PowerPedia - Changing Energy Usage with the Help of a Smartphone Application

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Abstract

When it comes to conserving electricity, it is crucial for users to know how much energy is consumed by individual appliances. However, the technical feedback provided by existing energy consumption feedback systems in the form of dry numbers and intangible units is not appropriate for most users. To address this shortcoming we developed PowerPedia, a system that provides behavior-influencing feedback over and above pure consumption values. By integrating a community platform – a Wikipedia for electrical appliances – PowerPedia enables users to identify and compare the consumption of their domestic appliances with that of others. It thus helps users to better understand their electricity consumption and take effective action to save electricity.

Keywords: Energy use, smart meter, mobile computing, feedback systems.

1 Introduction

Domestic electricity consumption accounts for about one third of the total electrical energy produced [1, 2]. Despite considerable efficiency gains that have been accomplished with respect to large, ubiquitous household appliances (e.g., refrigerators, freezers, and washing machines), electricity use by household appliances in the IEA19[1] grew by 57% from 1990 to 2005 [3]. It is well known that electricity consumption in residential buildings is highly dependent on the behavior of the inhabitants. The energy consumption of virtually identical households (the same buildings with the same number of inhabitants, identical age groups, the same location,

and a similar set of appliances) can easily vary by a factor of more than two [4]. This indicates that motivated and informed users can positively influence energy consumption.

One major difficulty for people who are willing to save energy at home is the lack of information about their energy consumption [5]. Today, feedback on energy usage is typically only provided by a monthly (if not yearly) utility bill, which offers very limited guidance or feedback for individual energy-saving actions that could have been taken.

Although there are helpful off-the-shelf products that depict energy consumption in near real time, they do not fully meet the user's needs since their representation of consumption values is typically rather technical and difficult to understand [6]. They lack the ability to position the intangible consumption in a bigger picture that would allow users to draw conclusions and take effective measures. Current solutions leave users with absolute numbers that are difficult to interpret and do not indicate how efficient a specific device really is.

Although several more complex energy measurement systems have been brought onto the market that provide visual feedback on the electricity consumption of either individual devices or the whole household, such systems are not always easy to install or use, and they often provide only a partial picture. Many consumers are thus discouraged from utilizing such products. Nevertheless, providing consumers with feedback on energy consumption can increase awareness, strengthen energy literacy, and motivate at least some of them to change their habits and ultimately save energy [7].

Commercial energy monitors come in various forms (e.g., portable or fixed installations), visualization approaches (ranging from 7-segment displays to high-resolution graphics interfaces), and

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[1] 19 out of 22 countries covered by the International Energy Agency (IEA) provide detailed insights into household energy use.

measurement techniques (e.g., adaptor plugs for power outlets, sensors attached to the fuse box or mains, and smart electricity meters). Despite recent advances in design and usability, one common problem still appears to be that most approaches do not succeed in sustaining a high degree of user interaction over time. A pilot study conducted among households in the UK, for example, revealed that the batteries were replaced in only 50% of battery-driven power monitors once the devices stopped working [8].

In the following, we present a system that intends to overcome the above-mentioned drawbacks by providing users with action-guiding feedback rather than mere numbers. Our PowerPedia system enables users to identify and compare the consumption of their domestic devices with that of others. At the same time, an efficiency ranking shows users how their appliances perform compared to other appliances in the same category. In addition, general and device-specific measures for conserving energy can be obtained from the community and from consumer websites.

2 Portable energy feedback systems

Ubiquitous computing technologies make it possible to capture real-world information at an increasingly detailed level. Combined with a strong market growth in smartphones[2], this has led to information provisioning on portable devices in various application domains, e.g., emergency response [9], claims assistance [10], environmental information [11], and mobile shopping assistance [12]. Energy monitoring seems to be another promising application area. Systems that support this can be classified into two categories. First, systems that provide feedback on consumption at household level and second, those that provide feedback at device level.

Household-level systems visualize total domestic electricity consumption. The data is typically gathered by a sensor that is either installed in the fuse box or at the electricity mains. Several commercially available solutions exist, e.g., TED-1000 [13], Onzo [14], and Wattson [15] (see Figure 1) to name but a few. Some more advanced research prototypes also exist. The work of Peterson et al. [16], for example, builds upon a circuit breaker box that is attached to the fuse box in order to acquire consumption

(a)   (b)

Figure 1. Display unit and sensor of Wattson (left) and Click (right).

information per circuit. The authors also propose a design for a user interface on a mobile phone. In addition to displaying current overall consumption, most of the solutions mentioned also provide other features, such as a presentation of historical consumption, accumulated consumption over time, and consumption equivalents (e.g., CO2). However, with such systems users cannot easily determine the consumption of individual appliances. Another downside is their complex installation due to the need to modify the electrical wiring. Other promising work in this category focuses on the design aspects of user interfaces for energy monitoring. Yun [17], for example, investigates the impact of a minimalist energy consumption user interface. This work proposes a wearable version of a user interface that displays energy consumption in real time as a bar graph, and compares it to a stationary display version. A sensor clip is attached to the home power breaker to measure overall consumption.

Device-level electricity feedback systems can provide more detailed information on the consumption of individual appliances. Such systems mostly build on smart power outlets that are connected between the power outlet and the power cord of the appliance being monitored. In order to visualize consumption data, systems such as Kill-a-Watt [18] and Click [19] (see Figure 1) feature a small, fixed display that often depicts rather limited information. Other smart power outlets [20] provide remote access to readings via wireless communications, thus enabling users to access the data on their mobile phone, for example. However, the feedback provided by such systems is limited to the devices directly attached to the outlet. To overcome this drawback, current research focuses on developing systems that integrate multiple sensors. In [21], for example, a gateway is responsible for discovering smart power sockets within wireless communication range. This approach facilitates functions such as remote switching, supports different user interfaces, and offers local aggregations of device-level services (e.g., the accumulated consumption of all sockets). A

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[2] Sales surpassed 41 million units in Q3 2009, a 12.8 per cent increase over the same period the previous year [29].

similar concept comes from Jahn et al. [22]. Jiang et al. [23] developed a wirelessly networked sensor node that comprises a full IPv6/6LoWPAN stack. Paradiso [24] embedded a multimodal sensor network node into a power outlet to monitor electricity consumption and infer the appliances being used. While the concept of deploying mesh networks of sensor nodes is interesting, using a large number of current sensors and communication modules induces a high usage barrier as such systems are often too cumbersome and expensive to deploy [25].

More conceptual work is conducted by Björkskog et al. [26], who developed a mobile phone prototype targeted at establishing a more enjoyable way of accessing energy consumption data for the benefit of less technically literate user groups. Their user interface helps users to monitor the quality of their conservation efforts by giving consumption feedback at device level and providing awareness tips.

In contrast to the systems outlined above, our work positions energy consumption within a more comprehensive picture that allows users to better assess and classify the consumption of their domestic appliances. To provide behavior-influencing feedback, we propose PowerPedia, a system that is based on a smart metering infrastructure and provides users with community-based and appliance-specific information on efficiency and energy-saving measures they can apply. It thus bridges the gap between existing energy monitoring solutions on the one hand and isolated Internet platform[3] that provide users with efficiency rankings and energy-saving tips on the other hand.

3 PowerPedia

\In the following, we first describe the general concept of PowerPedia before presenting its architecture and finally the user interface.

3.1 General Concept

The goal of PowerPedia is to allow users to better assess their electricity consumption and energy efficiency of their appliances. For that, users are provided with a mobile phone application that enables them to determine the electricity consumption of individual devices in a simple manner. By connecting a mobile phone directly to a smart electricity meter, users can determine the current electricity consumption of single switchable appliances. However, since many users have no comprehension of intangible units such as a watt or a watt-hour, and thus are not able to judge whether these correspond to particularly high or low consumption, further support is required. So as well as measuring consumption, PowerPedia also helps users to derive information on the efficiency and specific energy-saving possibilities of devices. By publishing the measured device on PowerPedia, users can compare the consumption of their device against the consumption of other devices in the same device category that have been previously published by other people. In addition, device and category-specific energy-saving measures can be uploaded and shared with other users. So users become aware of the efficiency level of their devices as well as of measures taken by other users or recommended by consumer organizations. In order to keep track of the most energy-efficient devices in each category, PowerPedia embeds a harvester module that automatically updates the data by incorporating the best-performing devices gathered from consumer organizations. The harvester also initializes PowerPedia with a first set of energy-efficiency measures. As add-on functionality, PowerPedia offers users direct integration into social networking platforms such as Facebook and Twitter.

3.2 Architecture

The overall architecture of PowerPedia is depicted in Figure 2. It is realized as an additional component to the eMeter system, which is described in more detail in [27]. PowerPedia consists of three components: the SignatureServer that stores information about domestic appliances, a harvester that is used to
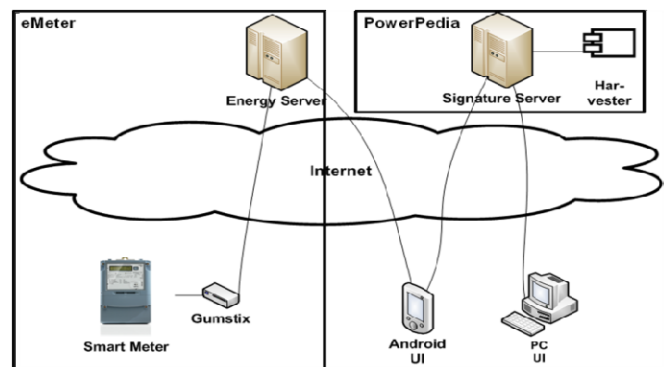
Figure 2. Architecture of PowerPedia realized as an extension to the eMeter system.

automatically update PowerPedia, and the user interface to access the functionality provided.

The first component, the SignatureServer, is written in PHP using the Recess framework. One of the advantages of Recess is its built-in support for REST [28]. This enables users to access the PowerPedia API using URLs. The services provided are bound to resources that can be accessed and modified with the usual http verbs (GET, PUT, POST, and DELETE). REST supports multiple data formats, giving a high degree of flexibility as data can be represented differently simply by adding the relevant file extension, e.g., .html for HTML or .json for JSON. Table 1 provides an overview of selected functionality that is provided by the RESTful PowerPedia API. It details the URL that can be called, together with the corresponding HTTP verb to perform the action indicated. As an example, Figure 3 shows the JSON representation of device number 96 that is stored on the SignatureServer. It is the response to a simple GET request on the following URL:

http://[serverAddress]/powerPedia/device/96.json

The SignatureServer follows the Model-View-Controller paradigm that forms the basis of the Recess framework. The following models are implemented:

- User: The user model is used to store user authentication information. This includes user name and password as well as first and last name.
- Category: The categories are used to group appliances of the same category (e.g., lights). Categories are structured hierarchically, meaning that a category can have multiple sub-categories.
- Devices: The device model contains fields for the device name and description, a picture, the manufacturer, the type, the consumption value, time information, and an efficiency rating (see Figure 3). Each device is linked to exactly one category.

Table 1. Example URLs of PowerPedia

| URI	Method	Action
/recognition	POST	Create new recognition
/device	POST	Create new device
/category/$id/rate/$watt	GET	Gather the efficiency rating of a specific device
/tipsCategory	GET	Get a list of all tips categories

```
{
    "device":{
            "id":"96",
            "name":"Osram - Mini Globe",
            "description":"Power (Watt)",
            "picture":"www.topten.ch/[...]/mglobe-e27.jpg",
            "manufacturer":"Osram",
            "type":"Mini Globe",
            "categoryId":"19",
            "createdOn":1272312189,
            "avgWatts":"7.0000",
            "efficiencyrating":{
                    "count":4,
                    "position":1,
                    "best":7W,
                    "worst":9W,
            },
            "userId":"5"
    },
    "user":{
            "id":"5",
            "username":"m",
            "password":"x",
            "createdOn":1273790766
    }
}
```

Figure 3. Json representation of a device stored in PowerPedia.

- Recognition: The recognition model is used to store the data that is collected when users measure electricity consumption and subsequently upload it to PowerPedia. A recognition is linked to a device and to the model of the user who uploaded the recognition.
- Device personals: To compute the cumulative energy consumption and associated costs for a device, the user can specify the utilization for every device measured. The model is linked to the user and the device. The user can also specify the location of the device (e.g., office, home).

The second component, the harvester, is used to initialize PowerPedia with a first set of devices and energy-saving measures as well as to update the database on a monthly basis with the most energy-efficient appliances in each category. The SignatureServer starts this update by issuing a GET request to the harvester's URI (Figure 4). The harvester then scans dedicated external consumer organization websites to acquire and extract the data before translating it into JSON. The result of the scan is then passed to the SignatureServer, which updates its list of devices in the database.

The third component, the mobile user interface (Figure 5), exploits the functionality provided by PowerPedia and the Energy Server. It is implemented in Java and runs on the Android operating system. To
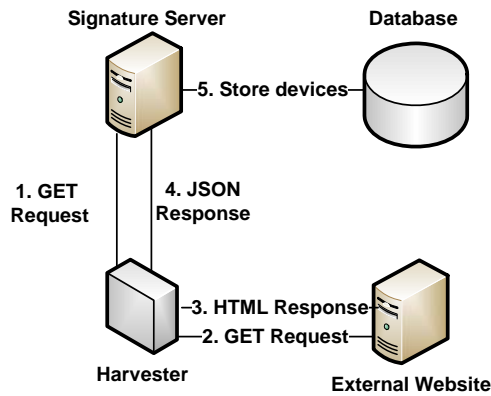
Figure 4. The harvester ensures that the SignatureServer holds a list of the most energy-efficient devices per category.

Figure 5. The user interface: Start screen to edit household settings and to setup smart meter pairing.

visualize the consumption data acquired by the smart meter, it sends a GET request to the Energy Server utilizing the REST API. The server responds with a JSON string, which facilitates data parsing in the application on the mobile device. The same principle is used for publishing new devices on PowerPedia as well as acquiring facts, such as efficiency or energy-saving measures, relating to a particular device from PowerPedia. In order to visualize the consumption data acquired by the smart meter, the mobile application accesses the functionality provided by the energy server.

To simplify the process of pairing a smart meter to the mobile phone application and to protect data privacy, we extended the capabilities of the smart meter to broadcast a unique token within the local network. To add a new smart meter, the user simply presses the scan button on the user interface. The application then screens for the multicast token and (assuming the user is connected to the same network) the smart meter gets automatically added to its list of accessible meters. As an alternative, it is possible to add a smart meter by using the mobile phone to scan the QR code or bar code attached to the smart meter.

3.3 User interface
In contrast to other energy monitoring systems, our system combines feedback on overall domestic energy consumption and – with a simple yet powerful functionality – on device-level consumption. In order to overcome the drawbacks of existing energy monitoring systems, the user interface aims to help users classify their consumption better by providing community-based feedback that goes beyond pure consumption information. As well as basic feedback features (e.g., current consumption, historic
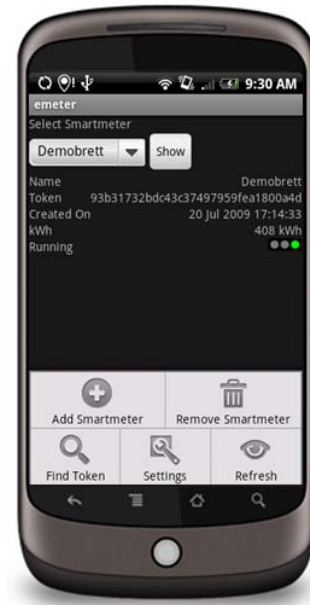
consumption, and standby consumption), the system therefore provides a measurement function that allows users to identify how much power individual appliances are consuming. To position this consumption within a bigger, more tangible picture, additional behavior-influencing information, such as appliance efficiency and user-based energy-saving measures, is provided. For this purpose, users can publish their devices on PowerPedia, and in doing so get instant feedback on how their consumption compares with the consumption of similar devices previously published by other users. In the following, we briefly explain each application view together with its functionality.

The start screen (Figure 5) allows users to select the data source for the application from a list of accessible smart meters. The view also allows users to add new smart meters to the mobile application and enter specific details that characterize the household – such as the number of occupants, their means of cooking (electricity / gas), type of heating, whether they own a washing machine or dryer, and the amount of their previous year's electricity bill. These details are subsequently used to provide comparisons (e.g., with a typical household of the same size), projections, and budget calculations.

The gauge view (Figure 6 left) provides users with information on their total current domestic energy consumption. The color-coded, self-adapting scale is updated in real time and provides users with an assessment of how their current consumption

Figure 6. The user interface. Gauge view (left) and history view (right).

compares to their historical consumption. After an initialization period, it automatically adapts colors and ranges according to the household's energy consumption. The scale is divided into four colored segments that help users determine how energy-efficient their current behavior is. Green denotes relatively low consumption, yellow is normal, and red denotes high consumption. The blue segment represents the base load of the household. This is automatically determined by a weighted moving average algorithm that only takes consumption values into account at night [27] and represents a simple way of identifying whether all devices have been switched off when the occupants go out.

The history view (Figure 6 right) enables users to view past consumption over different time spans (e.g., hour, day, week, month, etc.) using a line chart. In addition, this view makes it possible to compare the consumption of a selected time span with that of a typical household of the same size and characteristics. To do this, users have to specify certain details (e.g., the number of occupants) that characterize the household when they first start the application. Based on the previous period's energy bill, the history view displays the current remaining budget, together with a forecast of the resulting budget at year end.

The measure view (Figure 8) allows users to interactively measure the electricity consumption of single switchable appliances. To perform a measurement, users have to initialize the measurement by pressing the start button. They are
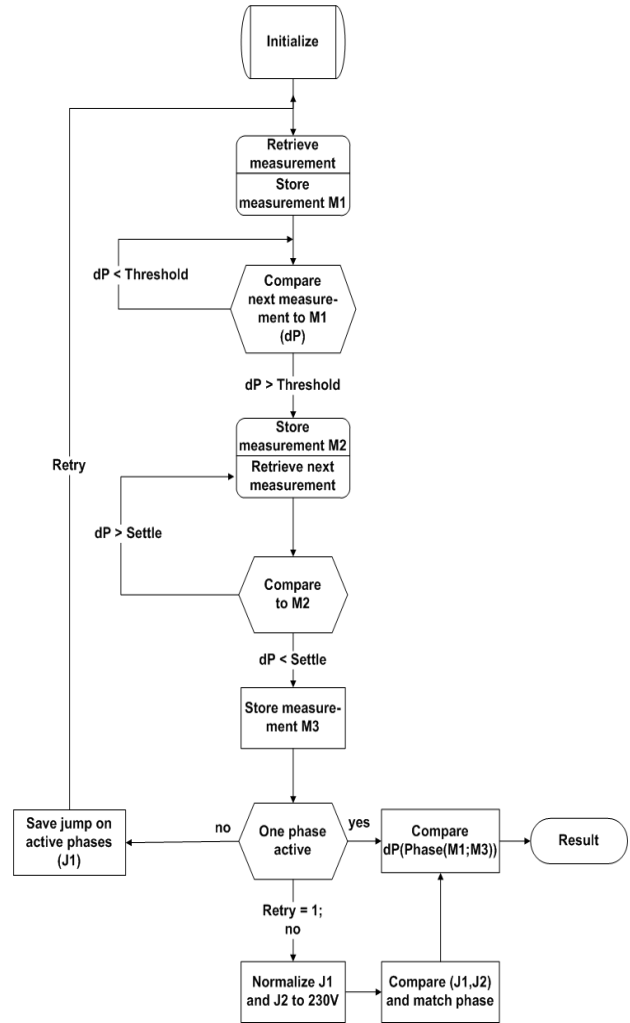
Figure 7. Flow diagram of the measurement algorithm.

then asked to turn the device being measured either on or off. Within a few seconds, the system then computes the result based on the algorithm outlined in Figure 7. After initialization, the algorithm stores the values of the first measurement and compares its power value to subsequent measurements until the difference is larger than a predefined threshold value (dP > Threshold). The algorithm then assumes that the user has switched a device on / off, and subsequently waits for the power to settle within a particular range (dP < Settle). Once this has happened, the algorithm stores the last measurement and checks the validity of the whole measurement. That is, besides considering the increase or decrease in real power, the algorithm also takes account of the different electric circuits and additional physical variables, such as apparent power and power factor. This not only makes it possible to determine the line on which the switching event has occurred, but also enables failures to be detected if two appliances attached to different lines are switched on at the same time. In this case, the algorithm detects an edge on
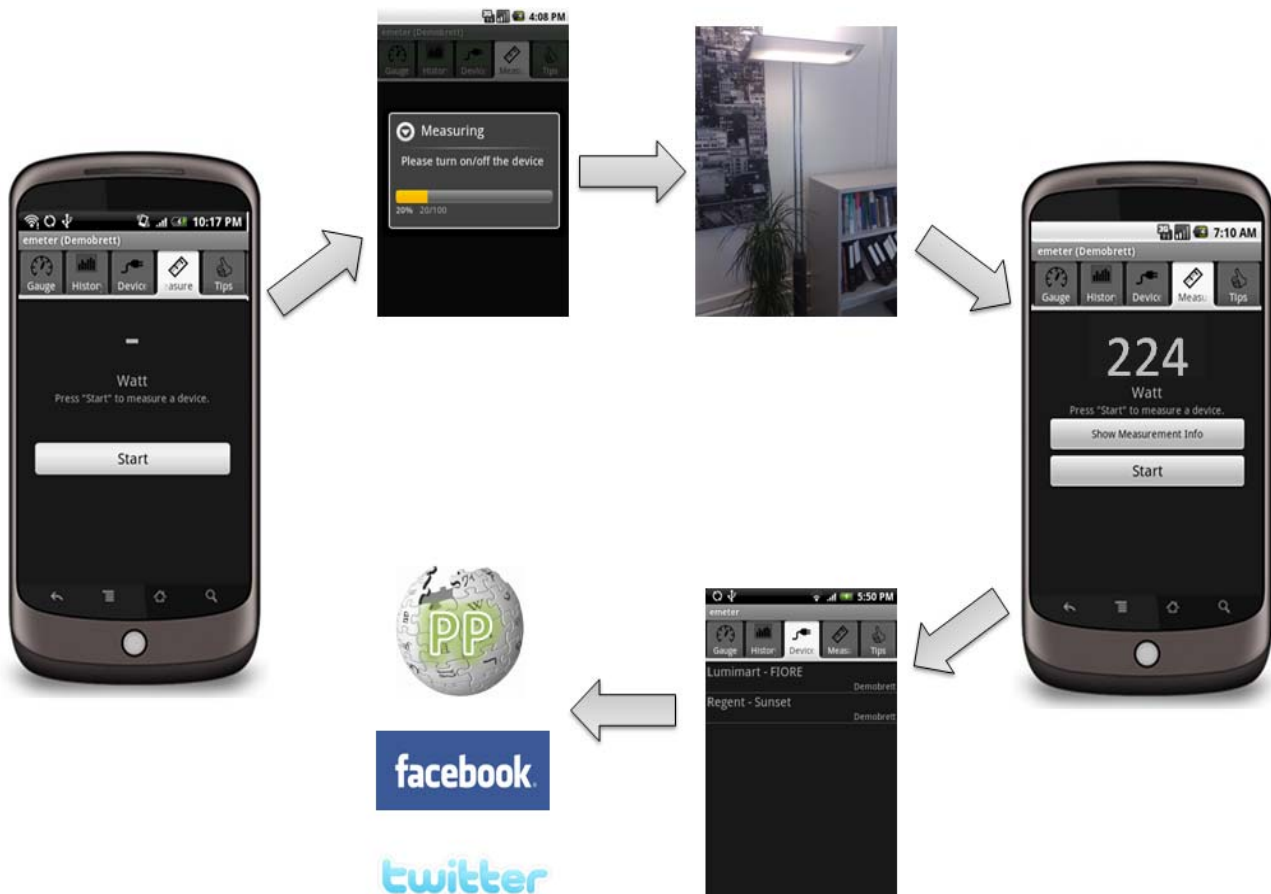
Figure 8. Measure and publish. Users first have to initialize the measurement by pressing the start button and thereafter turning the device of interest on/off. Within seconds the result gets displayed on the user interface. After saving the measurement to the device inventory, users can publish the device to PowerPedia, facebook, or twitter.

two lines and the user is prompted to repeat the measurement process. By comparing the value of the second measurement after normalization to the previous measurement (compare (J1,J2)), the phase on which the switching event has occurred can be identified and the consumption of the device can be identified (compare dP(Phase(M1,M3)).

Users can subsequently personalize the measurement and store the measured device in the device inventory (Figure 9 left). The user interface provides the option of taking photos of the measured appliance, assigning a location, specifying a device category and manufacturer, and indicating its utilization to calculate the annual costs incurred. In order to simplify the process for users, location, categories, and device names are downloaded from PowerPedia in the background and provided via an autocompletion feature. For example, the device categories are structured hierarchically (e.g., consumer electronics, TV, LCD, 34-inch, Samsung, type). By uploading the device to PowerPedia, users can compare their consumption against the consumption entered by other users as well as the

consumption of the most energy-efficient appliances in the category harvested from consumer organization websites. An efficiency ranking based on all PowerPedia's community entries places the consumption within a more tangible context. It shows users the efficiency ranking of their device, information on the best and worst performing devices, and the total number of uploaded devices in the category. In addition, users can share their information on popular social networks such as Facebook and Twitter.

The advice view (Figure 9 right) displays energy-saving measures downloaded from PowerPedia. It consists of tips that can be applied in general as well as tips relating to specific device categories. In addition, users can publish energy-saving tips on PowerPedia and so share their experiences with other users. Tips can be flagged to indicate that they have been applied. This allows PowerPedia to indicate the percentage of users who have already applied a particular measure. Users can also publish their experiences directly to their friends

Figure 9. Android user interface: Device details (left), energy saving measures (right).

on their preferred social network, in a similar manner to the device inventory.

4 Laboratory Deployment

We deployed the first prototype of the application and backend infrastructure in a lab setting and then distributed the application to students and other team members. The system has been running reliably since September 2008. In order to test the infrastructure with multiple smart meters, we deployed a second meter at the beginning of 2009. Each smart meter sends its measurements to the EnergyServer on a second-by-second basis. So far, this has resulted in over 40 million measurement entries in our database. We currently have 12 active users registered on our system, who have accounted for over 100 application sessions.

Before designing and deploying the application, we held a focus group discussion and conducted a paper-based survey to gather insights into the expectations of potential users of such an energy feedback application. Based on the results [30], we developed an initial prototype application that not only implemented the most promising feedback functionality, but also offered a clear use case scenario ("you can measure the electricity consumption of individual devices"). In a follow-up lab test involving 25 participants (from different backgrounds ranging from students to marketing and sales people and industry experts), we evaluated the general assessment of the application and the accuracy of the measurement functionality. We asked

each user to measure three different devices using the mobile phone application. After the measurement we asked the users about their perception of the functionality. Most participants perceived the measurement functionality to be easy to use, and their measurements achieved an overall accuracy of ±5% compared to the consumption we had previously verified. However, some users did encounter problems determining consumption, and they accounted for the few measurement failures that were experienced. This was mostly due to the fact that participants were not following the instructions (e.g., turning the device on/off before pressing the start button).

We then interviewed participants to explore all the functionality of the smartphone application. In a follow-up questionnaire, we asked users to rate the complexity of the application on a five point Likert scale. Participants rated the ease of use (4.04), ease of learning (4.04), and their satisfaction with the application (4.16) all as significantly above average (mean results in brackets). Taking into account that we covered a wide age range (18 to 51 years), we regard this as a very positive response for a prototypical application. Moreover, general results also indicate that the feedback latency was perceived as satisfying (with a mean of 4.52).

During the test, users experimenting with the mobile application particularly liked the interactive component. That is, the fact that feedback was available when needed, together with the straightforward measurement functionality. Users reported that this enabled them to satisfy their initial curiosity to discover more, not only about their overall consumption, but also more specifically about the consumption of individual devices. However, many users acknowledged that although they knew how many watts a particular device consumed in operation or standby, they were unable to draw conclusions either on its efficiency or on effective measures that could be taken to conserve electricity. This motivated us to develop a way of positioning consumption within a more tangible picture by allowing users to share information on the electricity consumption of individual devices and their experience with energy-saving measures.

After making these action-guiding features available, we observed that users spent more time on personalizing measurements (a previously little-used feature). Most of them were also curious to know how an appliance performed energy-wise compared with typical devices in the same category and so they

uploaded their measurements to PowerPedia in exchange for further information, such as energy efficiency rankings. This helps users position their electricity consumption within a bigger, more comprehensive picture.

5 Conclusions

We have presented a smartphone application that is integrated into a smart meter infrastructure. The application tries to overcome the drawbacks of conventional energy monitoring solutions, which typically provide rather technical and intangible electricity consumption feedback. It does so by allowing users not only to interactively explore their energy consumption at a household and device level, but also to compare their consumption with that of peer groups. The ability to upload data to PowerPedia (which operates like a Wikipedia for electrical appliances) plus Facebook and Twitter introduces a social networking aspect to energy consumption feedback systems. It places their electricity consumption in a broader picture beyond pure numbers and encourages users to compare the consumption of their devices with that of others. As the system updates the database regularly with the most efficient device types from external sites, it succeeds in providing users with feedback on the best-rated devices at any given time.

Besides evaluating our prototype in a real-world setting, the aim of future work is to gather a broad collection of appliance signatures that in turn can be used as input for pattern-recognition algorithms to automatically recognize switching events of devices in the load curve. This could permit automated device-level feedback and enable other concepts that further encourage users to deal with their energy consumption.

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