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Do home energy management systems make sense? Assessing their overall lifecycle impact

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HIGHLIGHTS

- We conducted a lifecycle assessment of three Home Energy Management Systems (HEMS).
- We developed six scenarios to find the breakeven point where $e_{invested}=e_{saved}$.
- All three HEMS can achieve net energy savings over the course of five years.
- Within the scenarios, it can take up to two years to achieve net energy savings.
- No HEMS achieve a positive return on investment within five years in all scenarios.

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ABSTRACT

An ever-increasing body of research explores the effectiveness of Home Energy Management Systems (HEMS) in achieving energy savings in households. To date, however, the overall life cycle impact of the HEMS itself has not been taken into account. Thus, no assessment has been made whether the amount of energy saved (e_{saved}) outweighs the energy needed for production, use and disposal ($e_{invested}$). Therefore, an eco-cost and a Cumulative Energy Demand (CED) method were used to analyze three distinct types of HEMS. Based on the literature, six scenarios were developed in order to find the break-even point, where $e_{invested}=e_{saved}$. The results show that the overall impact is dependent on the type of HEMS, and that if the duration of use is short and the achieved savings are small, the benefits do not always outweigh the environmental costs. Care should be taken not to develop HEMS with unnecessarily elaborate parts or functionalities and that their own electricity consumption is minimized. The paper concludes by discussing the implication for polices concerning the implementation of smart meters and HEMS and their design.

1. Introduction

HEMS are defined as intermediary devices that can visualize, monitor and/or manage domestic gas and/or electricity consumption (van Dam et al., 2010). 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 for automatic two-way communication of energy data between the gas or electricity supplier and homes. Smart meters generally need HEMS to give users the intended feedback and insight (van Dam et al., 2010; Klopfert and Wallenborn, 2011).

HEMS, often in combination with smart metering, are receiving increasing attention for achieving domestic energy savings both in academia (van Dam, 2013; Froehlich et al., 2010; Hargreaves et al., 2013) and in commercial enterprises, in part due to stimulation from legislation (State Government Victoria, 2013; UK Gov, 2013). Studies have reported positive results of up to 10% or even 20% savings for individual households, at least in the short term (less than four months) (Ueno et al., 2006; Wood and Newborough, 2003) in the mid- to long-term studies, it was found that HEMS are less effective (van Dam et al., 2010; van Houwelingen and van Raaij, 1989; Hutton et al., 1986).

Recently, research has started to explore not only the savings that can be achieved by means of a HEMS but also the role that the design of HEMS has on their effectiveness and their ability to effectuate behavior change. Contributing factors that have been discussed are, for example, the location, display methods, measurement units, type and

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level of feedback, and the esthetics, understandability, trustworthiness, and timeliness of the information (van Dam, 2013; Fischer, 2008; Froehlich et al., 2010; Pierce and Paulos, 2012; Strengers, 2011; Wood and Newborough, 2007), but this field warrants further research to ascertain their exact influence.

While savings of 5–15% (Darby, 2006) in electricity or gas consumption might sound impressive, this is not a complete picture for a number of reasons. Savings are regularly not achieved on the total energy consumption of a home but on only a part of it. For example, savings were only achieved for the gas or electricity consumption of one appliance (McCalley and Midden, 2002; Wood and Newborough, 2003), or for overall electricity consumption but not for heating or gas (van Dam et al., 2010), or vice versa (van Houwelingen and van Raaij, 1989). There is currently little evidence that these same savings can be achieved for other appliances and little research on spill-over effects to other types of energy.

A second reason why the stated savings present an incomplete picture is that studies tend to report on the resulting straightforward, direct energy reductions within the home. In such studies, the savings are usually calculated in the following manner: a number of households are selected, pre-trial baseline consumption measurements are made and/or control group(s) are selected, the HEMS are installed and the meters are read (or the consumption data are tracked) and, after a specified period of time, the meters are read again and the HEMS uninstalled. The two (or more) readings are subtracted from each other, possibly corrected for seasonal influences and compared to the pre-trial baseline or control group measurement. This is an important assessment. However, it should not be the last or the only assessment. In the strictest sense of the word, not all these 'savings' are savings. Energy is needed to produce, use and dispose of the HEMS. HEMS need hardware to measure the consumption of appliances and/or energy types. More hardware will probably mean that more energy is needed to produce and/or run the HEMS. When this energy is subtracted, the net energy savings become apparent. This is a more accurate depiction of the effectiveness of HEMS.

A third reason is that the savings are calculated over a limited period of time. However, the period after an intervention has ended presents a number of uncertainties. Care should be taken when extrapolating the savings to the period after the intervention. There is evidence that the achieved savings decrease over time (van Dam et al., 2010; van Houwelingen and van Raaij, 1989), and that not everyone manages to save with a HEMS (van Dam et al., 2010). There is also a risk that HEMS will become obsolete before their technical lifespan has ended (Ueno et al., 2006). Taking these factors into consideration, a holistic approach becomes essential. Only then can it be assessed whether the benefits outweigh the costs. Therefore, a holistic view is advocated by taking the overall lifecycle impact of the HEMS itself into account. This is currently not a standard approach. Only one study could be found where the overall lifecycle impact was analysed and reported. This was for a HEMS intended to conserve the amount of water needed for showering and, in doing so, the energy needing for heating the water (Willis et al., 2010).

2. Objective

This article provides a more complete picture of the overall effectiveness of HEMS. Consideration should be given to the overall lifecycle impact of HEMS and not only to the direct energy savings that can be achieved. In other words, a trade-off needs to be made between the energy needed for the production, use and disposal of the device versus the amount of energy saved within the home by using it. When the savings achieved through HEMS are sustained for only a short period, it is hard to break even with the amount of energy invested.

Effectiveness was defined by van Dam et al. (2010) as the extent to which users can maintain significant energy savings over prolonged periods (>4 months). This definition is not sufficient for this article, as the meaning of 'energy savings' needs to be more specifically defined. A distinction must be made between net, direct and indirect energy savings. In the literature on implementing HEMS, 'energy savings' usually refer to direct energy savings on gas and/or electricity, depending on the type of energy the HEMS targets. Spill-over effects to other forms of energy or savings on indirect energy consumption (i.e. energy embedded in the production, transport and disposal of consumer goods such as fruit, ready-made meals, etc.) are difficult to measure and attribute to a particular intervention. As such, they are less studied, with a few exceptions (Abrahamse et al., 2007). In this article, the focus is on positive *net* energy savings where $e_{\text{saved}} > e_{\text{invested}}$. So, within the stated definition of effectiveness, the words 'energy savings' refer to a positive outcome of the equation: direct energy savings through use of the HEMS minus the energy invested in the HEMS itself.

The primary objective of this research was to assess whether the environmental benefits of HEMS outweigh the environmental costs, and in doing so effectively contribute to household energy savings. As this is time dependent, an additional objective was to determine after what time a break-even point can be achieved where $e_{\text{invested}} = e_{\text{saved}}$ and whether it is realistic that this will be achieved during the economic and technical lifespan of a HEMS. The final objective was to evaluate whether the HEMS are economically viable for households and what the payback is.

Based on our previous experiences with conducting Lifecycle Assessments (LCAs) and savings achieved with HEMS in past studies (van Dam et al., 2010; van Houwelingen and van Raaij, 1989; Mountain, 2006) we had certain expectations. Because 'simple' HEMS (e.g. HEMS with few parts or with small displays rather than LCD touchscreens) are relatively low-tech products, we thought that these would have a positive net energy balance. In contrast, as our experience from running trials with HEMS showed that the energy consumption of more complex HEMS was not optimal, in part due to the fact that older, inefficient, or duplicate peripheral devices (e.g. routers, adapters) were sometimes implemented as part of the setup of the HEMS, we thought it highly questionable that the net energy savings would be positive in these cases.

3. Setup and methodology

To assess the impact of the production, use and disposal of HEMS on the overall effectiveness of HEMS, three HEMS were analysed using Cumulative Energy Demand (CED) and eco-costs indicators. For the use phase of the HEMS, a number of scenarios were developed for the potential energy savings. The three HEMS were chosen due to their diverse nature and as a representation of the different types of HEMS available on the market. The three HEMS employ different energy saving strategies and behavior change mechanisms. The HEMS were an energy monitor, a multi-functional HEMS and an energy management device.

3.1. Description of the three HEMS

3.1.1. The energy monitor

The energy monitor is a small, straightforward, dedicated device that gives real-time feedback on overall electricity consumption within the home in numerical values and with a flashing light. Fig. 1 gives a schematic visualization of the setup of the energy monitor and Fig. 2 depicts the hardware of the energy monitor.