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DEHEMS: Empowering the Domestic Energy Consumer with Persuasive Interfaces

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Abstract

Globally, there is rising concern about the impact of energy consumption on the environment, coinciding with increasing energy costs. The Digital Environment Home Energy Management System (DEHEMS) project aims to provide householders with persuasive tools that improve awareness of the energy behaviour of their household and allow them to manage their energy consumption more efficiently. This paper presents the overview of the envisioned DEHEMS system, and proposes that there is a real user requirement for intelligent, persuasive energy monitoring systems.

Keywords

Persuasive interfaces, behaviour change, energy monitoring, energy feedback

ACM Classification Keywords

H5.2. User Interfaces. User-centred Design.

Introduction

The relationships between energy consumption, carbon emission and green house gases have been highlighted quite prominently in recent years. However, even though environmental concern may be on the rise, the

fact remains that there is a void between attitudes towards the environment and attitudes towards ecological behaviour, where even simple energy saving behaviours may tend to be overlooked. It has been suggested that switching off appliances instead of leaving them on standby can save the UK enough energy to power 400 000 homes [1].

Persuasive technologies for changing ecological behaviours are increasingly gaining momentum in the form of real-time energy monitoring systems. In this paper, we suggest that there is a real user requirement for smart energy monitoring systems that apply intelligent persuasive strategies. To our knowledge, DEHEMS [2] is unique in this regard compared to existing energy monitoring systems as it discovers user requirements by leveraging techniques which are grounded in sociology, incorporates multi-modal persuasive strategies and user interfaces, and collects and exhibits community-level energy information. We present the DEHEMS system, and the quantitative and qualitative results of the pilot user study in three UK cities (Bristol, Birmingham and Manchester). The rest of the paper is as follows. First, we provide a critical analysis of existing persuasive strategies for establishing energy awareness. Next we describe the DEHEMS system, followed by a summary of the quantitative and qualitative results of the pilot user study. We conclude by outlining future work briefly.

Persuasive Strategies for Energy Behaviours

Environmental behaviourists conceptualize persuasive strategies as either antecedent or consequence strategies [3]. Antecedent strategies announce the availability of positive or negative consequences through information, prompts, demonstration,

commitment or environmental alterations.

Consequence strategies provide rewards and feedback, following particular behaviours. Table 1 summarizes the various persuasive strategies and experiments on promoting positive energy behaviours carried out over the past three decades. Existing research demonstrates that feedback on energy consumption is more effective than antecedent strategies, especially when given immediately following an action [4]. The final version of the DEHEMS system will incorporate and extend some of these strategies, as shown in the next section.

DEHEMS System: Looking Forward

DEHEMS is an EU funded Framework 7 project, which equips households with tools that enable occupants to be aware of their energy behaviours, along with techniques to be more energy efficient. The DEHEMS system development methodology is a cyclic learning / development process that undergoes three cycles of design, implementation, deployment and behaviour assessments. Figure 1 presents the envisioned DEHEMS system components: (1) *Infrastructure*, with sensors that measure electricity usage both at mains supply and appliance-level, gas usage and indoor and temperatures (to help obtain context of energy usage), a data collector that sends gathered data over the Internet once a minute, servers that receive and store the time series data, and energy modelling and reasoning tools that infer energy behaviours of the household. (2) *Multimodal persuasive strategies* such as antecedent information and educational materials, graphical real-time and historical feedback, real-time personalized energy saving prompts and alerts via email, SMS, visual and audio interfaces, and comparison (reward) tools to encourage competitiveness against "similar" households, and

Table 1. Survey of persuasive methods that results in positive energy behaviour change.

Persuasive strategy	Persuasive methods and experiments
Antecedent strategy: Information/education	Putting up signs near light switches, resulting in 60% reduction in lighting usage[5]. Posters on energy awareness in a student housing complex, resulting in 30% reduction in energy use in the first week, and 9% reduction in the second week [6].
Antecedent strategy: Demonstration	20 minute TV program on energy saving monitored over 9 week period, resulting in 10% reduction in energy consumption [7].
Consequence strategy: Monetary reward	Reward is given according to rate of energy saving, carried out in an 80 person student housing complex for 90 days. Result is 33% reduction in energy consumption compared to 18% reduction by those given only feedback on energy use [6].
Consequence strategy: Written feedback	Daily feedback of percentage of predicted electricity use for that day on a board outside kitchen window, in 29 houses for 1 month, resulting in 10.5% reduction in usage [8].
Consequence strategy: Social commendation/ reward	Social commendation on feedback slip on fuel-oil usage in 122 households monitored for 4 months. Social commendations resulted in significantly reduced average oil consumption from 0.146gal/day to 0.129gal/day [9].
Consequence strategy: Billing feedback	Increased frequency of energy bills along with graphical historical data and energy saving tips, across 1386 households monitored for 2 years. Results are 10.5% reduction of energy use in the first year and 7.5% reduction in second year [10].
Consequence strategy: Electronic feedback	Electronic display in 25 new houses for 11 months, using Fitch Energy Monitor where energy is measured from the mains supply. Result is 12% reduction electricity usage [11]. Residential Electricity Cost Speedometer (RECS) software installed into the PCs of 25 homes resulting in 12.9% reduction in electricity use [12]. Manual meter readings input by users into PCs in 120 households for 9 months, resulting in 15% reduction [13].

encourage social / communal ownership by comparing energy consumption of cities. Social networking tools are also used to increase community participation.

(3) *Multimodal user interfaces* that present persuasive strategies via the DEHEMS website, dedicated display

unit, mobile phones and PDAs, and ubiquitous interface such as a digital photo frame. The Cycle 1 DEHEMS system implements parts of the final architecture; electricity is monitored through a single sensor at the mains, and user interfaces are mainly the DEHEMS

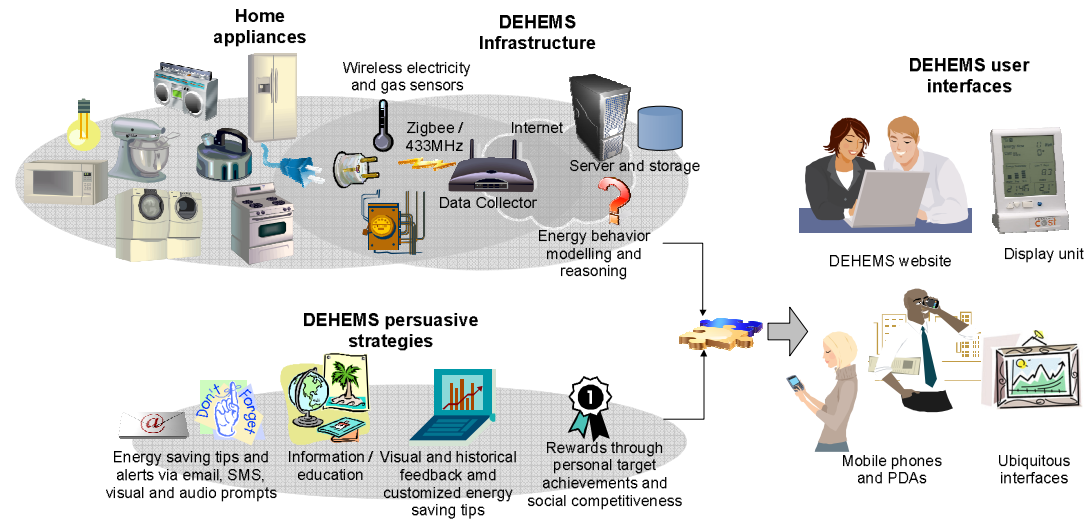


Figure 1. Figure 2. Overview of the DEHEMS system components

website and a Current Cost [14] display unit. Persuasive strategies implemented are antecedent information, graphical feedback, and comparison against other DEHEMS users. The pilot system is deployed in 77 households across the three UK cities from March 2009 and will be increased to 250 in March 2010, including households in Bulgaria. The in-house system will also be extended to include appliance level electricity monitoring and household wide gas consumption measurement, with the rest of the persuasive strategies in place.

Results and Discussions

Quantitative and qualitative action research is carried out via questionnaires and focus groups. In Cycle 1, a total of 45 randomly selected participants were surveyed, from Manchester, Bristol and Birmingham,

given open and closed questions to obtain probabilistic indication on the general public's attitude towards the environment, energy behaviours and the constraints they face in implementing energy saving behaviours. The focus groups help in understanding the mental processes underlying energy behaviours, and the usability of the DEHEMS system. We conducted four separate focus groups in Bristol and Birmingham, consisting around 10 participants in an interactive setting where participants were free to talk on the DEHEMS system and energy behaviours. We used NVivo to code the interpretative analysis. An extensive report on the user study is available online [15].

- *Attitude towards environment and energy use.* Concern towards environmental issues is prevalent among the householders (none show disinterest). 88.4% are proactive in (often) recycling paper, plastic,

cardboard, glass and metal/cans. 72.7% consider individuals as most responsible for environmental protection. There is a clear indication that households are keen to save energy; only 2 households do not pay attention to energy usage. Energy rating is considered one of the most important factors when buying a new appliance, equivalent to functionality and price. However, the key motivations for saving energy are split between financial and environmental concerns.

- *Attitude towards energy saving behaviours.* The most commonly practiced energy saving behaviour is switching off appliances when they are not in use (32.1%), switching to energy efficient appliances (26.1%) and home improvements such as insulation and double glazing (15.3%). Households are also interested in reducing dependency on appliances.
- *Constraints on energy saving behaviours.* The following constraints hinder householders from practicing energy saving behaviours: (1) Financial, cited as the main reason for *not* switching to more energy efficient appliances, making home improvements, and installing an energy monitoring system (69.2% would install if the cost is below £50, and none would do so if it exceeds £300). (2) Lack of opportunity to carry out energy efficient behaviour. This is especially apparent in standby power use, where 50% of the 80 reasons given are to do with appliances not having an "off" switch, standby mode required for functioning, inaccessible switch positions, and the need to be connected to mains supply directly. (3) Lack of information on energy efficiency of their household and appliances. 91.1% do not know their own home's energy performance rating. Ignorance on standby power use causes impatience and laziness and makes up almost 50% of the reasons for standby use. Meanwhile, 53.5% (23) assume the kettle, hot water

shower and washing machine to be the highest energy consuming appliances if switched on for 20 minutes whilst in reality, a cooker hob, oven and grill have the highest peak energy [16]. In fact, only 18.6% (8) correctly cite the cooker and the oven.

- *Usability of the pilot DEHEMS system.* Participants of the four focus groups are unanimous in remarking that the DEHEMS system provide new and interesting information on their energy usage. We find an encouraging indication of behaviour change; stopping dishwasher usage, changing light fittings to fit energy efficient bulbs, boiling less water in the kettle, changing to a smaller sized freezer, reducing temperature for the washing machine, etc. Participants stressed the need for gas monitoring (from the survey of hot water, heating, cooker, oven, cooker hob and grill, 60.6% of these appliances across 45 households are powered by gas). There is an equal split in their support between having a handy display unit (but with simplistic information), and the website which allows in-depth information (but requires login effort). User interface also needs to be children and youth friendly, such as innovative tangible and ubiquitous interfaces, besides being inclusive of disabilities. Participants would like to be motivated to continue their interest in the system, (via interesting facts on energy and the environment, and stimulating interfaces). Some worry on privacy issues if their appliance usage is monitored, while there is also concern on the validity of the information on their energy usage, including cost calculations. They especially like comparing their usage to similar households, but doubt that the data is really comparable. Participants also prefer not to be connected continuously to the Internet, and agree that the infrastructure needs to be wireless and minimalistic.

Conclusions and Future Work

The pilot deployment and user study of the DEHEMS system reveals that while environmental concern is high, various constraints such as financial concern, lack of opportunity to act, and lack of information are prime factors in hindering energy saving behaviours. While the Cycle 1 version of the DEHEMS system indicates positive behaviour change, the next version of the system, to be deployed from March 2010 onwards will be improved based on the pilot study which is transformed into user requirements; appliance and gas monitoring will be included, the future DEHEMS website will be more engaging and stimulating with multimodal persuasive strategies and user interfaces, along with a more intelligent semantically enhanced reasoning tool for personalizing energy saving techniques and household comparisons. We aim to measure behaviour change through extensive field study in the UK and in the cities of Plovdiv and Ivanovo in Bulgaria.

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