high potential' appliances are those that have the highest potential for large energy reductions, such as pumps for under-floor heating, close-in boilers, or digital set-top boxes.
- Openness to innovations.
  - One example is the use of electromagnetic interference for disaggregation algorithms or non-intrusive load monitoring (Zoha et al., 2013), which gives the benefit of disaggregated feedback without the need for extra hardware due to the plugs.
- Different marketing models should be explored to take the effectiveness of HEMS and their embedded energy into consideration.
  - For example by leasing or renting them to households for a short period.

§ 3.5 Lessons for industry concerning the implementation of -and research with- HEMS in existing households

This section focuses on the question: 'what can industry and researchers learn from implementing HEMS and conducting research with HEMS in existing households?' Two of the case studies reported in the thesis encountered challenges during the setup and execution (Ch. 5 thesis). Chapter 9 of the thesis reflected on the challenges encountered in different case studies, which gave an unexpected dimension and a different layer of insights on helping households manage their energy consumption. The conclusions are briefly listed in this booklet for the housing sector, the HEMS industry and companies researching HEMS.

§ 3.5.1 For housing and the building industry:

§9.6.1-§ 9.6.2 of the thesis reflected on the implication for housing and the building industry. The main conclusions were:

- It is important to be aware that the implementation of energy reduction measures in dwellings does not automatically lead to their inhabitants making energy savings. Taking the inhabitants into consideration is therefore a fruitful and essential approach to understanding household energy consumption and developing strategies to reduce their energy consumption.

"Even the new water metering project in Amsterdam [during which meters were installed for the first time at the request of customers] aims to install meters at the most appropriate place in terms of costs and existing infrastructure, which in many cases will be an inconvenient spot for regular household meter reading (GWL interview, 1999)." (Chappells et al., 2000).

- The design of dwellings can have unforeseen consequences for households' ability to achieve low energy consumption.
  - In the case of the HEMS, contextual factors concerning the location, the structure of the home and the embedded housing technology (including meters), all influence a household's ability to use and save energy with the help of a HEMS (Figure 8).

- Details, which are sometimes perceived as nitty-gritty, can have an unexpectedly large impact and should not be neglected.
  - Details, such as the location of sockets and technical installations, can strongly hinder the implementation HEMS and their successful use; therefore, the choice of HEMS and other energy saving technologies should be given careful consideration.

- To implement HEMS, a certain amount of retrofitting is currently often necessary, yet it is undesirable.

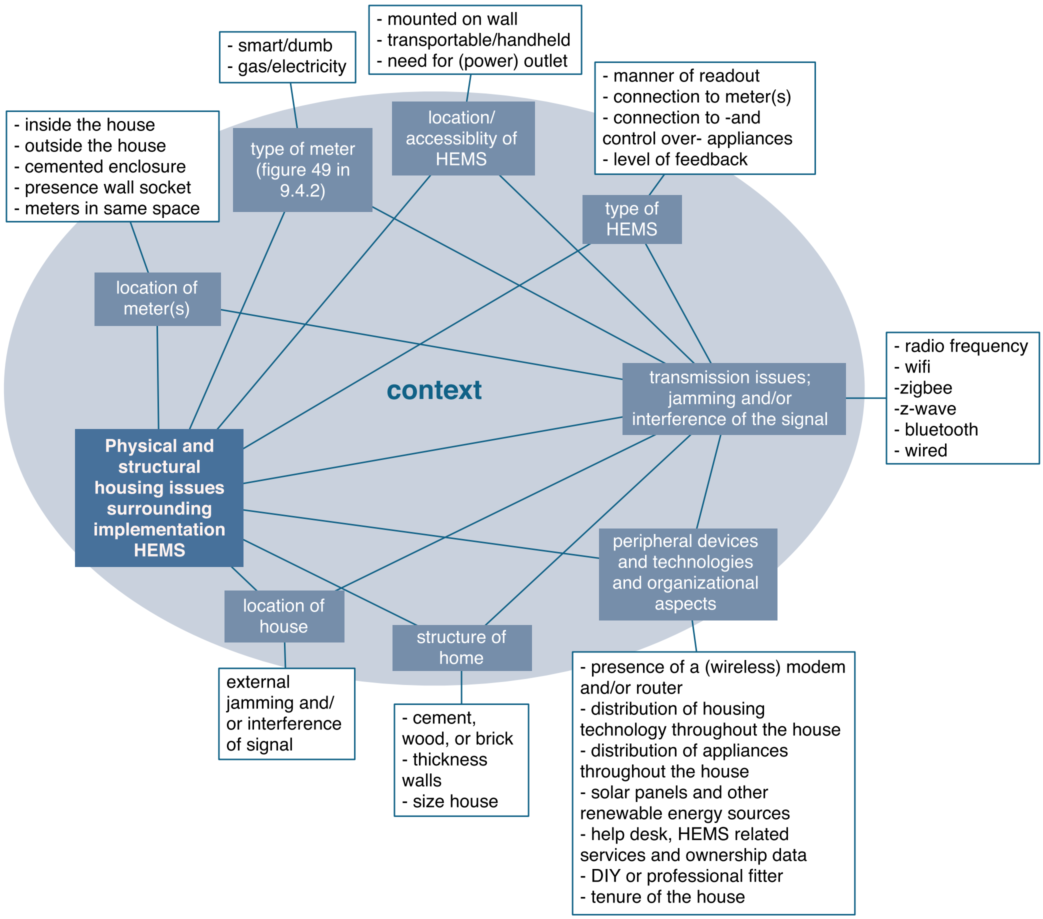


Figure 8

Contextual factors influencing the use and effectiveness of HEMS and their implementation in existing housing

§ 3.5.2 For the HEMS industry:

From the case study setup (Ch. 5 thesis) and the reflection (Ch. 9 thesis) the HEMS industry can glean the following knowledge with regard to the implementation of HEMS.

- Complexity is detrimental to the functioning of HEMS. When the complexity of a HEMS is increased by adding functionalities, the likelihood that the whole system fails increases exponentially. Extensive testing, piloting and iterating the design of HEMS in close collaboration with users is essential.
  - For example, when a HEMS needs to communicate with a heater, a gas meter and an electricity meter, all three installations need to be suitable

- Keep the communication with users open and appreciate those who provide either positive or negative feedback.

38MFAi: "That [it] doesn't work, doesn't matter, because it is a test thing. But look, I was going to be called back; I was going to be called back. It is just the communication. That is just really, really, really too crazy for words."

- Due to the interest of HEMS users in locally produced energy, and to the increase in the amount of energy that is locally produced, energy production should be given more attention in the design of HEMS.

41EMEi: "In first instance I had bought it [meter to measure consumption of an individual device] for the solar panels because I did not have a meter for them yet."

- The HEMS and its user need to be given more consideration in the design and choice of smart meters.
  - Smart meters do not always support types or frequentness of feedback that are desired by households.

§ 3.5.3 For companies conducting pilots with HEMS:

From the case study setup (Ch. 5 thesis) and the reflection (§ 9.6.3 thesis), the following conclusions can be drawn for companies researching HEMS.

- Be prepared for setbacks in the research setup: it is likely that case studies will take longer than expected.
  - Possible reasons are technical issues, delays in role-out, cooperation between parties, or lack of suitable houses

- Having a 'plan B' and a 'plan C' for gathering energy consumption and HEMS usage data is prudent.
  - for example relying on multiple meter readings (e.g. collected by a fitter, entered into the HEMS by households, or through a questionnaire) and remote data collection.

- Keep technology as simple as possible.

- Due to drop-out and technical complications, it is tactical to include many more households than strictly necessary.

- Develop a communication strategy towards participants beforehand to able to manage expectations and communicate challenges that may be encountered.

38MFAi "That [it] doesn't work, doesn't matter, because it is a test thing. But look, I was going to be called back; I was going to be called back. It is just the communication. That is just really, really, really too crazy for words."

- Cooperations between HEMS manufacturers, energy companies and the scientific community can aid in reduce preparation time, resolving technical issues , and prevent reinventing the wheel. However good communication and project management is essential.

- Try to make clear agreements with the various parties involved in the process as early as possible, for example with regard to the division of tasks and the sharing and analysing of data.

- Take careful consideration of the privacy of households and who has access to the data while remaining pragmatic. In particular, be open in the communication with participants.

"The possibilities that energy companies have to gather information through 'HEMS-like' appliances disturbs me." (first case study)

§ 3.6 Conclusions on the design-related strategies may influence the use and effectiveness of HEMS

Household energy consumption is a complex issue. This research found that the role of HEMS in reducing the energy consumption of households is constrained. The assumption that feedback is an effective strategy to reduce the energy consumption of households in general is problematic, at least when feedback is implemented in isolation. It should not be expected that implementing HEMS in households, without any consideration for, amongst others, their design, their usability, the context, accompanying interventions, and family dynamics, will achieve substantial and lasting energy savings for households. The design-related insights and guidelines that where inferred with the aim of improving the use and effectiveness of HEMS can be found in the blue text boxes in § 3.1–§ 3.4. HEMS should be seen as part of a range of energy conservation strategies, and their implementation should be given careful consideration and extensive planning.

4 Reflections

Here, three issues are addressed. The first is the choice of framework and the relevance of the different elements within the framework. The second concerns the current shifts in the marketing and development of HEMS, also in relation to smart grids, and the time-bound nature of this research. The third relates to the design guidelines and whether solutions for increasing the effectiveness of HEMS or reducing the energy of households should be sought in the design of HEMS or in the design of energy-using products.

§ 4.1 Reflections on the framework: Relevance of the various elements and relational lines within the framework

The thesis provides empirical evidence that the relational lines and elements within the framework, visualized in Figure 1, influence the use of HEMS. With regard to the influence of the relational lines and elements on the effectiveness of HEMS in reducing energy consumption, the influence of the element of time was confirmed.

That the other relational lines and elements have an impact on the effectiveness was deduced based on the use/non-use of HEMS and the challenges that were encountered, but could not be measured or quantified in energy consumption figures due to technical challenges during the second and third case studies. The need to consider the relational lines and elements within the framework when studying the use and effectiveness of HEMS has nonetheless been validated.

However, the significance of the relational lines may be dependent on circumstances, particularly for the relational lines 'HEMS <-> other products' and 'HEMS <-> other people'. These lines are dependent on the HEMS and the household involved and are not always apparent or visible. An energy management device may make the relational line 'HEMS <-> other products' more apparent and relevant than an electricity monitor, and the design of the HEMS could be improved so that other members of households become more involved. As this was an exploratory research, the relational lines and elements warrant further investigation in future research.

§ 4.2 Reflection on the development and marketing of HEMS

The insights in the thesis and this booklet are based on the current situation and portray the issues that currently arise in relation to HEMS and their technology in the Netherlands. Between 2008 and 2013, numerous parties became interested in HEMS and the number of concepts, pilot studies, start-ups and stakeholders has exploded. In this rapidly growing market, there are numerous new initiatives taking place, but the technological developments are also growing exponentially. The HEMS studied in this research were all new products that had recently entered the market; in fact, the third HEMS was introduced only as the thesis was being finalized. Nonetheless, the technology is rapidly developing and therefore some of the mentioned issues could be passé within a couple of years. While there is a risk that some of the issues mentioned in this booklet are out-dated, they do provide a large number of aspects for both researchers and practitioners to consider, whether they are HEMS designers, implementers or installers, or housing experts. The next two paragraph will discuss two topics that are highly relevant for the further development of HEMS: smart grids and the marketing of HEMS.

§ 4.2.1 Developments surrounding smart grids

We are in a period of transition. Large changes to the electricity grid are being planned and implemented. Investments in smart grids and related technologies are booming. The balance of types of energy sources, such as fossil fuels and renewable energy, are shifting, as are countries of origin. Until now, the role for HEMS has predominantly been to save energy within the home, but this is quickly changing to include peak shifting. Additionally, the local production of renewable energy is becoming more important to the use of HEMS. Therefore, a shift and an expansion in the usage of HEMS is taking place. However, it is prudent to still consider the original energy-saving goal of HEMS and whether they make sense when taking their embedded energy into account, particularly when additional technology such as smart meters are added to the equation.

§ 4.2.2 Marketing of HEMS

HEMS were created with the goal of helping households reduce their energy consumption or shift their energy consumption to a different point in time. Yet as time progresses, and perhaps in part due to setbacks in achieving this goal, certain HEMS companies have stopped developing HEMS that are specifically intended to save energy. Rather, some have started to focus on giving a central information point or insight. In some cases, the energy saving goal simply became snowed under, but the marketing and positioning of HEMS seems to be a larger contributing factor. Although this research did not focus on the marketing and positioning of HEMS, the close cooperation and diverse contacts with industry seem to indicate that the marketing and positioning is not always straightforward. Two major global players – Google and Microsoft – discontinued this line of business while the present research was being conducted. As customers may be wary of paying for a device that is only intended to reduce their energy bill, different marketing strategies are being devised. However, there seems to be a risk inherent to certain marketing strategies. What may start as merely a marketing strategy to position a HEMS as a product to provide customers with insight, may soon metamorphose into developing a product capable of only doing that. While marketing a product need not focus on its energy saving intent (and there may be good reasons not to focus on it), developing a product to save energy requires focusing on that goal throughout the development, including further development throughout the use phase of the product.

There is a real danger that the erosion of this goal will result in a situation whereby we have merely added yet another piece of technology to our already tech-filled homes. This could lead to an increase in total energy consumption rather than energy reductions (Ch. 8 thesis). This leaves us with an unsettling question: in the long run, will HEMS actually contribute to an overall decrease in energy consumption on a global scale?

§ 4.3 Reflection on the design of energy-using products

The thesis and this booklet have been geared towards improving the use and effectiveness of HEMS. As such, the insights and guidelines are aimed at the design of HEMS. However only so much can be achieved in the design of HEMS, and in certain cases a more straightforward and less cumbersome solution is at hand in, for example, the design of appliances and technical installations. This is especially the case concerning the baseline consumption of households and the reduction thereof. Feedback can make households aware of this consumption, but it is up to the user to act on this, which regularly does not happen. An energy management device can potentially assist in automatically powering appliances off when not in use, but a more straightforward and transparent solution lies with the appliance or technical installation itself.

Examples of guidelines that can be formulated concerning energy-using products are:

- Designers should strive to decrease the consumption of energy-using products and, in particular, their standby consumption as far a possible,
- Designers should enable the complete powering off of appliances, prevent malfunction, and reduce the need to adjust or reset (time) settings when appliances are turned on again.
  - Malfunction, for example, may occur with digital set-top boxes after a long holiday. While batteries may be an easily considered option to be able to switch off appliances with clocks, it should also be considered whether a (function) clock is necessary for the functioning of appliances, such as ovens.
- Energy-efficient power setting of energy-using products should be simplified and easily accessible or made the norm.

5 Recommendations

This has largely been an exploratory research on HEMS and therefore recommendations for the future are in place. This booklet therefore concludes by making recommendations for the various disciplines involved in this research, namely housing, the HEMS industry and researchers.

§ 5.1 For housing and the building industry

This booklet has highlighted the importance of understanding and collaborating with inhabitants in order to gain insight into the energy consumption of households, factors influencing that consumption and ways of attaining energy reductions. However, during the workshop and in communications with the buildings industry, it surfaced that there still seems to be a tendency to design around the user, or remove the user from the equation. Additionally, expectations were voiced that technique will solve the energy reduction challenge. However, the challenges documented in the thesis seem to indicate that this is too optimistic. As Midden (2006) also states:

"These constraints caused by users have made engineers long for full automation, assuming that by excluding the user from the operational process, the efficiency, for example of a washing machine, can be optimized. One might wonder if such a setup would really lead to energy reductions." (Midden, 2006)

Attention to inhabitants, their behaviours, and their use of their homes and technical installations needs to become more ingrained in the field of housing and the building industry. While a user-centred design approach and usability testing is relatively common in the field of industrial design engineering, post-occupancy evaluation is not the norm in the housing industry and instead is mainly practiced on the margins. The application of user-centred design approaches and post-occupancy evaluations and the knowledge that is gleaned through this process need to be disseminated within this industry to achieve more effective designs and greater energy reduction.

§ 5.2 For companies researching HEMS

Longitudinal qualitative and quantitative research is of essence to make a correct assessment of the effectiveness of HEMS. Consideration needs to be given to the aspects within the framework of this research (Figure 1) to make a correct assessment of the benefits and effectiveness of HEMS. Lastly, in the study of HEMS, cooperation between industry and the scientific community has decisive benefits. However, considerations need to be given to the potential pitfalls that were addressed in chapter 5 and 9 of the thesis and § 3.5.3, and the necessary precautions need to be taken.

§ 5.3 For the HEMS industry

The extensive contacts with HEMS users during this research resulted in insights into improving the design and potentially the effectiveness of HEMS, but it also drew attention to the need to take a user-centred approach and collaborate with users in the design of HEMS. The gap between current HEMS and users' needs and desired utilization of HEMS needs to be bridged, for which collaboration with users is an essential strategy. The avenues for increasing the effectiveness of HEMS suggested in this booklet need to be explored. It is important to test, pilot and iterate the design of HEMS even more extensively in a natural and realistic setting, to prevent malfunction in the field. However, it is also important to find a balance between the interests that are at stake.

Furthermore, a number of challenges need to be overcome in order to increase the use and effectiveness in homes. The technical look and feel that is common to HEMS needs to be adjusted to make HEMS appealing to more households. Even more so, the technical challenges that are common to HEMS need to be overcome. Complexity is detrimental to the functioning of HEMS. When dealing with existing housing and multiple types of energy and linked appliances or technical installations, the chances that one element in the system does not function properly increase exponentially, thereby jeopardizing the whole system. Because of the likelihood of encountering challenges during the implementation of HEMS, keeping the communication lines with users open and also appreciating those users who complain are essential to improving the design of HEMS. (Smart) meters are a crux, and in designing them more consideration should be given to the needs of households in relation to energy management, especially with the emergence of local renewable energy sources. Interest in self-sufficiency or the local production of energy and HEMS, seems to be a natural combination to which HEMS should be better suited.

6 Acknowledgements

This research was funded by the Delft University of Technology, Aliander, and Uneto VNI. However, other companies also made (financial) contributions to this research. In closing I would like to thank all the companies and people that were involved: Innovaders, Plugwise, Quby, Alliander, Eneco, and Aurum for your openness and/or willingness to let me come aboard the different initiatives you were undertaking; all the participants of the three case studies, and in particular the 50 participants who (repeatedly) gave me so many meaningful insights into their lives, for your willingness, time and, perhaps most of all, patience and endurance; and all the participants in the three think tank sessions: Anke van Hal, Conny Bakker, Arno Wayenburg, Norbert Vroege, Pim van Gennip, Gijs Postma, Dirk Smallenbroek, Hanneke van der Horst, David Keyson, Henk Seinen, René Nederhoed, Roelof de Vries, Mark Spee, Pablo van der Laan, Jan Willem Croon, Zeno Winkels, Marie Therese Anderwegen, Patrick Koch, Charlotte Kobus, Harry van Breen, Geert-Jan Dirven, and Dirk te Winkel for your input and feedback.

7 References

Chappells, H., Klintman, M., Linden, A. L., Shove, E., Spaargaren, G., & Vliet, B. v. (2000). Domestic consumption, utility services and the environment. Final Domus report. Wageningen University. Retrieved from http://dbiref.uvt.nl/iPort?request=full_record&db=wo&language=eng&query=doc_id=85694.

Cialdini, R. B. (1993). Influence: science and practice (3rd ed.). New York: HarperCollins.

Fogg, B. J. (2003). Persuasive Technology: Using Computers to Change What We Think and Do: Morgan Kaufmann.

Fogg, B. J. (2009). Creating Persuasive Technologies: An Eight-Step Design Process. Paper presented at the Persuasive 2009, the 4th International Conference on Persuasive Technology, Claremont, California, USA. http://www.bjfogg.com/design_files/page8_1.pdf

Kidd, A., & Williams, P. (2008). The Talybont Trial, exploring the psychology of smart meters. Brecon, Wales: The Prospectory. Retrieved from http://theprospectory.files.wordpress.com/2011/08/talybont-trial-report.pdf

Lockton, D. (2012). The Design with Intent Toolkit. Design with Intent: 101 patterns for influencing behaviour through design Retrieved 1 June, 2013, from http://requisitevariety.co.uk/design-with-intent-toolkit/

Midden, C. J. H. (2006). Sustainable technology or sustainable users? In P.-P. Verbeek & A. Slob (Eds.), User Behavior and Technology Development (pp. 191-200): Springer Netherlands. doi: http://dx.doi.org/10.1007/978-1-4020-5196-8_19

van dam, S. S. (2013). Smart energy management for households. (PhD thesis), Delft University of Technology, Delft. doi: http://dx.doi.org/10.7480/a+be.vol3.diss5

van Kuijk, J. (2010). Managing product usability; how companies deal with usability in the development of electronic consumer products. (PhD thesis), Delft University of Technology, The Netherlands. Retrieved from http://repository.tudelft.nl/view/ir/uuid%3A4329f7e0-a47d-48fc-b8a3-b1723c790d78/

Wever, R., van Kuijk, J., & Boks, C. (2008). User-centred design for sustainable behaviour. International Journal of Sustainable Engineering, 1(1), 9 - 20. doi: http://dx.doi.org/10.1080/19397030802166205

Zoha, A., Gluhak, A., Imran, M., & Rajasegarar, S. (2012). Non-Intrusive Load Monitoring Approaches for Disaggregated Energy Sensing: A Survey. Sensors, 12(12), 16838-16866. doi: http://dx.doi.org/10.3390/s121216838 Full text is available at: http://epubs.surrey.ac.uk/741874/