Increasing Energy Awareness Through Web-enabled Power Outlets

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ABSTRACT
Rising global energy demand, increasing electricity prices, and the limitation of natural resources has led to increased thoughts on residential energy consumption. A necessary step towards energy conservation is to provide timely and fine-grained consumption information. This allows for users to identify energy saving opportunities and possibly adjust their behavior to conserve energy. In this paper, we present a device-level energy monitoring system that is based on off-the-shelf components and enables users to monitor, control, and compare the electricity consumption of their appliances. By providing a RESTful API, we seamlessly integrate the smart power outlets into the web and facilitate the development of extensions and novel features. We demonstrate this through the implementation of a web user interface and a mobile phone interface. We further confirm the suitability of our approach with the help of a 12 months pilot deployment. The results of a questionnaire provide insights into additional user features and the interviews conducted with developers who used our open sourced system illustrate the usefulness of the RESTful approach for the smart energy domain.

Categories and Subject Descriptors
H.m [**Information Systems**]: Miscellaneous; H.4.m [**Information Systems Applications**]: Miscellaneous

General Terms
Management, Measurement, Design, Human Factors, Experimentation.

Keywords
Energy use, load monitoring, energy conservation, visualization, mobile phone, feedback systems.

1. INTRODUCTION
In addition to the industrial and the transport sector, residential and commercial buildings are a major consumer of resources. Their share is increasing, and together they account for approximately 73% of total electricity use in the U.S. The residential sector alone consumes 29% of electricity end use in the European Union, whereas it consumes as much as 37% in the U.S. according to the U.S.[1] Electricity usage highly depends on the inhabitants' behavior living or working in such environments [25]. However, due to the lack of consumption transparency, even people willing to save energy can hardly adapt their behavior in order to conserve energy [11].

To better enable users to identify how energy usage relates to different devices or actions, more frequent and timely consumption feedback are required [9, 28]. This should also answer questions such as how much a specific device consumes in operation, standby, or even powered off; whether the consumption of an energy-saving lamp is significantly lower in the long run compared to a standard light bulb and what devices are running even if they are not used. This would allow to further apportion the entire energy consumption, which is key to understand where energy can be saved by taking simple measures [12].

Currently available off-the-shelf products that depict the energy consumption in near real time are helpful, but do not fully meet the user needs as they have a high usage barrier and often require complex installations [15]. Furthermore, they are not able to provide the most promising feedback [14] since they lack the ability to provide an appliance-specific break down of the energy consumption and are not able to compare the consumption of individual devices in an appealing manner on a central screen. In addition, they do not meet the needs of software developers as they do not offer open APIs, and developing applications on top of them is rather cumbersome.

In this work, we present and discuss a system for increasing energy awareness in domestic and office environments. The system aims to overcome the above-described limitations of existing electricity consumption monitoring systems. It is rather simple to set up, can be easily used in everyday life, and provides instantaneous consumption feedback on device level. The implemented system consists of a user interface, a gateway, and the underlying back-end infrastructure, where every device that is to be monitored is coupled to a commercially available smart power outlet named Plogg [4].

Ploggs are a combination of an electricity meter plug and a data logger. Furthermore, they offer a Bluetooth and Zigbee interface

[1]See www.eea.europa.eu/data-and-maps/figures/final-electricity-consumption-by-sector-eu-27-1 and www.eia.doe.gov/aer/

to retrieve the current or logged consumption. The gateway extends the functionality of the Ploggs to allow for continuous energy measurements on a fine granular time basis. It further manages and integrates the Ploggs into the web through a RESTful API [13, 29], which also allows for easy interoperability with other applications. The user interfaces exploit the functionality provided by the gateway API to attractively visualize, control, and compare the consumption, costs, and efficiency levels of the connected devices. Thus, the user interfaces not only provide feedback, but also stimulates electricity conservation by allowing users to draw conclusions on the link between their actions and impacts on the electricity consumption.

This paper is structured as follows. We next review relevant work in the field of residential energy monitoring and electricity consumption feedback. Thereafter, we present the architecture and the user interfaces we developed to acquire, visualize, and control the energy consumption. The following section describes the real-world deployment and the evaluation of both, the system and the ease of development on top of the presented architecture. Finally, we conclude the paper with a discussion on the possibilities for future work on the proposed sensor-based architecture.

2. RELATED WORK

We can classify related work in the field of residential energy monitoring and fine granular consumption feedback by examining the type of the sensor that is used to acquire the consumption data. In general, we can differentiate between two areas.

The first area includes solutions that use a single sensor to derive information on the entire energy consumption of a household. Currently, there exist several commercially available products that aim at illustrating the overall power demand. Wattson [2], Onzo [5], Power Cost Monitor [1], and TED-1000 [3] reside among the most prominent. In general, they consist of a central device with an attached display for the user interface or they feature a separate screen that besides providing feedback on the electricity consumption is capable of displaying related equivalents such as cost. However, in order to monitor the consumption, these products require a complex installation around the electric wiring or the fuse box, which often is not easily accessible. This leads to high adoption barriers since users are reluctant to deploy systems that are rather hard to set up. Moreover, these systems are not able to provide feedback on the consumption of single devices which is helpful to draw conclusions on how consumption and behavior relate to each other. Another drawback results from the battery which is embedded in most of the portable screens that depict the consumption information. As trials have shown [32], for 50% of the displays the battery is not replaced once depleted. This strongly indicates that users loose interest after their inital curiosity has been satisfied. Thus, since not beeing integrated into users' daily life, these systems are often not capable to motivate users for longer time periods.

Other approaches focus more on the design aspects of user interfaces for energy monitoring. The authors of [34] developed an interactive system that provides instantaneous feedback concerning the energy usage on household and device level. It is based on a smart electricity meter and a portable user interface on a mobile phone that allows for users to measure, control, and compare their electricity consumption. Yun [38] investigates the impact of a minimalist user interface on the energy consumption. The work proposes a portable, wearable version of a user interface that shows the energy consumption in real time as a bar graph, and compares it to a stationary display version. To measure the entire consumption, a sensor clip is used that is attached to the home power breaker. More conceptual work is conducted by Bjorkskog et al. [10], who developed a mobile phone prototype targeted to establish a more playful access to energy consumption data to better address less technophile user groups. Their user interface aims at helping users to monitor the quality of their conservation practices by providing consumption feedback on device-level and so-called awareness tips. Peterson et al. [27] build upon a circuit breaker box that is to be attached to the fuse box in order to acquire consumption information per circuit. Their work indicates first results about the user preferences on portable energy feedback. They also intend to develop a portable user interface on a mobile phone. However, the work does not state technical details about feedback times and measurement granularity that can be achieved with their system.

Other approaches try to further apportion the entire energy consumption. The information is acquired by a single sensor that is, in the extreme case, situated at the electricity meter. Statistical signature analysis and detection algorithms are used to infer from the current and voltage wave forms what appliances are currently running [21]. Patel et al. [26] developed a system that tries to infer this from the electrical noise on the residential power line. They use a single sensor that can be plugged-in anywhere to the electric circuit of the household. It listens on the residential power line and detects unique noise changes that occur through the abrupt switching of devices. This allows to determine the status of an appliance, but not its actual electricity consumption.

The second area classifies approaches that rely on an electrical current sensor to be installed in-line with each appliance or the deployment of multiple sensors throughout the household. Commercially available products in this category are smart power outlets such as Energy Optimizers Ltd.'s Plogg [4], Kill-a-Watt / Tweet-a-Watt [6], SmartLinc INSTEON Central Controller [7], and Tendril [8]. In general, these products are easy to deploy, but aim more at automating and controlling the directly attached devices rather than at concentrating on the electricity feedback. They therefore lack the possibility for aggregating the consumption of multiple sensors as well as the possibility to easily develop applications on top of them.

Other system-oriented work in this area focuses on developing mashups of electricity sensors, which allow for both, monitoring on device level and providing an overview on the total load attached to multiple outlets. Lifton et al. [22] embedded a multimodal sensor network node into a power outlet to monitor the electricity consumption and infer the appliances being used in the house. Microsoft research developed a 'smart socket'- sensor network that uses web services to interconnect devices on top of standard web protocols. Jiang et al. [18] developed a wireless networked sensor node that measures the power consumption at the outlet and uses the communication interface to automatically transmit the data to an application tier that stores the readings in the database. Their approach consists of a three layer architecture that builds on a wireless current sensor per outlet that is to an extent similar to ours. However, compared to the architecture proposed in this paper these solutions are not easily expandable and do not support off-the-shelf products that are easily available for users. In addition, we focus on the ease of development on the application side by trying to build a system on top of a commercially available product that is open and allows for easy interoperability with other applications.

URI	HTTP Method	Description
/energievisible	GET	Index page
/energievisible/ploggs	GET	Lists all the available Ploggs in range
/energievisible/ploggs	POST	Create new Plogg on discovery
/energyieisible/ploggs/all	GET	Show consumption of all Ploggs
/energievisible/ploggs/[NAME/ID]	GET	List the consumption of Plogg [NAME/ID]
/energievisible/ploggs/[NAME/ID]	PUT name	Set the name of the Plogg
/energievisible/ploggs/[NAME/ID]/status	GET	Displays the current status of the Plogg
/energievisible/ploggs/[NAME/ID]/status	PUT on/off	Switches Plogg on or off
/energievisible/ploggs/[NAME/ID]/[RESSOURCE]	GET	Measured value of RESSOURCE (e.g., power, current, and voltage) of Plogg [NAME/ID]

Table 1: Example URIs of the Gateway API.

A different idea is based on acquiring context information and infer from that what devices are currently running. Kim et al. [19] developed a system that provides fine-grained feedback on the power consumption by combining a single electricity sensor with three different types of passive sensors (magnetic, acoustic, and light) that are deployed near devices throughout the household. The context sensors help to infer which appliance is currently operating from the measurable signals it emits. Within a defined set of appliances, the authors show that the system can estimate device-level power consumption within a 10% error range. However, the system's performance depends highly on the correct calibration and placement of the distributed context sensors, which is not an easy task for the average user.

In this paper, we propose a system for energy savings in buildings that uses off-the-shelf components to provide users with fine-grained feedback on the electricity consumption. Compared to other solutions, our system is simple to install and does not require any modification of the wiring, which in many houses in Europe is difficult to access. By providing a RESTful gateway that is open-sourced we aim at increasing the ease of development and enable others to more simple deploy such systems in real world environments. At the same time, the web-based API integrates the sensor nodes' functionality into the web and enables easy interoperability with other applications that can be built on top of the system. Moreover, we present two user interfaces, a stationary and a portable version, that allow for users to monitor, compare, and control the electricity consumption of devices at home.

3. SYSTEM ARCHITECTURE

The architecture of our prototype is based on four main layers as shown in Figure 1. The Device Layer is composed of appliances we want to monitor and control with the system. At the Sensing Layer each of these appliances is plugged to a Plogg sensor node. In the Smart Gateway Layer, these nodes are discovered and managed by a gateway software which can be installed on any computer or embedded device (such as a home wireless router) with sufficient memory and Bluetooth or Zigbee communication capabilities. The gateway also embeds a micro web server which offers the monitoring and control functionalities of the Ploggs as structured URLs, in a RESTful manner detailed in the following. Finally, on the Client Layer two user interfaces are proposed that demonstrate the ease of development on top of our RESTful infrastructure.

3.1 Smart Gateway

The Smart Gateway is a component written in C++ whose role is to automatically find all the Ploggs in the environment and make them available as web resources (Figure 2). The Gateway first discovers the Ploggs on a regular basis by scanning the environment for Bluetooth devices. It then filters the identified devices according to their Bluetooth identifier. The next step is to make their functionalities available though simple URLs. For this purpose, a small footprint web server is used to enable access to the Ploggs' functionalities over the web. This is done by mapping URLs to native requests on the Plogg Bluetooth API (see Table 1). For instance,

http://[gatewayAddress]/energievisible/ploggs/roomLamp

is automatically bound by the Gateway to a method that runs a low-level call that first initiates a Bluetooth connection, then connects

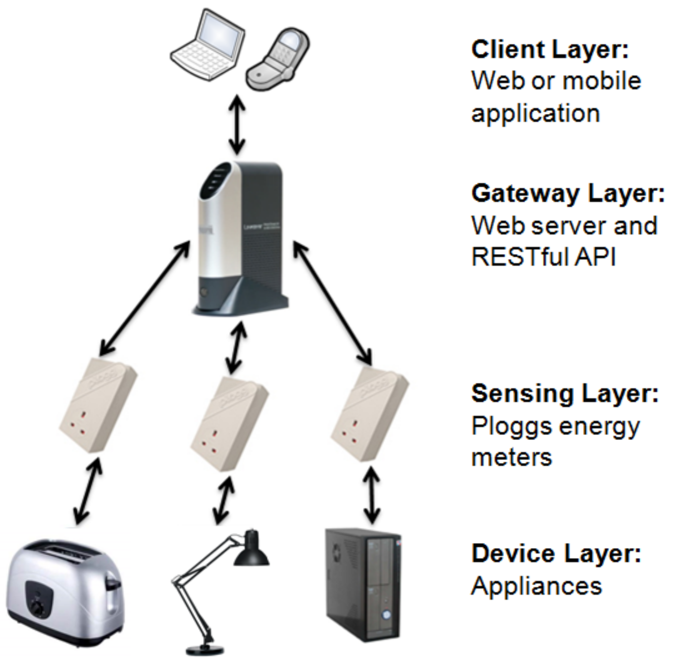

Figure 1: Appliances connected to Ploggs communicate with a Smart Gateway offering the Ploggs' functionality as a RESTful API. Two client applications with user interfaces are then built on top of the Gateway Layer.

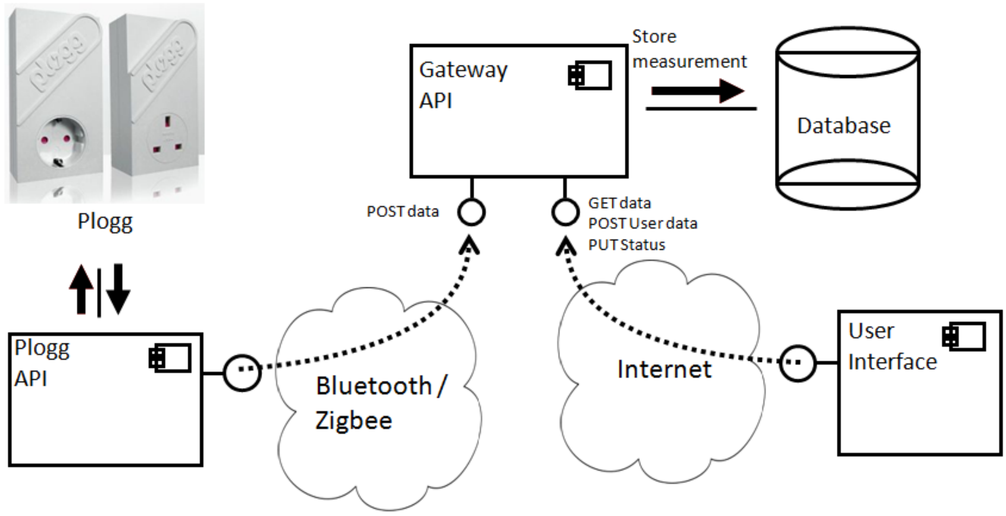

Figure 2: Communications overview: The Gateway is responsible for discovering the smart power outlets within communication distance. Through providing a RESTful API on top, it leverages the outlets' functionalities to the web. This allows users to easily access their energy consumption using a web browser and at the same time opens the system to developers.

to the Plogg named "roomLamp", and polls the Plogg for reading the current load of energy measured.

The approach that makes an application's functionalities accessible through an interface respecting the core principles of the web is often referred to as RESTful. Traditionally, this type of approach is used to integrate several websites together. However, in recent research [23, 34] REST is used to seamlessly connect real-world objects, embedded devices, and sensor nodes to the web. Systems using the REST paradigm and HTTP as a basic architecture for communicating with smart objects are subsumed under the term Web of Things [17].

The most interesting benefit of this approach in our case is the seamless integration of the Ploggs to the web which eases the development of applications and prototypes on top of the Ploggs using popular web languages (e.g., HTML, JavaScript, PHP, Python, etc.) and toolkits (e.g., DOJO, jQuery, etc.). This is in contrast with the proprietary closed protocols used by most commercially available solutions that do not allow for easy integration.

It is worth noting that using HTTP introduces an overhead when compared to ultra-optimized proprietary solutions. Thus, systems relying on a very small latency might require a different solution than our RESTful approach. However, for most common applications, the small overhead is justified by the greater ease of interaction [17, 37].

Devices connected to the Ploggs can be monitored in real-time simply by calling the corresponding URLs in a standard web browser or HTTP client library. As an example, the monitoring data of all the currently available Ploggs can be retrieved by accessing the following URL:
http://[gatewayAddress]/energievisible/ploggs/all.

As a result, the Smart Gateway calls all the Ploggs and wraps the results in the form of a JSON (JavaScript Object Notation) document. JSON is an alternative to XML often used as data-interchange format for web mashups. Since JSON, compared to XML, is a lightweight format, we believe it is more adapted to devices with limited capabilities. The JSON data resulting from the call to all the Ploggs contains consumption information for each individual device as shown below.

```
[{
  "deviceName": "ComputerAndScreen",
  "currentWatts": 50.52,
  "currentVoltage": 220.52,
  "currentAmperage": 0.23,
  "kWh": 5.835,
  "time": 08.15,
  "date": 19.08.2010,
  "maxWattage": 100.56
}, {...}]
```

Similarly, the appliances can be started and stopped remotely by sending PUT requests to their corresponding URLs. As an example, the room lamp device can be turned off remotely by sending a PUT request containing "off" to the following URL:
http://.../energievisible/ploggs/roomLamp/status.

Additionally to the JSON representation, the Smart Gateway can deliver HTML representations of the resources. Using this human-friendly representation, users can discover and test the available functionalities simply by following hyperlinks and using web forms in any browser.

3.2 User Interfaces

Thanks to the RESTful API we developed for the Ploggs, creating a compelling user interface (UI) becomes quite easy: all the interface needs to offer is a HTTP client library. Since there is an ubiquitous support for HTTP across all programming and scripting languages, this allows developers to choose literally any language

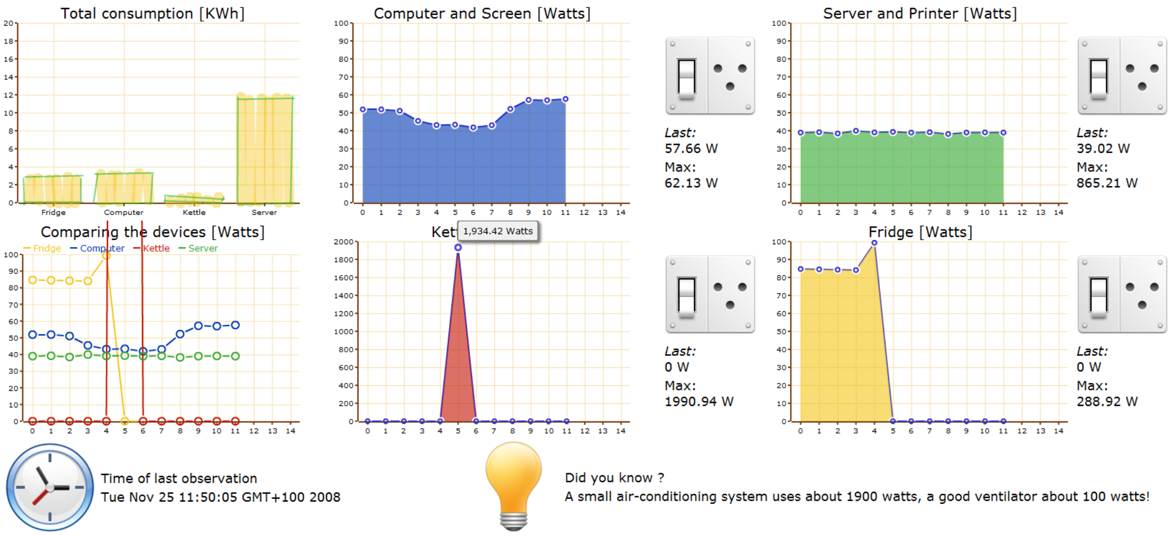

Figure 3: The monitoring and control web user interface for the Ploggs shows the consumption of each connected appliance. The switch icons can be used to power on / off the devices.

to build applications on top of the smart metering infrastructure. Thanks also to the abstraction of devices behind smart gateways, there is no need for the chosen language to support Bluetooth or whatever protocol the device uses.

We illustrate this by means of two different UIs. The first is a Javascript web UI that allows users to monitor and control the consumption of the attached devices from a standard web browser. The second is an iPhone application that provides more flexibility by allowing users to interact with the system directly from their mobile phone.

3.2.1 Web User Interface

The web UI was designed to be attractive, easily-accessible, and to display real-time data rather than snapshots. It is a dynamic website which was easily built on top of the RESTful API offered by the Smart Gateway. The implementation was made in Javascript (using the Google Web Toolkit (GWT)). To get real-time results, the UI simply calls the gateway URL every few seconds and feeds the JSON Ploggs' results to interactive Javascript graph widgets. As shown in Figure 3, the resulting interface offers six real-time and interactive visualization widgets. It is dynamically created depending on the number and names of the discovered Ploggs. The four graphs on the right side provide detailed information about the current consumption of all the appliances in the vicinity of the gateway. The two remaining graphs show the total consumption (kWh) and respectively a comparison (on the same scale) of all the running appliances. A switch icon next to the graphs enables users to switch on and power off the devices via their Plogg directly from web. Finally, the lower part of the UI provides guidance that shows users effective measures to decrease their energy consumption.

It is worth noting that creating such an interface by directly connecting to the Ploggs would not have been feasible. Indeed, widely popular web languages such as Javascript do not offer support for Personal Area Network (PAN) protocols such as Bluetooth. However, thanks to the RESTful API, connecting to the smart meters is reduced to being able to call a URL and parse JSON messages, which web languages can do out-of-the-box.

3.2.2 Mobile User Interface

Since it is desirable to be able to access consumption information from anywhere when needed, we decided to implement also a portable UI that provides instantaneous feedback. The UI was developed as an iPhone application and not only provides feedback about the energy consumption, but also calculates cost equivalents and allows users to remotely control the status of each appliance attached to the system. According to the literature [15, 16], effective energy feedback has to

- feature a low usage barrier,
- be presented on a device that is already integrated in users' daily life,
- be given frequently, in real time, and at hand when needed, and
- provide the possibility to apportion the entire electricity consumption.

As shown in Figure 4, the UI consists of three views. The overview panel displays continuous information about the entire electricity consumption of all Ploggs discovered by the gateway. Similarly to the web UI, the mobile UI acquires the information by calling the Smart Gateway URL and thereafter processes the JSON response. The device view dynamically shows a list of all the devices including their current consumption. Each list entry can be selected to obtain more detailed information such as annual cost and total amount of kWh consumed. In addition, the UI includes a button that allows to remotely activate / deactivate the device via its Plogg. Finally, to keep the system easily manageable, the put method provided through the API allows users to maintain the discovered Ploggs by assigning a name. For the case where just a single device is connected to the smart outlet, users can also specify a device category.

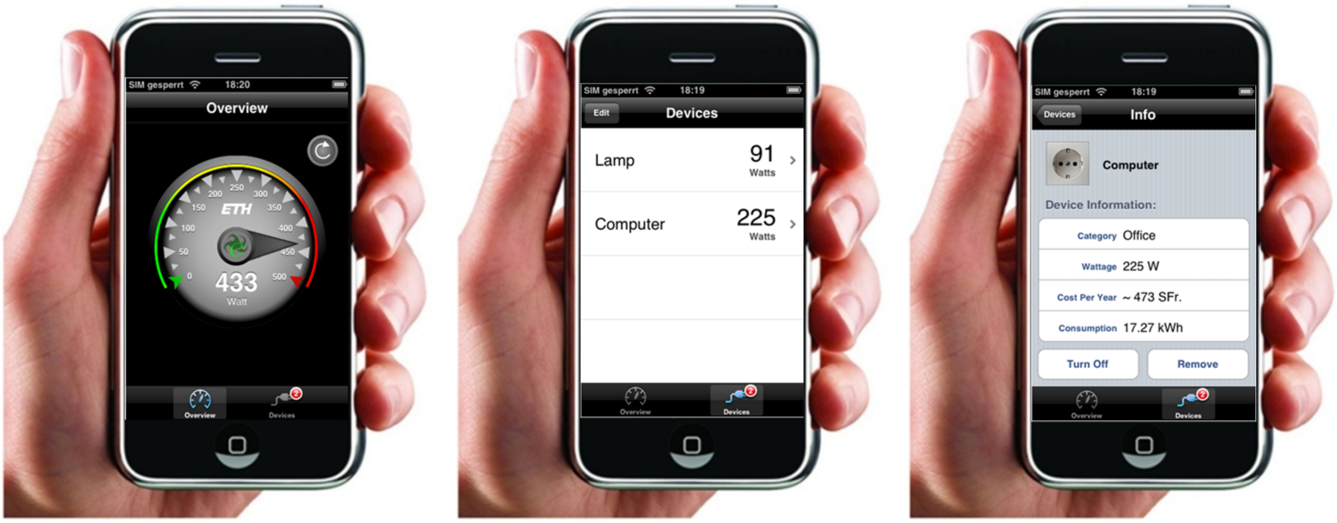

Figure 4: The mobile user interface shows the current entire consumption of all devices attached (left), a list of discovered Ploggs including their name (middle), and more detailed information per Plogg (right).

As for the web UI, creating such an application would not have been possible without the Ploggs' RESTful API as the iPhone SDK does not support Bluetooth.

4. DEPLOYMENT AND SYSTEM EVALUATION

The web UI and the Smart Gateway were released for public use as a packaged project named "Energie Visible" and are available on the web for free[2]. The software is a "download and run" application currently being used by a dozen of (mostly tech-savvy) people around the globe to monitor the energy consumption of their households. In order to evaluate the suitability of the system to provide feedback in a real-world environment, Energie Visible was permanently deployed at the Cudrefin02 headquarters as described next. Afterwards, we report and the initial findings in a formative evaluation on the usability of the system, the two UIs and the measures people applied due to the increased energy consumption awareness. However, since there existed no fine-grained data on the energy consumption before our deployment, we cannot quantify the energy savings that were achieved with our system. Furthermore, it is in general difficult to quantify savings as direct effect of a system, since such real world deployments contain numerous side effects that cannot be controlled or kept constant. Thereafter, we provide insights from the developer perspective gathered from experts who developed on top of our RESTful system after we released the open source code.

4.1 Pilot Deployment at Cudrefin02

The prototype was deployed at Cudrefin02.ch, a private swiss foundation active in the field of sustainability and is now running for reliably running for more than 12 months. Regarding the given setting and the goal to raise consumption awareness, our prototype had to fulfill certain requirements. Due to the fixed setting in the office, the fact that continuous operation should be ensured and users were not technological affine, the prototype had to be easy to install and simply to use. Hence, the UI had to be developed in an attractive and easily accessible way (no additional software to learn or install) that allows both, staff and visitors, to become aware of the electricity consumption of appliances running in the headquarters. From a feedback perspective, the breakdown of the entire energy consumption, e.g., for specific rooms, appliances, or times of the day, is a powerful way of establishing a direct link between action and effect. This considerably improves the intensity of reflection and interpretation of a measure or omission [14]. However, besides providing this possibility to apportion the entire consumption to single devices, it is important to enable users gathering feedback frequently and in real-time. This allows for users to relate feedback to a certain behavior or device usage [9] and thus take effective measures regarding the energy consumption. Continuous feedback has thereby been proven to be most effective [31]. In addition, only feedback that is at hand when needed is able to satisfy users' spontaneous curiosity.

The system is deployed in the ground-floor office of the headquarters. There, the Ploggs are used to monitor the energy consumption of various devices such as a fridge, a kettle, several printers, a file-server, and computers including their screens. The Smart Gateway software is deployed on a small embedded computer consuming about 20 Watts, but also used as a file-server and multimedia station. During idle periods (that is when no additional query from a user interface is present) it discovers all Ploggs within communication distance every hour and queries their consumption values every 30 seconds. However, in case of a direct UI request, the corresponding Plogg is queried right away and the value can be gathered in near real time. During the whole time a large display in the shop-window of the office encouraged people passing by to experiment with the system. The staff used the system to monitor the consumption and remotely control the appliances by browsing to the web UI on their desktop computer. In addition, the mobile UI was completed towards the end of the experiment and users were given the chance to explore the portable electricity consumption feedback feature.

[2] http://webofthings.com/energievisible

4.2 Web User Interface

In this section, we report on initial findings of the impact of the deployment, which was confirmed by the logged data. For that, we conducted guided interviews with the foundation staff after eight month of operation and verified the results with the logged data.

The aim of the deployment was to raise consumption transparency to help visitors as well as members of the staff to better understand how much energy different devices throughout the office consume in operation and in standby. At the beginning, staff members had to get used to the system and started exploring the energy consumption of different devices. By experimenting with the kettle and the different printers, for example, they learned that the amount of water heated up as well as the type of printer being used has a high impact on the energy consumption. Staff members also started instantly comparing how much energy their office desks consume. Moreover, during breaks groups were discussing about the energy consumption of single devices and the energy used for different actions (e.g., cooking tea). After the first month the staff members' initial curiosity was satisfied and they thus reported they started using the system less. However, they then looked more into details such as the standby consumption of different devices, the accumulated consumption over time, and once identified where electricity was wasted, took effective measures to conserve energy. For instance, they identified that the computer screens, even when completely turned off, still consumed a considerable amount of energy and that even when not used for several consecutive days, the file-server kept consuming about 30 Watts. To prevent this waste of energy, concrete technical and behavioral measures were implemented. In order to avoid residual electricity usage such as with the computer screens, all the appliances within the headquarters except for the fridge are now connected to a central power switch. As a policy, the last person leaving the office is now in charge of turning off the central power switch. Moreover, the computers and the file-server are now shutdown every evening. The information item at the bottom of the web UI, which displays contextual hints, was also seen as very helpful. However, the staff reported that it would be better if the hints related to the current consumption. During the whole time the system has been demonstrated to visitors. They especially liked to remotely turn devices on or off and the possibility to see the accumulated consumption together with the monetary cost caused by the device.

Our formative evaluation hints that the prototypes' functionality is well suited to increase the consumption transparency and helps users to save energy. We realized that in the exploratory phase people like to interact with the system and are looking for a simple and fun way to identify the electricity consumption of different devices. Later, it becomes important to provide functionality that constitutes added value to keep users motivated. Therefore, it is not sufficient to provide feedback on the current consumption on appliance level, but also account for how much energy has been consumed over time. Thus, the system allowed users to identify sinks where energy was wasted. In addition, we identified it is important to relate the consumed energy to the incurred cost to draw conclusions and take effective measures.

4.3 Mobile User Interface

To gather further insights, we evaluated the mobile UI in a moderated discussion in a focus group. The focus group consisted of four industry experts, three experts from academia, and two experts from consumer organizations. The discussion confirmed that live information that can be achieved with our system is key to relate the electricity consumption to the operation of single devices and thus allows users to draw conclusions. However, in order to target a broader user base, the group identified key aspects that should be implemented in the future to guarantee both, a low barrier of entry for people who are not technology affine and a sustainable long term usage of the application.

Better understanding. Although near real-time information is key, the group found that the feedback on the mobile UI is presented in a very technical manner. Pure numbers are easy to understand at first glance - however, they require users' knowledge how this translates into a high, typical, or low consumption. Especially for technology non-affine people who do not have a thorough knowledge in terms of electricity, intangible units such as Watt, kWh, or even CO_2 require a more abstract representation (e.g., potentially through analogies). In case users specify a category for the device that is currently attached to the smart outlet, the information could be used to display an efficiency rating. This action-guiding feedback helps users to put the consumption in a tangible picture. In addition, easy comparisons could be implemented for better understanding. For instance, the color coding of the scale in the overview panel can be adapted to relate to historically measured values.

Long term usage. Mobile phone applications can easily be downloaded and installed. On the other hand, this low usage barrier leads to a multitude of applications being installed, many of them being no longer used after the user's initial curiosity has been satisfied. Thus, it is crucial to implement features that attract the user's attention and involvement for a longer period of time. In the case of our portable energy monitor, we identified a simple measurement functionality as such a feature. The idea is to provide a function that allows for users to measure the consumption of single switchable devices attached to one of the smart outlets simply by pressing a button on the mobile UI. Thereafter, the system measures the power increase or drop and provides an over the thumb feedback on the consumption of the device. This provides users a simple possibility to disaggregate the entire attached electricity consumption. At the same time this feature targets the interactivity that aims at involving users further in their electricity consumption. Further features that were identified to engage users were electricity alerts and energy saving tips. In terms of our architecture this could be based on push notifications. If applied in a larger deployment, one could even think of energy consumption-related games that increase the awareness. An example would be a game, where users have to identify a device that consumes certain amount of Watts.

In order to get a better feeling what feedback users would like to be provided in terms of energy consumption on a mobile phone, we conducted a small survey at lively points throughout the city center. 185 people (50.3 % male) answered the questionnaire with all age groups evenly represented. Figure 5 shows the assessment of different functionalites. The figure shows that participants overall value the indication of yearly cost of single appliances most, followed by the consumption figures of the previous month and a list of the main energy guzzlers. The consumption to friends seems not to play an important role. These results serve as an indicative basis for our futher prototypical development of the mobile UI.

The evaluation of our mobile phone application shows that the mobile UI is easy to understand and especially the fact to have the feedback at hand when needed is perceived beneficial. However, the post evaluation also indicates that there is room to improve the rather technical feedback of our UI. To maximize energy savings in

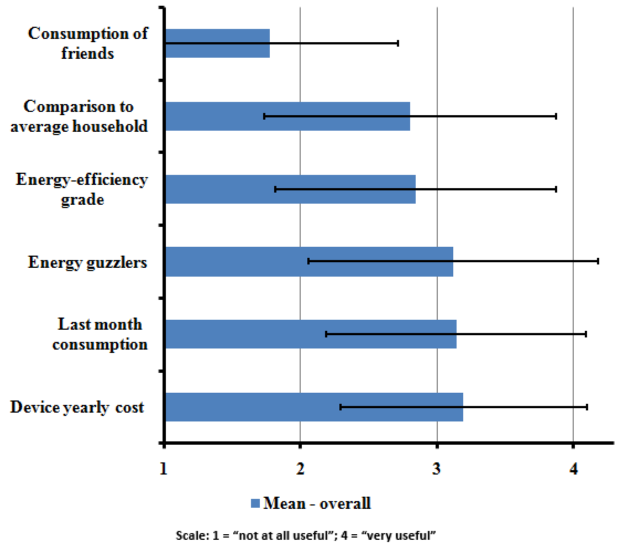

Figure 5: User assessment: Features provided on a portable energy monitor.

households and to effectively induce behavioral change over longer periods of time, one has to combine direct feedback with persuasive and psychological concepts [30]. Moreover users utilizing the mobile application acknowledged that although knowing how many Watts a particular device consumes in operation or standby, they were not able draw conclusions neither on the efficiency of the device, nor on effective measures that allow to conserve energy. Thus, we intend to develop mechanisms, such as device efficiency ratings or sharing of energy saving measure among friends that put the consumption in a more tangible picture [35, 36]. Together with a focus group and survey we derived options that in general should help developers that work on implementing portable energy feedback. The highlighted options in terms of better understanding, long term usage, and functionalities will serve as basis for our further development.

4.4 The Developer Perspective

The main goal for offering a web layer on top of the Ploggs is to ease development of applications on top of an otherwise closed system. The web-enabled smart power outlets thus offer a platform for the fast prototyping of energy awareness-related demonstrations.

Since the release of Energie Visible on the web, several development teams have used our software to build new prototypes upon. As an example, the RESTful gateway has been used by two external development teams. In the first case, the idea was to build a new mobile energy monitoring application based on the iPhone and communicating with the Ploggs. In the second case, the goal was to demonstrate the use of a browser-based JavaScript Mashup editor with real-world services [20]. According to interviews we conducted with these developers, they in particular highlighted the ease of use of a web "API" versus a custom "API". For the iPhone application a native API to Bluetooth did not exist at that time, but like for almost any platform an HTTP (and JSON) library was available. One of the developer mentioned a learning curve for REST, but emphasized the fact that it was still rather simple and that once it was learned the same principles could be used to interact with a large number of services, languages, and possibly soon also with smart devices. The developers finally outlined the direct integration to HTML and web browsers as one of the most prevalent benefits. This significantly eases the development on the vendor's side, since applications can be built on languages for which a plethora of libraries and frameworks are available. Furthermore, the use of popular languages makes it easier to find adequate developers. This also unveils the possibility for external developers to create small web applications and plug-ins on top of smart appliances.

Furthermore, our system also seems to be stable enough to be applicable to larger and more robust deployments. Indeed, the web UI and the Smart Gateway have been running successfully at Cudrefin's headquarters since December 2008 without the need for any kind of maintenance.

5. CONCLUSIONS AND FUTURE WORK

In this paper, we presented an easy to use system for energy savings in home and office environments. Our contribution on the architecture level is twofold. Firstly, we extended the capabilities of the Ploggs by providing a RESTful API on a gateway that discovers and integrates the available physical devices, and that provides access that can be exploited by the UI. Secondly, we demonstrated the easy extendability and interoperability of the system by developing energy applications on two different UIs that are well integrated into most people's daily life.

The system allows for users to monitor and compare the energy consumption on device level in real-time and enables them to remotely switch appliances on or off. Through using off-the-shelf components, and since not requiring any modification around the wiring, the system is simple to install. To overcome the drawbacks of existing energy monitoring solutions, we developed a RESTful API which eases the application development on top of the Ploggs. Using these commercially available components and open-sourcing the developed work, our contribution enables others to build applications on top of the system and widely apply them in real-world deployments. Our work shows that the Web of Things approach [17], where RESTful APIs are bound to physical objects and thereby integrated in the web, can also be successfully applied to prototyping the smart energy domain.

Our evaluation of the pilot deployment confirms the suitability of the concept and provides insights on the potential of the developed system and the user expectations towards electricity feedback systems. However, due to the nature of Bluetooth our system is limited to the given range of these systems. As the next step we plan to integrate multiple gateways in order to extend the solution to (multiple) PANs. Our solution contains the inherent trade-offs of client-server or pull-based interaction due to the use of HTTP. While this greatly contributes to the scalability of the system, for devices such as smart meters, a sensor-push interaction model seems more adapted and thus we currently work on a scalable Web-push version of the Smart Gateways.

It is well known that direct consumption feedback leads to energy savings and more general information is key to change behavior. However, technology itself is not sufficient. As discussed throughout the evaluation, most available energy feedback solutions today provide a very technical consumption feedback. To become more efficient, feedback has to be combined with other concepts from marketing and consumer research, however [24]. Pervasive energy systems are most likely to be successful if they offer a clear value proposition to users [33] and are integrated into a broader context or story [36]. This involves psychological concepts such as goal setting, defaults, or budgeting, and a suitable visualization (e.g., using real-world analogies). For example, virtual budgets can lead to considerable savings over normal data representations and goal selection can turn saving into a game. Besides this, engagement strategies that aim at sustaining the user's interest and motivation have to be investigated (e.g., competitions can be implemented for the short term where as a reward system can help to enable long term involvement).

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