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Investigating the link between well-being and energy use; an explorative case study between passive and active domestic energy management systems

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ABSTRACT

The aim of this study was to explore how the remote control of appliances/lights (active energy management system) affected household well-being, compared to in-home displays (passive energy management system). A six-week exploratory study was conducted with 14 participants divided into the following three groups: active; passive; and no equipment. The effect on well-being was measured through thematic analysis of two semi-structured interviews for each participant, administered at the start and end of the study. The well-being themes were based on existing measures of Satisfaction and Affect. The energy demand for each participant was also measured for two weeks without intervention, and then compared after four weeks with either the passive or active energy management systems. These measurements were used to complement the well-being analysis. Overall, the measure of Affect increased in the passive group but Satisfaction decreased; however, all three measures on average decreased in the active group. The measured energy demand also highlighted a disconnect between well-being and domestic energy consumption. The results point to a need for further investigation in this field; otherwise, there is a risk that nationally implemented energy management solutions may negatively affect our happiness and well-being.

1. Introduction

In 2009, the UK along with the other 26 member states of the EU adopted a wide-ranging package on climate change, including a commitment to reduce energy consumption by 20% by 2020 [1]. To help achieve this goal, the UK government mandated the installation of electricity smart meters with in-home displays (IHDs) across all homes in Great Britain [2]. However, previous quantitative and qualitative studies researching the effect of IHDs on energy demand show that the likely response by consumers remains uncertain. Adding to this uncertainty, is also a dearth of research investigating the link between domestic energy management systems (such as smart meters and IHDs) and well-being. To address this lack of dialogue, this study used household case samples from Cambridge, UK to explore how IHDs and active demand response systems (the remote management of appliances/lights) affected home occupants' subjective well-being.

For this study, households were divided into the following three groups: active group (given an IHD and active demand response system); passive group (given only an IHD); and non-intervention group (given no equipment). An active demand response system was defined as a system capable of remotely controlling appliances and lights. In total, 14 households in Cambridge, UK participated in the six week study which included measuring their electricity consumption and administering two semi-structured interviews; one each at the start and the end of the study. The overarching framework for this research was that of an interdisciplinary explorative case study.

The significance of this research is that if nationally coordinated, such an active demand response system can reduce peak demand during constrained periods of energy supply (in the UK, this occurs during the early winter evenings); thereby reducing the need for polluting and economically marginal peak energy generators [3, pp77]. However, the impact of such domestic energy management systems on household well-being should also be considered alongside their technical merits. By investigating the link between well-being and domestic energy consumption, it is intended that these results will improve the acceptability and effectiveness of future energy management systems. Such systems are significant for policy makers and members of industry, who are not only working towards

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achieving national energy and greenhouse gas emission targets, but who also want to improve our quality of life and well-being.

2. Background

The effectiveness of IHDs and energy management systems, in terms of reducing domestic energy demand and changing behaviour, is a well researched and widely debated topic. Prior to the recent interest in 'smart meters', the impact of IHDs was studied by Sexton et al. [4] in a study that employed an analysis of covariance (ANCOVA) framework to analyse the effect of giving information to householders about their electricity consumption. In the study, Sexton found that IHDs did not significantly reduce electricity demand. More recently Darby [5] produced a review of the current literature on metering, billing, and direct displays for the UK Government Department for Environment, Food, and Rural Affairs (DEFRA). In this review, Darby found that the norm for electricity savings from direct feedback (i.e., from an IHD or meter) is in the range of 5–15%. In the US, a dozen IHD pilot programmes were reviewed and on average it was found that occupants who actively used their IHD were also able to reduce their electricity consumption by approximately 7% [6]. Further results that supported these findings were shown in a 15-month IHD pilot study in the Netherlands, where van Dam et al. [7] found initial energy savings of 7.8%, but this was not sustained after the first four months of the installation of the IHDs. Burgess and Nye [8] also presented a review paper that discussed transparent energy monitoring and management systems and their effects on energy use and consumer behaviour. The results showed that an interactive smart meter demand-side system can produce a 2.5% reduction in peak demand for electricity and gas [Baldock, 2006, pp 18 cited in Ref. [8]]. While the aforementioned research, particularly Darby's literature review, provide a broad range of quantitative examples, these studies fail to discuss the qualitative effects that IHDs and active demand response systems directly have on home occupants.

Addressing this qualitative question, a more recent study by Darby [9] using the Theory of Affordance challenged the results presented in her earlier work [5], by showing first that demand reduction did not necessarily flow naturally from an improvement in awareness, and second, that there was still much to be learned about how households engage with feedback from smart meters and IHDs [9]. As such, the specific design of IHDs and the type of feedback reported back to households are both important considerations. Investigating such issues, Bonino et al. [10] presented the results of an online user survey which measured household attitudes and preferences towards IHDs, specifically by asking for their preferred locations and evaluating the clarity of different IHD feedback mechanisms. Bonino et al. found that most of their survey participants suggested to place the IHD in the kitchen or lobby, but that "about half of respondents, in choosing a location, looked for a visible and central place, while the others suggested places less visible but "esthetically acceptable," for example by indicating to put the IHD near the electricity control system (i.e., energy meter and/or circuit breaker)" [10]. From a design perspective, their study found that nearly all suggestions to improve the feedback included an adjustable energy goal setting visualisation, but that preferences did vary [10]. Hargreaves et al. [11] also qualitatively explored how UK households interacted with feedback from IHDs. The main conclusion here was that while IHDs were capable of informing consumers about their energy consumption, they were not enough to create sustained behaviour change. Another interesting result from this study was that some households were not able to reduce their energy baseline, and those participants became stressed and anxious when constantly reminded of how much energy they were using. Using a more technical approach to understand feedback design, Wood and Newborough [12] discussed different methods for presenting energy consumption information to encourage energy saving behaviours. Their conclusion also supported the finding that information about energy use alone is not enough to motivate energy saving behaviour, instead information needs to be "displayed in a simple manner and appropriately grouped in order to motivate energy savings" [12]. While not directly mentioning well-being, the results from such studies point to the need for future research to consider the human consequences of IHDs, in order to increase their effectiveness.

Some attempts have been made to include human factors, for example the UK regulator (Ofgem) is currently attempting to address the social aspects of a smart metering roll-out with a Consumer Advisory Group and workshops [9]. Neenan and Hemphill [13] also introduced a theoretical framework for characterising and quantifying the societal benefits of smart meters, but acknowledged that while smart metering might produce societal benefits, measuring such benefits is not without ambiguity [13]. Owens and Driffill [14] also presented a social science review paper on the difference between behavioural changes and attitude in the context of energy. For example, a Swiss study presented in Owens and Driffill's paper found that variables, such as interpersonal rules and social networks, are more likely to create behaviour change than the availability of detailed information (as presented on most modern IHDs) [Jaeger et al. cited in Ref. [14]]. However, most current research focuses on broad behaviour change, rather than the study of more direct effects, such as well-being. Supporting this sentiment, Henryson et al. [15] found in their study that more research is required to understand how human factors, in the context of the home, affect energy consumption. Their study reviewed measures introduced in Nordic countries (such as changing electricity bills, introducing IHDs, or creating general information campaigns), that produced varied results, from a 10% saving to an increase in electricity use.

The above research highlights how introducing IHDs or energy management systems can not only affect domestic energy consumption, but occupant experience as well. With regard to occupant experience and well-being, recent studies have tended to focus mainly on office buildings or large apartment complexes [16–19]. As such, this study aims to focus on the domestic built environment and explore the link between domestic energy management systems and specific aspects of the home occupants' subjective well-being.

Well-being itself can be broadly divided into two perspectives: the hedonic view (subjective well-being); and the eudaimonic (psychological well-being) [20,21]. The former comprises personal measures and refers to how people feel pleasure, enjoyment, and happiness; while the latter also considers their psychological needs, such as: autonomy; competence, and relatedness [22]. Ryan and Deci [21] give a review of research on hedonic and eudaimonic well-being. In order to measure the effects of energy management systems on well-being, the established subjective well-being measures of Satisfaction and Affect were selected as the most relevant. Satisfaction is defined as the feeling that one has accomplished a goal during a certain period of time [23], while Affect is defined as "a feeling or emotion as distinguished from cognition, thought, or action" [24].

3. Methodology

The research design was that of an inductive exploratory study, allowing the researcher to work with a small group of participants, in order to seek new insights from multiple in-depth semi-structured interviews and conversations. Therefore, a subjective and interpretative framework was adopted to include the motivation, feelings, and contexts for each participant. This epistemological