Energy Awareness Displays

Prototype for personalised energy consumption feedback

Dirk Börner, Jeroen Storm, Marco Kalz, and Marcus Specht

Centre for Learning Sciences and Technologies, Open Universiteit, Heerlen, The Netherlands
{dirk.boerner, jeroen.storm, marco.kalz, marcus.specht}@ou.nl

Abstract. The paper presents the "Energy Awareness Displays" project that makes hidden energy consumption data visible and accessible for people working in office buildings. Besides raising awareness on the topic and introducing relevant conservation strategies, the main goal is to provide dynamic situated feedback when taking individual consumption actions at the workplace. Therefore a supporting infrastructure as well as two example applications to access and explore the consumption information have been implemented and evaluated. The paper presents and discusses the approach, the developed infrastructure and applications, as well as the evaluation results.

Keywords: Energy Conservation, Ubiquitous Learning, Situational Awareness, Feedback

1 Introduction

Modern office buildings are usually equipped with building automation systems that provide among others central energy management and monitoring services. Data from such systems is often gathered through proprietary software and made available only to a selected audience of engineers or facility managers. Typically, the level of detail of the gathered data does not go beyond a breakdown for the whole building, floor, or department. The main idea of the presented project is to make this data and thus the information that is hidden deep within the office building's infrastructure visible and accessible for the people working in the building - right up to a personal level of detail. In doing so the project sets up to change the energy consumption behaviour as well as the attitudes towards energy conservation of employees.

Besides raising employees' awareness on the topic and introduce relevant conservation strategies, the main goal was to provide dynamic situated feedback when taking actions. The underlying assumption is that the raised awareness on the actual consumption fosters a change in behaviour among employees and thus leads to reduced total energy consumption for the employing organisation. The idea was to reach the goal by the means of so-called eco-visualizations [1], a novel approach to display (real time) consumption data for the goal of promoting ecological literacy. On the long-term this visual, situated, real-time feedback on electricity consumption and respective conservation opportunities should facilitate environmental learning and behavioural change. The theoretical foundation and implications have been elaborated in [2].

2 Approach and Implementation

The presented project elaborated and developed an infrastructure that supports the concept of "Energy Awareness Displays" in office buildings with the following functionality:

- Inclusion of individual energy consumption information (device specific or personal level of detail).
- Aggregation of available information extending and enriching the overall energy consumption picture.
- Sensoring and logging to measure the effectiveness in terms of energy conservation and enable the prototypical evaluation.

Based on the supporting infrastructure respective display prototypes have been developed upon the following characteristics: (a) public interactive representation of the overall and individual energy consumption in several levels of detail, (b) explorative comparison of the consumption information in relation to fellow employees, departments, and/or floors, and (c) motivating and persuading conservation facilitation patterns based on the presented information, such as visual incentives.

The described approach required accessing and using external services offering the needed functionality. For the inclusion of individual energy consumption information the Plugwise[1] system was chosen. The system provides the needed sensor hardware to manage appliances and get access to energy consumption details. Furthermore the included software allows configuring the informational access via web services. The result is a wireless smart meter plugs network that can be accessed using the bundled software. The system was set up in such a way that individual appliance, room, and group information could be accessed. A basic application programming interface (API) can be used to access this information. The existing API was slightly adapted and enhanced to deliver all needed information in the right format. All changes are implemented based on the existing Plugwise Source[2] software template engine.

For the aggregation of available information respectively the logging of sensor data the Pachube[3] system was used. The system offers a free real-time open data web services that allows to aggregate, store, and access all kinds of sensor data, e.g. energy, home automation, and weather data can be aggregated, enriched, and accessed utilising different means. The system was set up to aggregate all the available sensor data for each room, i.e. (daily) total power usage and additionally the occupation.

1 http://www.plugwise.com/
2 http://www.plugwise.com/idplugtype-f/source
3 https://pachube.com/

2.1 Infrastructure

The developed software infrastructure supporting the intended end-user applications is conceptually based upon the architectural framework Robotlegs[4], implementing a Model-View-Controller+Service (MVC+S) design utilising the Dependency Injection (DI) pattern. The framework is implemented in Actionscript 3. Based on the open-source Flex SDK 4.5.1 the infrastructure has been implemented using the Adobe Flash Builder[5] development environment.

Following a shared library approach the infrastructure is comprised of a library that bundles all necessary functionality for applications developed on top of it. Based on Robotlegs this library bundles model, command, event, and service components. The applications then consist of views and respective mediators that handle their functionality. Each application simply incorporates the shared libraries' functionality.

2.2 Applications

On top of the outlined infrastructure a mobile and a web/desktop end-user application have been developed using the Adobe Flash Builder development environment. Based on the open-source Flex SDK 4.5.1 the environment supports the development of mobile, web, and desktop applications. The applications visualise the gathered information within the infrastructure. Thus the information can be accessed and explored online or with existing institutional or personal devices, including desktop computers, tablets, smartphones, and so on.

Mobile Application. The developed mobile application consists of a title and navigation bar as well as a content area. When launched the application shows an overview of available rooms. The list items are rendered in such a way that each item presents at a glance its title, the current power usage, and the daily total usage. The list is sorted on the daily total usage in descending order. The coloured circles indicate visually the current power consumption (green = 0W, yellow <= 10W, red > 10W). When selecting items detailed information for the room is shown. When navigating to the groups section the application switches to the overview of available groups, providing the same functionality as for rooms.

Web/Desktop Application. When launched the developed web/desktop application shows a simple dashboard. The lists provide an overview of available rooms/groups and their appliance(s). The lists are sorted on the daily total usage in descending order. Thereby the appliance items are rendered in such a way that each item presents at a glance its title and the current power usage. The coloured circles again indicate visually the current power consumption (green = 0W, yellow <= 10W, red > 10W).

---

[4] http://www.robotlegs.org/
[5] http://www.adobe.com/products/flash-builder.html

When selecting items in the lists detailed information for the room, group, or appliance is shown. In addition to that users can explore, relate, or compare the item's consumption.

3 Evaluation and Results

As part of the design cycle the developed display prototypes and used visualisation techniques have been evaluated in user-studies to reveal which are most effective in communicating energy consumption data and motivating energy conservation. Furthermore surveys have been conducted to assess whether dynamic visual feedback and the provided facilitation patterns can promote the conservation of electricity at the workplace and measure the increased awareness on the topic as well as changed attitudes and/or changes in behaviour. Furthermore the user acceptance and interest have been measured. The methodology and detailed evaluation results are presented in [3].

In an informative study university employees have been asked about their opinion on energy consumption and conservation at the workplace. The respondents (N=190) had to rate several statements on a 7-Likert-Scale describing their awareness or willingness ranging from not at all up to completely. The median results show that the respondents want to be more aware about their own energy usage and would like to receive more information on how to save energy at the workplace. Most likely they would reduce their individual consumption accordingly. Furthermore the results show that they would like to compare their consumption with colleagues, although they are not profoundly convinced.

In a comparative study university employees working in the office building where the prototype was intended to be deployed have then been asked about their awareness, concern, and attitude regarding energy consumption and conservation at the workplace. The respondents (N=58) had to rate several statements on a 5- respectively 7-Likert-Scale describing their awareness, concern, and attitude ranging from not at all up to completely. After deploying the prototype the study has been repeated among the employees who actually used the prototype (N=14). Both results were then compared. Comparing the median results reveals that the respondents' self-assessed ability to estimate their own energy consumption increased, while still staying relatively low. Furthermore the respondents' concern about their own energy consumption increased after deploying the prototype. Interestingly their concern about personal efforts and the attitude to take more conservation actions is consistent.

To clarify this the respondents were furthermore asked to indicate their actual energy conservation behaviour as well as motivating/demotivating reasons. Comparing the results highlights that in total 5 actions with high conservation potential (e.g., disconnect power supply units when not in use, deactivate screen savers) are not performed more often. The reasons can be manifold and need to be explored in further research. Either the questioned actions have already become part of daily practice and are thus not performed explicitly or participants really need more information on what actions to take in which situation. On the other hand 6 conservation actions are performed equally or even more often (e.g., switch off lighting when leaving a room, use appliance built-in energy saving options) then before.

To evaluate the prototype the participants who used the web/desktop application have been asked to give some feedback. To do so the participants (N=14) had to rate the statements presented in **Table 1** on a 7-Likert-Scale ranging from not at all up to completely.

Table 1. Prototype evaluation: rated statements and means

Statement	Median
Did you make use of the energy dashboard?	2
Have you been aware what kind of information was visualized?	4
Did you understand the information given?	5
Was the used information visualization appealing to you?	4
Was the information presented useful and relevant for you?	3
Were you satisfied with the amount of information presented?	4
Were you satisfied with the granularity of the information presented?	4

The results show that although not all participants made extensive use of the display, the information visualized was perceived and understood. Furthermore the actual visualization was rated appealing, useful, and relevant. Thereby the amount of information presented as well as the information granularity satisfied their needs.

The sensoring and logging to measure the effectiveness in terms of energy conservation and enable the prototypical evaluation has been done using the introduced Pachube system. For each room and group a respective feed has been created. Each feed aggregates the total power usage and the daily power usage of the room or group. For rooms with shared workplaces, additionally the total power usage and daily power usage of each workplace are aggregated. On the short term several effects have been observed. Among others the most interesting one is that participants were especially interested in investigating and adapting their consumption patterns, e.g. switch off their appliances over the weekend instead of leaving the appliances in stand-by.

4 Discussion and Conclusions

The evaluation results presented above show the general interest in the topic and indicate the effectiveness of the introduced means towards the conservation of energy. On the long term the sustainability of these effects as well as the actual conservation potential of the deployed infrastructure of course needs to be examined and validated.

In the context of the conducted user studies and when presenting the project ideas several helpful comments as well as critical issues were raised that reflect some major points of discussion. Although the prototype was well received by the participants the actual daily usage was not as high or frequent as expected. As suggested by one participant the tool should maybe be promoted more or possibly it's use should even be enforced. Another solution would be to promote the information itself, trying to put it even more in context and thus prevailing daily practice and working routines.

Some participants also raised general concerns about the energy saving potential at the workplace and thus the usefulness of the prototype. Especially the usefulness and legitimacy of comparing the energy consumption among colleagues, departments, or buildings was questioned. The opinions drift apart widely at that point, which indicates the need for further research and discussions.

Regarding it's instructional capabilities and the application within the described learning context the prototype goes beyond the mere level of information perception. Instead the addressed situational awareness demands at least the comprehension of the available informational cues. In order to make use of the prototype efficiently and thus eventually conserve energy, even demands to forecast and estimate the implications of the personal consumption behaviour. In the terms of the used feedback characteristics the prototype provides simple verification feedback that can be more elaborated on demand. Thereby the timing can be described as immediate, although the delivery of information is not happening in real-time due to technical restrictions. The feedback intends to convey at best relational rules as learning outcome, while not going beyond the confirmatory analysis of errors.

Besides measuring the effectiveness of the prototype, an informative study, a comparative study, and a user evaluation of the prototype were conducted. The results indicate the general interest in the topic as well as the usefulness of the prototype. Nevertheless further work needs to be invested especially in the long-term sustainability of the behavioural change, design implications and improvements, as well as the way of embedding the prototypes into daily practice.

References

1. Holmes, T.G.: Eco-visualization. Proceedings of the 6th ACM SIGCHI Conference on Creativity & Cognition. pp. 153-162. ACM Press, New York, New York, USA (2007).

2. Börner, D., Kalz, M., Specht, M.: Beyond The Channel: A Literature Review On Ambient Displays For Learning. Computers & Education. Elsevier, Amsterdam, The Netherlands (in Press).

3. Börner, D., Storm, J., Kalz, M., Specht, M.: Energy Awareness Displays: Motivating conservation at the workplace through feedback. International Journal of Mobile Learning and Organisation. Inderscience Publishers, Geneva, Switzerland (in Press).