Energy Consumption Information Services for Smart Home Inhabitants

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Abstract. We investigate services giving users an adequate insight on his or her energy consumption habits in order to optimize it in the long run. The explored energy awareness services are addressed to inhabitants of smart homes, equipped with smart meters, advanced communication facilities, sensors and actuators. To analyze the potential of such services, a game at a social network Facebook has been designed and implemented, and the information about players' responses and interactions within the game environment has been collected and analyzed. The players have had their virtual home energy usage visualized in different ways, and had to optimize the energy consumption basing on their own perceptions of the consumption information. Evaluations reveal, in particular, that users are specifically responsive to information shown as a real-time graph and as costs in Euro, and are able to produce and share with each other policies for managing their smart home environments.

Key words: Energy Awareness, Smart Home, Social Networks, Energy Efficiency, Visualization, User Interfaces

1 Introduction

With the growing concerns of climate change, society, in particular, the European Union, shows increasing interest in energy efficient living that would lower carbon dioxide emission [10]. Many energy-related projects have been dealing with lower layer infrastructures, however very few addressed creation of information services delivering valuable energy consumption data to the service providers and end-consumers.

Now there is a large number of Internet of Things enablers for smart metering, home automation (sensors and actuators installed in buildings) and communication opportunities allowing creation and affordable deployment of energy efficiency services addressing smart home inhabitants. Automation control systems and energy optimization services enable the users to co-control their environment (switching on/off of devices, configuring actuators, etc.) according to their policies and together with the energy supplier, for achievement of a higher level of energy optimization. *Smart Meters* are devices to read the energy consumption data more frequently (typically, every 15 minutes) and automatically, being internationally on the rise, and the expectation is that they will be installed ubiquitously in the EU within a number of years [3, 12, 13]. Approaches on how this information can be used to help the consumers actually save energy, have been investigated [1, 4, 2, 6] and show that giving the users a feedback about energy consumption definitely has a positive impact. Also until Smart Meters are widely installed, various end-user devices are already on the market to give the consumer insight on consumption patterns [5, 8, 7]. Due to the novelty of such technologies, there is still insufficient knowledge about how the consumption data needs to be visualized to motivate the user to be most energy efficient.

Furthermore, the new generation of the energy efficiency user interfaces can benefit from modern content-rich communication technologies, such as social networking platforms where the consumers can interact with each other while using the interfaces. While people never really had a chance to interact with each other about their energy consumption, now Social Networks and the Web give this opportunity, and their potential benefits need to be investigated.

The paper is structured as follows. Section 2 defines the objective of the work and the solution approach. Section 3 provides the technical implementation details. The user study and experimental settings are discussed in Section 4. The results are presented in Section 5. Section 6 summarizes and concludes the paper.

2 Objective and Approach

The overall objective of this research is to facilitate home owners and building managers in saving energy within their environments and in optimizing their energy costs, while actively controlling and maintaining their preferred quality of living.

Therefore, to approach the energy efficiency goal, we leverage on a technical solution that integrates smart metering and building automation in order to offer energy-optimization capability for both the energy consumer and provider. This solution enables both parties to profit from the deregulated energy market, by leveraging information about the energy usage, about the user needs, and about the potentials for optimization through a smart environment control. For the energy end-consumers we assume a knowledge acquisition solution that supports creation and maintenance of policies describing preferences in energy use (e.g., green energy), as well as the rules for controlling the devices on the basis of the real-life sensor data from actuation of appliances.

Energy information services automatically channel relevant energy information (e.g., pricing, real time consumption) over the Internet into the user policy framework for employment in the reasoning mechanisms. Our goal in this research is to understand and analyze the effect of different energy consumption and home automation visualizations and rich communications on the energy-effectiveness of smart home inhabitants.

To achieve the realization of the optimal energy information services, a prototype of an energy awareness service was set up within the Social Network *Facebook*[4] to visualize consumption data for participants while their interactions with the service where monitored by *Google Analytics*[5].

To promote the prototype to the users of Facebook the name *GreenHome-Challenge*[6] was invented. Players have had their own virtual flat that they are in charge of, and the goal of the game has been to keep the energy consumption of this virtual place as low as possible. Therefore players can either apply *SmartRules* [9] (Energy Saving Approaches) or turn off appliances that other players turned on, as soon as noticed. A visualization on the start-page of the game shows the user the current energy consumption in his or hers own virtual flat. Within the prototype, every user got randomly assigned one of the shown visualization approaches (Table 1) while their interaction with the interface was monitored within the span of one week. Furthermore, a follow-up survey with 115 participants was conducted.

Data	Entity	Visual	Explanation
Trees	Number	Number	Number of trees needed to absorb carbon dioxide (CO2) emitted by producing consumed energy
Energy	Watts	Graph	Realtime energy consumption graph in Watts
CO2	Number	Number	Amount of carbon dioxide (CO2) emitted by producing consumed energy
Energy	Watts	Graph	Calculated Watt usage per hour as a bar graph
Cost	Euro	Number	Calculated cost of energy used in Euro
Energy	Watts	Graph	Consumption graph in comparison with other users
Energy	Watts	Number	Watt usage as a number

Table 1. Selection of possibilities to visualize consumption data.

3 Implementation

The experiment was implemented as a public Facebook application GreenHome-Challenge where the user had to add the application to his or her profile before starting the game. By adding the application a record for the user was generated automatically, including a random number between 1 and 7 to decide which visualization will be presented to the user within the game. Furthermore, this number decided which SmartRules the user found pre-defined within the virtual flat. The energy consumption graph from the game is shown in Figure 1, and a list with the most current activities happening in the smart home has been presented to the user: in this example, someone is charging a laptop.

[4] http://www.facebook.com - Facebook is a registered trademark of Facebook Inc.

[5] http://www.google.com/analytics - Google Analytics is a registered trademark of Google Inc.

[6] http://apps.facebook.com/greenhomechallenge/

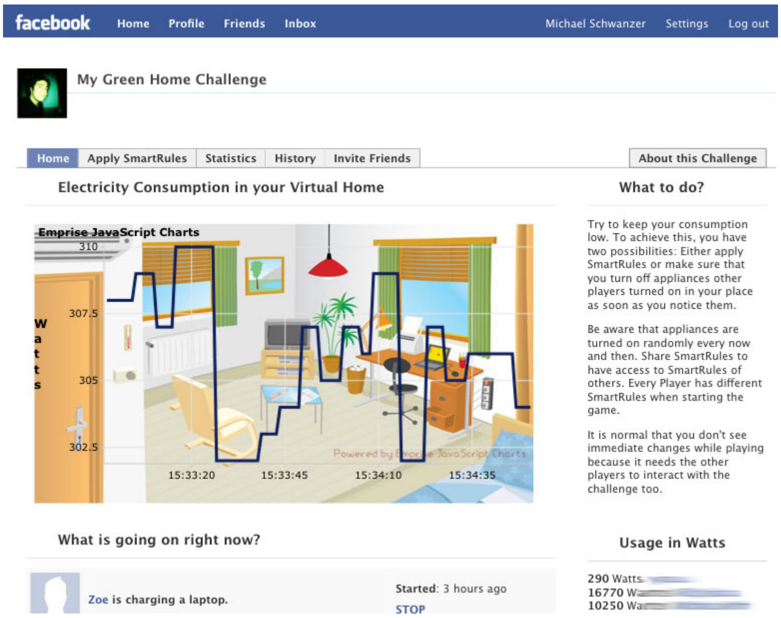


Fig. 1. Prototype of an energy awareness information service within *Facebook*, showing energy consumption visualized as a realtime graph.

All predefined SmartRules were based on a publication by Greenpeace[7]. All participants had the opportunity to create their own SmartRules by posting them as a natural language comment within the application. The direction 'to turn off the oven automatically if it is working for more than 2 hours without a human intervention' or 'turn off all the lights in the house between midnight and 7am' are examples of such user-created rules. Within 24 hours those rules got manually translated to a machine-readable format for the virtual flats, so the participants could add the existing SmartRules to their profiles and see the outcome. Every sub-page of the application included a Google Analytics Snippet to monitor usage of the GreenHomeChallenge.

To keep participants active within their virtual flats, a script started by a cronjob (scheduled start time on the server) turned on appliances in the name of other players (i.e. friends visiting your virtual home). This was necessary to keep the game steadily updating itself and more interesting to the users.

To harvest the real-time consumption data to be shown within the mentioned virtual flat, a market-ready device giving a direct feedback on a display (CurrentCost[8]) was set up and connected to computer. Through an inbuilt interface, data collected by the device could be preprocessed by the computer and uploaded to an online database. High density of data-reading (every 3 seconds) was necessary to provide flexibility for the visualization approaches tested within

[7] http://marktcheck.greenpeace.at/1537.html
[8] http://www.currentcost.com

the virtual environment. These data were used as a basis for the consumption rates in all virtual flats but were preprocessed with appliances that were turned on or off by the users in their virtual home before it got visualized.

4 Evaluation Set Up

After the GreenHomeChallenge game was added to the Facebook Application Directory, it could be potentially reached by any of its 350 million users. It was promoted on the SESAME project weblog[9] as well as on Facebook itself (mainly as postings to friends of friends).

Furthermore, interactions with the prototype where monitored automatically with Google Analytics. As the call to take part was public on the Internet, there was no access control for any particular demographic group and furthermore, this information was not recorded on purpose to keep the participants' privacy intact.

In order to evaluate the approach, to complement the Facebook game as an experiment, a 12 questions web-survey user study was conducted comparing the effectiveness of different consumption visualization approaches and additional aspects of energy efficiency.

The survey questionnaire was sent to all participants of the experiment as well as an open call via email to random other people known by the authors. Beside that, the survey was promoted on Facebook by sharing the link to the application and furthermore the call to take part was replicated on the fast growing social network Twitter (which is a free social messaging tool that lets people stay connected through brief text message updates up to 140 characters in length).

5 Results

Here we present the finding received from observing the Facebook game interactions and the user survey.

5.1 Facebook Game Interaction

Overall, 41 participants added the GreenHomeChallenge to their Facebook profile. The participants interaction within the virtual flat, trying to keep energy consumption low, were monitored and analyzed depending on the visualization method the user was presented to. Altogether 41 users played the GreenHomeChallenge on Facebook and caused more than 900 unique visits monitored by Google Analytics.

The interaction within the virtual flats (applying SmartRules, turning off appliances) to keep energy consumption low where monitored and analyzed depending on the visualization method the user was assigned to. Figure 2 thus

[9] http://sesame.ftw.at/2009/12/30/sesames-greenhomechallenge-play-it-now-on-facebook/

shows that the approach to show consumption cost in Euro caused the highest rate of interaction (twice as much as any other approach) within the prototype, followed by the realtime graph showing immediate changes (20% more than others that caused almost the same interactions).

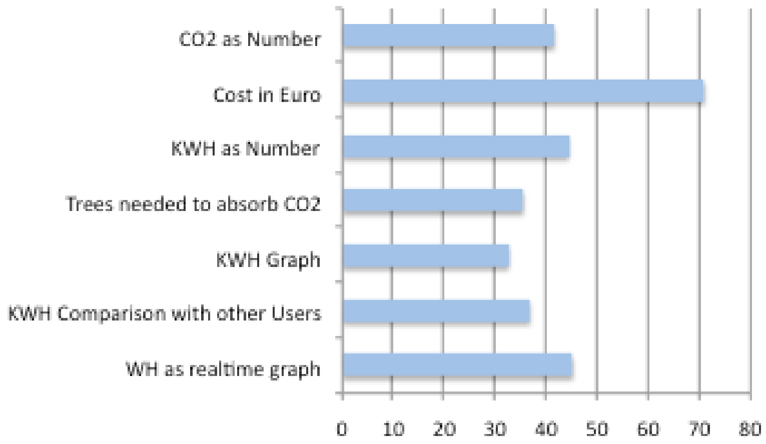


Fig. 2. Average user interactions depending visualization

5.2 Survey Results

The survey results have produced additional data, complementing and at times confirming the data obtained via the Facebook game. The survey itself was completed by 105 participants fully and 15 participants partially, including 24 people that identified themselves as participants of the GreenHomeChallenge experiment as well.

Regarding the user awareness about energy efficiency, only 39 of the 115 participants know what a Smart Meter is, but 97 are ready to save energy by changing habits. Results also show that only 19% are informed online by their energy provider about their consumption, while 33% inform themselves more often than once a year about their energy consumption.

The survey with 115 participants gave insights about the effectiveness of the alternative energy consumtion visualisations: 28.95% of respondents see their consumption the clearest and most meaningfully shown as a realtime graph, followed by 21.05% seeing their motivation most conveyed by a visualization of trees needed to absorb CO2 produced by the consumed energy. Further results are shown in Figure 3.

Asking participants for their motivation for saving energy, Figure 4 shows clearly that cost savings are the most important criterion while just a few are

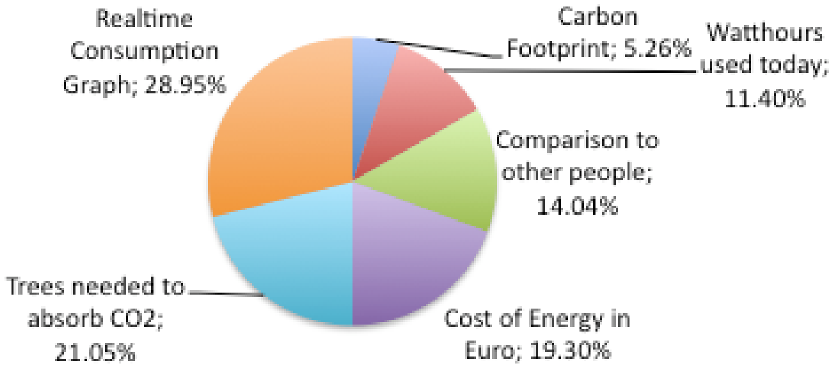


Fig. 3. Diagram showing which visualization approaches users think convey them the most.

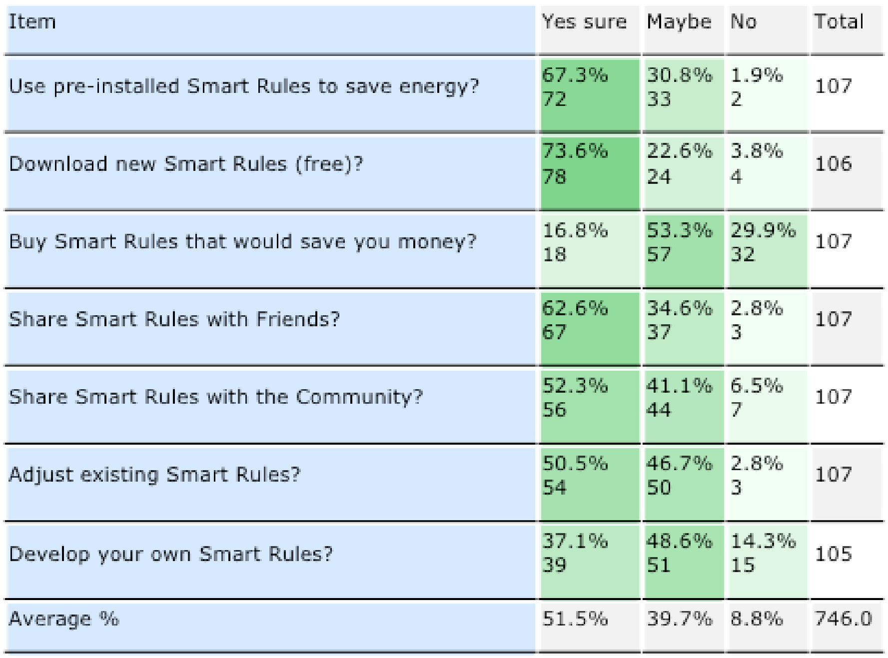
trying to save energy because of reputation, for example. For different visualization methods, 28.95% of the users see their consumption the clearest and most meaningfully shown as a realtime graph, followed by 21.05% seeing their motivation most conveyed by a visualization of trees needed to absorb CO2 produced by the consumed energy. Only 5.26% answered that carbon footprint would motivate them.

ITEM	1	2	3	4	5	Total Stars	Average Rating
Cost Savings	1.8% 2	7.0% 8	7.9% 9	21.9% 25	61.4% 70	114	4.3
Reduction of CO2 emission	9.7% 11	8.0% 9	19.5% 22	25.7% 29	37.2% 42	113	3.7
Social Responsibility	13.8% 16	14.7% 17	26.7% 31	19.0% 22	25.9% 30	116	3.3
Reputation	44.0% 48	18.3% 20	19.3% 21	10.1% 11	8.3% 9	109	2.2
	77	**54**	**83**	**87**	**151**	**452**	**3.4**

Fig. 4. Users motivation

Giving the same answer options (regarding visualization methods) as when asking which methods express the participants' consumption most, they answered very different to the question which method shows the biggest energy waste. Here the visualization of carbon footprint shows for 23.76% the biggest waste of energy, while only 14.85% think that the cost of energy shows the biggest waste.

Being explained what Smart Meters are and how they can be combined with home automation systems, between 105 and 107 participants answered the questions about SmartRules and gave very positive answers about using them in the future if their home automation system would support them (see Figure 5). Out of the 24 participants that identified themselves as players of GreenHomeChallenge, 52.38% think they will become more energy aware because of smart visualization and information systems like GreenHomeChallenge showed them. 42.86% answered neutral and only 4.76% disagreed.



Item	Yes sure	Maybe	No	Total
Use pre-installed Smart Rules to save energy?	67.3% 72	30.8% 33	1.9% 2	107
Download new Smart Rules (free)?	73.6% 78	22.6% 24	3.8% 4	106
Buy Smart Rules that would save you money?	16.8% 18	53.3% 57	29.9% 32	107
Share Smart Rules with Friends?	62.6% 67	34.6% 37	2.8% 3	107
Share Smart Rules with the Community?	52.3% 56	41.1% 44	6.5% 7	107
Adjust existing Smart Rules?	50.5% 54	46.7% 50	2.8% 3	107
Develop your own Smart Rules?	37.1% 39	48.6% 51	14.3% 15	105
Average %	51.5%	39.7%	8.8%	746.0

Fig. 5. SmartRules Usage

According to the participants answers, more than 70% want realtime or at least timely consumption data as necessary for the perfect energy awareness information system. With over 60%, extrapolation of possible cost savings is a mandatory feature for the participants. More than 50% see the perfect energy awareness system online through a website while only 15% want that information offline through a monthly bill.

6 Conclusions and Future Work

To investigate how different visualization approaches impact the end-user, an energy awareness information service was designed and a prototype implemented within the social network Facebook. Real-time consumption data have been collected through a market ready device set up in a flat and streamed to the Internet. Users of the prototype were shown randomly assigned visualizations and had the opportunity to turn on and off virtual appliances in a virtual place and define policies to influence the consumption visualization. Interactions were monitored and showed that the approach to show consumption cost in Euro caused the highest rate of interaction (twice as much as any other approach) within the prototype, followed by the realtime graph showing immediate changes (20% more than others, that caused almost the same interactions).

The contributions of this work comprise advancement in understanding the users' motivations for being more energy-efficient. A prototype for the users of Facebook, named GreenHomeChallenge, has been developed and employed for evaluation, where players have their own virtual flats that they are in charge of, with the goal of keeping the energy consumption of this virtual place as efficient as possible. A visualization on the start-page of the game shows the user the current consumption in his or her own virtual flat. The participants interaction within the virtual flat, trying to keep energy consumption low, were monitored and analyzed depending on the visualization method the user was assigned to. Also the players showed themselves capable to define and apply SmartRules (Energy Saving Approaches) as well as managing the smart home by turning off appliances that other players turned on, as soon as noticed. The results from the conducted survey complement and support the findings derived from monitoring of the game, and confirm the consumers' interest in the topic and the approach.

In real life, the described services would work on an ontology-based models describing the environments and situations that can be detected [11]. These models are being complemented with the service access points that encapsulate different interactions: data harvesting or control - between the users and the system. The preferences of the users in respect to the system behavior are modeled with a set of rules. The application of information services eventually merging both physical and virtual environments contribute to the pan-European vision of the Internet of Things.

For the future work, with the rise of smart meters usage and therefore accessibility of energy consumption data as well, energy awareness information systems have the opportunity to become handy enablers for consumers to save energy by changing their consumption habits. Bringing these data into social networks, people can team up and help each other detect energy waste and develop methods to save energy as a community. It would be necessary to investigate how users will react on social encouragement or 'shame' as soon as their data in the GreenHomeChallenge are real and not processed for a virtual place. Naturally, privacy would then also become an issue to be addressed.

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