Energy Awareness Displays
Motivating conservation at the workplace through feedback

Abstract: The paper presents the "Energy Awareness Displays" project that sets up to make 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 resulting prototype fosters a ubiquitous learning process among the employees with the goal to change their consumption behaviour as well as the attitudes towards energy conservation. The paper presents and discusses the approach, the implementation requirements, the developed infrastructure and applications, as well as the evaluation results of the conducted informative study, comparative study, user evaluation, and design study.

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

1 Introduction and background

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 (Holmes, 2007), 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.

1.1 Background

Given the main idea and formulated goal, the expected environmental learning and behavioural change is seen as part of a technology-enhanced learning process within a ubiquitous learning environment. Thereby the ubiquitous technology that can be utilised is manifold, ranging from public displays in shared office spaces, over individual

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workstations, to personal mobile devices. Thus these technologies are encapsulated as ambient displays, i.e. according to Wisneski's (1998) definition technology embedded in the environment close to the user and presenting information related to the user's current context. Awareness can be deduced as a main instructional characteristic for these displays. Furthermore awareness is also one of the key concepts of informal learning support (Syvanen et al., 2005) that can be used as instrument to acquire information relevant (e.g. about tasks, concepts, or the workspace) for the learner within the ubiquitous learning environment (Ogata, 2009).

To grasp the application possibilities in a learning context especially the concept of situational awareness (Endsley, 2000) needs to be further explored. Endsley defines situational awareness as "the perception of elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future". Following this definition the author presents three levels of situational awareness, namely perception, comprehension, and projection. Perception is related to situational cues and important or needed information, comprehension relates to how people integrate combined pieces of information and evaluate their relevance, and finally projection relates to how people are able to forecast future events and situations as well as their dynamics. Especially on the higher levels of situational awareness the type and characteristic of feedback given plays an essential role for the effectiveness, impact, and behavioural change capabilities and thus is another important instructional characteristic that should be considered. Mory (2004) presents an extensive research review on the concept of providing (instructional) feedback. While her review is not focused specifically on computer-mediated feedback the general feedback research variables of interest presented are also applicable for studying the interaction between learners and mobile respectively ubiquitous technology. These variables are information content and load referred to as complexity, timing, error analysis, learning outcome, and motivation. Thereby the author differentiates several levels of complexity like simple verification, try-again feedback, or elaborated feedback. The timing of the feedback can be immediate or delayed, while errors can be analysed if at all in a corrective or confirmatory manner. The learning outcome can target again several levels, including declarative knowledge or concept learning and even higher-level outcomes like rule learning, problem solving, cognitive strategies, psychomotor skills, or attitude learning. In addition feedback can have effects on a motivational level, e.g. in relation to self-efficacy and task expectancy, triggered by goal or performance discrepancy, or exposed by causal attributions.

2 Approach

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:

- Public interactive representation of the overall and individual energy consumption in several levels of detail.
- Explorative comparison of the consumption information in relation to fellow employees, departments, and/or floors.
- Motivating and persuading conservation facilitation patterns based on the presented information, such as visual incentives.

2.1 Implementation

Requirements. The described approach required accessing and using external services offering the needed functionality, i.e. inclusion of individual energy consumption information, aggregation of this information, and logging. 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. When requesting information from the API, the information is returned in a simple XML[3] structure that can be incorporated into applications.

For the aggregation of available information respectively the logging of sensor data the Pachube[4] 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.

Infrastructure. The developed software infrastructure supporting the intended end-user applications is conceptually based upon the architectural framework Robotlegs[5], 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[6] 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

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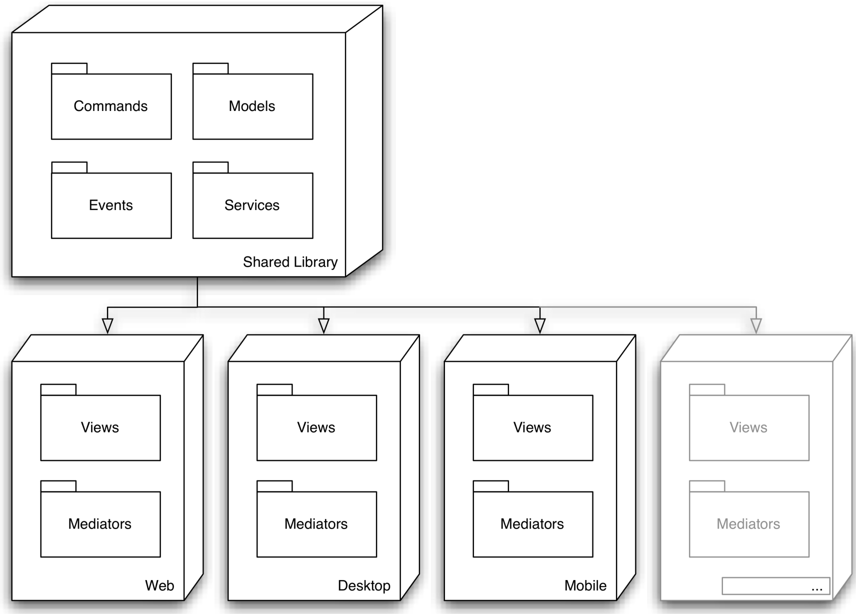
1 http://www.plugwise.com/
2 http://www.plugwise.com/idplugtype-f/source
3 http://www.w3.org/XML/
4 https://pachube.com/
5 http://www.robotlegs.org/
6 http://www.adobe.com/products/flash-builder.html

applications then consist of views and respective mediators that handle their functionality. Figure 1 illustrates the architectural overview. Each application simply incorporates the shared libraries' functionality.

Figure 1 Architectural overview of infrastructure



Thereby the *services* package interfaces all necessary services implemented in the contained classes. One class provides methods to access the information available within the Plugwise system regarding groups, rooms, and appliances and offers the needed functionality to parse this information. Besides the implemented Plugwise service, other services can be included in the package on demand. The *models* package depicts all necessary data structures and thus represents the used application data. The data stored is comprised of entities related to the system, i.e. room, group, and appliance value objects. Each object instance includes properties storing id, title, power usage, total usage, and daily total usage. The *events* package represents the frameworks' pipeline for handling all occurring events, e.g. when a room has been selected within a view. Finally the *commands* package builds the bridge between the other packages. Each contained class can call service methods, access model data, as well as listen and dispatch specific events.

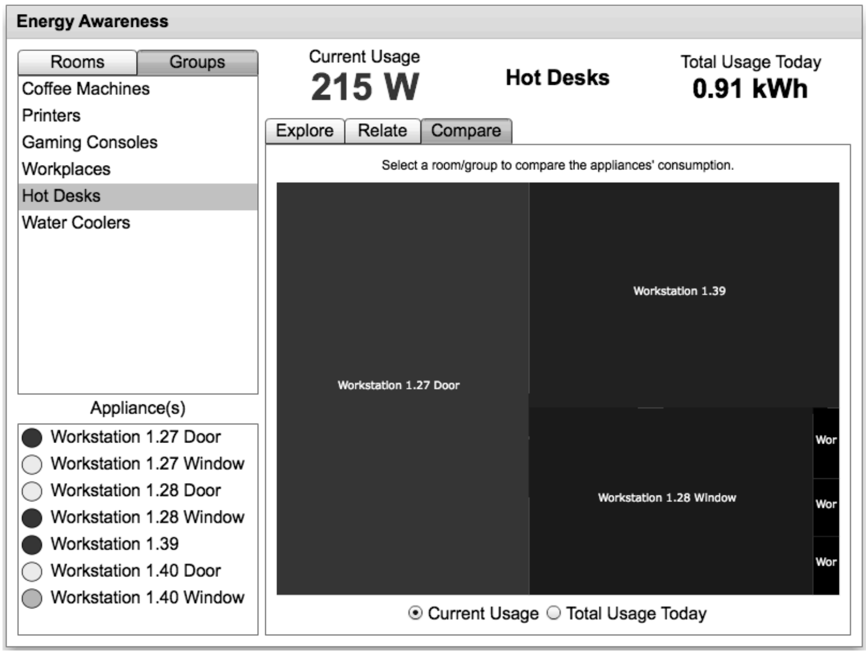
The applications' *views* package defines all possible views the application can take. Thereby views can comprise visual components and/or renderer. The views' *mediators* package then bundles the necessary functionality for each view. Each contained class can access model data and listen for specific events.

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.

Figure 2 Mobile application (left to right: rooms overview, room details, groups overview, group details)

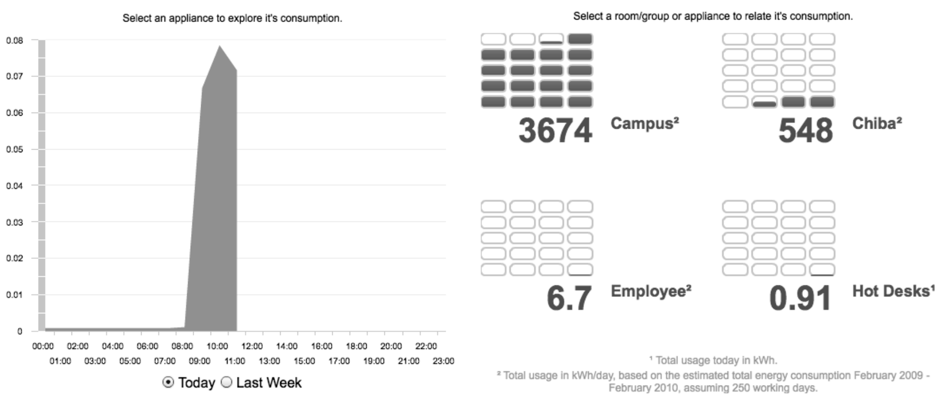
Mobile Application. The developed mobile application is shown in Figure 2. The application consists of a title and navigation bar as well as a content area. When launched the application shows an overview of available rooms. The list items are rendered in such a way that each item presents at a glance 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.

Figure 3 Web/Desktop application



Web/Desktop Application. The developed web/desktop application is shown in Figure 3. When launched the 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).

Figure 4 OverViewComponent (left: explore consumption; right: relate consumption)



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. Figure 4 shows the exploration (left) and relation (right) visualisations. When exploring the consumption an area chart depicts the daily or weekly usage. The relation visualization uses an existing pictogram chart component[1] to relate the room, group, or appliance's daily total usage with the average daily total usage of the campus, the respective office building, and each employee. The comparison visualisation is shown in Figure 3. Thereby an existing treemap component[2] allows comparing the room/group appliances' current power usage or daily total usage.

2.2 Evaluation

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.

Setup. The described infrastructure has been set up in a university campus' office building. In total 7 workplaces and 7 hot desks have been equipped with smart meter plugs. Additionally a meeting room and some shared facilities (e.g. printer, coffee machines, water cooler) were included in the setup. The setup considers the system's main limitation. Each plug has to be within a range of 5 to 10 meters to another plug, in order to establish a mesh network[3]. Utilizing a USB dongle the network then communicates with the system software. To allow remote access to the system and the data without the need to setup a dedicated server machine, the software has been installed on a virtual server machine that communicates with the USB dongle through the network. At each workplace the consumption is measured as a whole, i.e. the combined power usage of workstation and screen. In the meeting room all appliances (e.g. beamer, desktop computer, video conferencing system, smartboard, amplifier, power supplies) are measured separately. The coffee machines, printers, and water coolers are also measured separately. **Figure 5** shows an equipped hot desk (left) as well as a fully equipped meeting room (right).

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1 http://lab.kapit.fr/display/kolbert/Kolbert#pictogramchart
2 http://lab.kapit.fr/display/kolbert/Kolbert#treemap
3 http://en.wikipedia.org/wiki/ZigBee

Figure 5 Office building setup (left: hot desk; right: meeting room)

In addition to the measured consumption the actual occupation of the hot desks has been registered to eventually relate the individual consumption and the workplace. To do so a registering mechanism has been introduced for the hot desks. Using a touchscreen application located at the entrance of the hot desk area employees can register by simply dragging their name to the desired hot desk. When leaving their hot desk they drag their name back to the list. Based on this mechanism two different scenarios could be implemented and evaluated. On the one hand the application just registers the hot desk occupation, while on the other the application directly controls its power supply. So when registering power is supplied at the hot desk until the employee leaves the hot desk.

3 Results

3.1 User studies

In the context of the evaluation four types of user studies were conducted and analysed using the appropriate descriptive statistics: an informative study, a comparative study to compare evaluation results before and after the deployment of the prototype, an evaluation of the prototype, as well as a design study for further development.

Informative Study. 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 results were treated as categorical data and thus statistically analysed using medians.

The median results presented in **Table 1** 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.

Table 1 Informative study: rated statements and means

Statement	Median

Would you like to be more aware of how much energy you use individually at your workplace?	5
Would you reduce your energy consumption if you were more aware of how much energy you use individually at your workplace?	5
Would you like to receive more information on how to save energy at your workplace?	5
Would you reduce your energy consumption if you would receive more information on how to do it?	5
Would you like to compare your individual energy consumption with your colleagues?	4

Comparative Study. 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. Again the results were treated as categorical data and thus statistically analysed using medians.

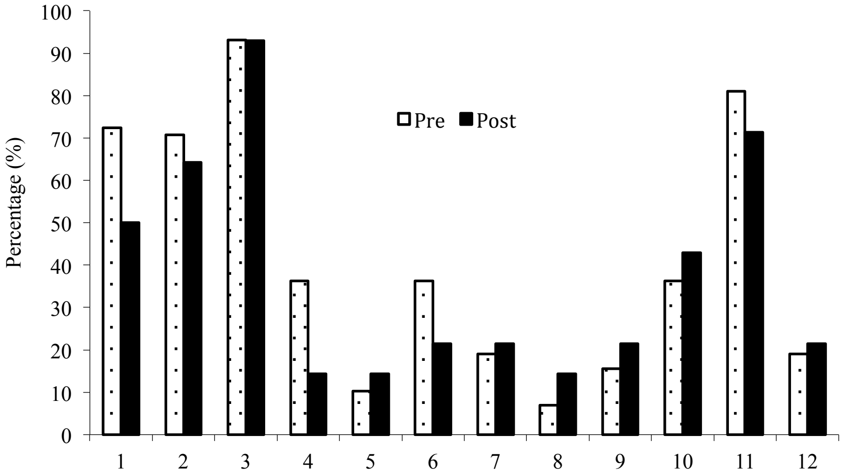
Table 2 Comparative study: rated statements and means

Statement	Median (Pre)	Median (Post)
To which degree can you estimate how much energy (electricity) you use individually at your workplace?[1]	1	2
Are you concerned about the amount of energy you are using at your workplace?	3	4
Are you concerned with what you can do personally to reduce the energy consumption at the university?	4	4
Are you planning to take more individual actions to reduce your energy consumption at your workplace?	4	4

Comparing the median results presented in **Table 2** 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. This could be an indicator that knowing how they actually perform, the respondents are satisfied with their actions taken. To clarify this the respondents were furthermore asked to indicate their actual energy conservation behaviour as well as motivating/demotivating reasons.

[1] Statement rated on a 5-Likert-Scale ranging from not at all up to perfectly

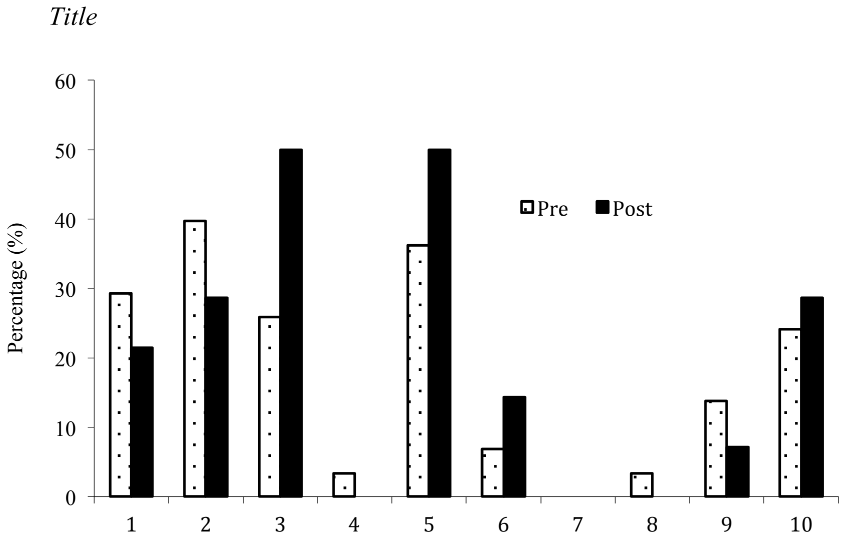
Figure 6 Pre/post conservation actions taken



1	cut down on heating/air conditioning
2	switch off appliances instead of leaving them on standby
3	switch off lighting when leaving a room
4	disconnect power supply units when not in use
5	use multiple socket power strips that can be turned off
6	deactivate screen savers
7	collect documents to print, scan, or copy
8	send/receive faxes on your computer
9	use appliances collaboratively
10	use appliance built-in energy saving options
11	use stairs instead of elevators
12	other

Figure 6 presents on overview of the conservation actions taken before and after the deployment of the prototype. 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.

Figure 7 Pre/post reasons for not taking more conservation actions



1	no clear incentive
2	do enough already
3	unaware of energy used
4	savings don't make a difference
5	not enough information
6	more important things to worry about
7	one person can't make a difference
8	never thought about it
9	would limit my performance
10	other

The results presented in Figure 7 emphasise the impact of the prototype stating that the respondents, although they received consumption information, feel even more unaware and thus request more (detailed) information. This is supported by the respondents' impression that they are not doing enough. Interestingly taking conservation actions is less perceived as factor that limits one's own performance. Furthermore it becomes more obvious that clear incentives to take conservation actions are missed.

Prototype Evaluation. 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 3*** on a 7-Likert-Scale ranging from not at all up to completely.

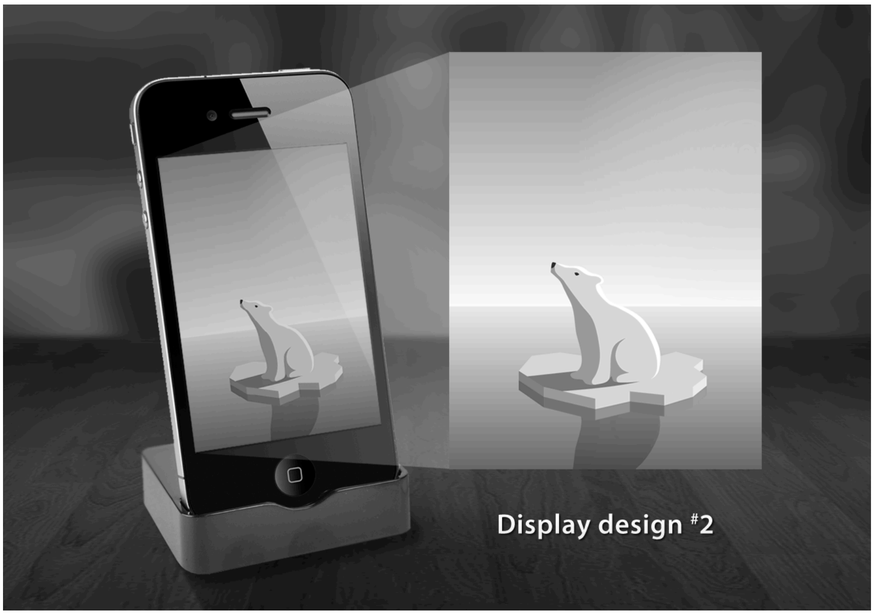
Table 3 Prototype evaluation: rated statements and means

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.

Display Design Study. For the display design research 3 different designs have been created and have been evaluated in a user study. Design #1 consists of an indexical presentation of real-time usage and consumption data using dashboard like meter and graph visualizations. Design #2 shown in ***Figure 8*** presents a polar bear icon in an environment that adapts to the current power usage, ranging in six steps, i.e. from lots of ice, food and bears for low usage to one bear or even an empty sea for high usage. Design #3 then uses a symbolic colour spectrum from blue for low to red for high consumption and additionally textual level from 1 to 10 for presentation. In individual sessions the designs were presented and explained to participants (N=17), who were already familiar with the infrastructure and the developed applications.

Figure 8 Design #2: polar bear icon in an environment that adapts to the current power usage



The participants were then asked to rank the designs depending on which one they find most appealing for receiving feedback on their energy consumption. Initial results indicated that participants tend to favour Design #2, but finally participants opted for Design #1. It should be noted that the ranking is determined by the participants' perceived opinion about the design. From the 17 participants 2 participants voted for Design #3, 5 participants voted for Design #2, and 10 participants voted for Design #1 making Design #1 the mode or most frequent response.

The participants also commented on the designs. The most heard comment was that they would actually like a combination of the designs with less detailed information than with Design #1, but more than with Design #3. Some other comments on Design #2 were that it is not suited for a workplace, as the iconic polar bear metaphor is too 'childish'. While the metaphor would be good for a group or community representation, it is not really suited for personal feedback. Also there were doubts with the direct connection of energy consumption and the environment (e.g. What if you use solar power? Does that effect the environment more or less and is the metaphor still correct in that case?). One participant also came up with the idea, to use personal images for the feedback instead. These images could then be toned with hot (orange/red) or cold colours (blue/green) for high/low usage and be shown on a personal device perhaps in combination with a small consumption indicator in the corner of the screen.

3.2 Energy Conservation

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. For hot desks the feed also aggregates the hot desk occupation. On the short term several effects have been observed. Among others the most interesting ones are the following:

- 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.
- In contrast to hot desks, participants with traditional workplaces already have well elaborated conservation routines. Although, it's not as easy to change these routines compared to hot desk workers.

For the hot desks the direct control of power supply had a very strong conservation effect and implied an active involvement in the process.

4 Discussion

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.

Hardly ever used it. I think it would have been necessary to "promote" the use of that dashboard some more, or possibly to even enforce it. […]

[…] I found it difficult to establish my personal use of this dashboard.

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. This is also supported with the following comment.

In order to contrast/compare the information given, I would provide info on how much energy consumes […] a unique activity. […] to order a coffee in a coffee machine […] a laptop switched on during one hour? This way you could assimilate these data being conscious on "Where can I save energy?" or "Am I wasting energy?".

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.

I think at home this would be very useful […] At the office, however, I found it pretty useless, because the only things I have plugged in are my laptop and my monitor and I have to work with both, so I don't see how I could influence my energy output. Moreover, I'm not really interested in how much energy my colleagues spend - that's none of my business.

5 Conclusion

The presented project elaborated and developed an infrastructure that supports "Energy Awareness Displays" in office buildings utilising existing services and including individual energy consumption information. Based on the supporting infrastructure two example applications to access and explore the information have been implemented. For evaluation in an authentic environment the infrastructure has been set up in a university office building and the example applications were deployed among a group of employees working in that building fostering a ubiquitous learning process.

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, a user evaluation of the prototype, and a design study 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.

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