Switch off the light in the living room, please! – Making eco-feedback meaningful through room context information

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Abstract

Residential and commercial buildings are responsible for about 40% of the EU's total energy consumption. However, conscious, sustainable use of this limited resource is hampered by a lack of visibility and materiality of consumption. One of the major challenges is enabling consumers to make informed decisions about energy consumption, thereby supporting the shift to sustainable actions. With the use of Energy-Management-Systems it is possible to save up to 15%. In recent years, design approaches have greatly diversified, but with the emergence of ubiquitous- and context-aware computing, energy feedback solutions can be enriched with additional context information. In this study, we present the concept "room as a context" for eco-feedback systems. We investigate opportunities of making current state-of-the-art energy visualizations more meaningful and demonstrate which new forms of visualizations can be created with this additional information. Furthermore, we developed a prototype for android-based tablets, which includes some of the presented features to study our design concepts in the wild.

1. Introduction

Residential and commercial buildings are responsible for about 40% of the EU's total energy consumption [1]. With disaggregated real-time energy consumption feedback, dwellers can be enabled to make better informed energy related decisions and therefore save energy. In general, empirical studies have shown that savings up to 15% [2] can be achieved.

These promising results have led to a vivid research discourse and development investigations in smart metering technologies. Based on these results, the fine-grained collection of consumption data is not a vision anymore, but reality. However, with the increasing volume of data, its visualizations become more complex. A major challenge in sustainable interaction and eco-feedback design (SID) [3] is to enable consumers to make informed decisions about energy consumption and thereby supporting the shift towards or implementation of sustainable actions. In particular, current research focuses on how to make feedback more informative and action-oriented. A promising approach presents the concept of context awareness. The aim of this approach is to reduce information complexity and to provide a rich context for interpretation to make data more meaningful for the user. By reducing the complexity of information and providing a rich context, context awareness enables the user to interpret consumption data.

Contributing to this, we present the concept of *room* as context information. Rooms play an important role in structuring domestic routines and thus domestic energy consumption. We developed various design studies that illustrate how room information can be used to enrich feedback mechanisms and contextualize user interfaces of mobile home energy management systems (mHEMS).

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2. Related Work

In recent years, several related concepts have emerged in the literature concerning eco-feedback systems for domestic environments that make information about energy consumption accessible to users. In this section we give a short overview about the evolution of eco feedback systems and about the relevance of context-information for designing eco-feedback systems.

2.1. Eco Feedback Design

Common concerns addressed by most eco feedback systems include the presentation of data, temporal aggregation/disaggregation, historical and normative comparison and the subject of motivation, support of devices and context [4]. Thereby a rapid development of energy feedback systems takes place. Early eco-feedback systems were simple video screens providing information about the total energy consumption of the household (smart meter systems), such as ‘eco-eye’ [5] or the ‘power-aware cord’ [6]. More sophisticated systems provide feedback on appliance level (smart plug systems) like ‘DEHEMS’ [7]. Nowadays, a variety of solutions are realized as web-portals [8] or smartphone applications [9], combining multiple features and visualizations.

Currently, it is noted in the literature that a simple indication of consumption data is not enough [8], [10], [11]. Additional context information is required to increase the interpretability of consumption data and to help users establishing a connection between the abstract concept of energy and their domestic life. Therefore, approaches of ubiquitous computing and context awareness get of sustainable interaction design research.

2.2. Context Awareness and Context-Aware Eco Feedback

In Sustainable Interaction Design, context awareness is defined as the consideration of the living environment of the user. Schilit and Theimer [12] were among the first to use the term, defining context-aware computing as „the ability of a mobile user’s applications to discover and react to changes in the environment they are situated in“ [12]. Hull et al. and Pascoe define context-aware computing (situated computing) more general, as devices detecting and sensing the user’s local environment, showing and using gathered information for system methods itself 01/08/2014 13:57:00 [13], [14]. Dey et al. divide context-aware systems into three categories [15]. The first category is “presenting information and services”. This means that the system provides the user with sensor information. For example, by showing the users’ current position through the placement of a marker on a map. The second type covers automatically executing services, such as car navigation systems that calculate a new route when an exit has been missed. Finally, according to Dey et al., a third group of context-aware software attaches context information for later retrieval and use. These categories are similar to the definition of context-aware computing by Brown [16], who defines three categories as follow:

- Presenting information to the user
- Running a program
- Configuring the screen of the user

In terms of energy feedback, there are already a number of approaches to enrich consumption data with additional context information. For instance, Costanza et al. [17] present an interactive feedback system, where users could tag their context directly within consumption feedback. On the one side this allows a visual linkage of specific activities and energy consumption and on the other side new forms of visualizations are possible (e.g. event-centric/energy-centric forms of visualizations). Neustaedter et al. [10] use data from personal calendars to contextualize consumption data of users. Although many events and especially most of routine activities were not registered, it could be recognized that calendar entries can be used for the declaration of energy consumption (e.g. a house party explains high consumption, while eating in a restaurant would imply low consumption). Also, people's location at home helps to contextualize and individualize feedback. Jahn et al. [18] e.g. use the position of the user to present eco-information for the devices at hand. Guo et al. [19] use an active user treatment approach with an RFID based check-in/check-out, to get the position of a user and personalize consumption data with it.

3. Room as a context

In several preliminary studies we examined, among other things, what information users needed to make sense of their energy consumption. We found out that their presence in a specific room is an important information for the user to reconstruct activities and thereby linking consumption patterns with activities [4], [11], [20]. In the following chapter, we describe the importance of rooms for everyday-activities and for identifying wasted energy.

3.1. Room as a domestic order for everyday activates

People live in homes and undertake activities and interact in this physical environment. Here, rooms have a special meaning when it comes to everyday-activities. Rooms often are decorated differently and serve a particular purpose. A room-structure specifies which activities are appropriate in it and what technology is available to carry them out [21]. For example, in the most cases cooking in the bedroom is unusual. Also for architects, rooms are of central importance. The planning of electrical sockets is related to the intended use of the room and switches for lighting and heating are used to control devices on room-level. Additionally, switches for lights are usually attached next to the door, that when entering or leaving the room, one can switch on/off the required appliances.

In the 1990s, the concept of rooms gained high attention in the context of designing information and communication technology. In their investigation Harrison and Dourish [22] linked insights from architects and urban designers with their own studies to differentiate between space and place. Space is therefore a three-dimensional environment with objects and events that have relative positions and directions and places are spaces that are valued ("We are located in space, but we act in place" [22]).

3.2. Understanding of energy consumption and energy wastage

The interplay between technology, places and activities can be used to classify energy consumption and thereby make wasting visible. Schwartz et al. [11] have demonstrated that dwellers distinguish energy consumption between consumption of background services (typically always-on devices like the refrigerator and freezer) and activity related consumption (like using TV for watching, light for reading, etc.). Generally, activity based consumption is closely related to the person's presence (respectively activities which in turn are related to places [21], [22]). Therefore, the actual place of habitants in their home is a strong indicator for energy being wasted (e.g. light in a room where no one is present is a wasting of energy). We use this heuristic by identifying the presence of users in the corresponding rooms to expand existing visualizations of eco-feedback systems and to create new forms of visualization to support the user in his sustainable practices. In the following sections we conceptually describe such a system.

3.3. Using room context to make eco feedback more meaningful

We identified four, non-exhaustive, visualization categories where room-context information could help to make feedback more meaningful for the user:

- Analytic charts identifying spenders in the home
- Time series consumption graphs enriched by dwellers' presence information
- Person and domestic activity centred consumption visualization
- Domestic scoreboard systems

Figure 1 *Using room-context information to enrich eco-feedback visualization (left) and to adapt home control interfaces (right)*

The room context information could therefore be used to identify spenders, which are defined as potential energy wasters. Analytic charts on device level allow making such spenders visible. For example, the device-level chart in figure 1, left, shows that 21% are potentially spending by splitting the overall consumption into consumption with presence and without. Such graphs help users to control their habit of switching devices off when not needed.

Further presence information could be used to enrich time series consumption graphs in various ways. For instance, historic feedback graphs commonly show a curve of the device's consumption in a daily, weekly or monthly interval. Such graphs on a room level could be enriched by peoples' presence time in that room, e.g. assign a colour to each dweller and colouring the graph's background accordingly for the time each person was in the room (see also in figure 1, left the bar diagram below). Such graphs may make it easier for dwellers to identify consumption patterns and match them with their own behaviour.

The third improvement reverses the previous visualizations, by showing the consumption of the person's immediate environment over the time. This person-centred visualization in combination with the previous one allows gaining new insights and surprising facts about one's own domestic energy practices. Last but not least, the room-context information could be used to define new indicators for domestic scoreboard systems like average room temperature when people are present and non-present. Further, this information could be used to personalize recommendations, tips, or statistics.

3.4. Room context aware home control interfaces

In a further step we explored, how room context information could be used to adapt home control panels. We have identified two categories, in which room-context helps to reduce the panel complexity and nudge people to switch off spenders:

- Adapt the control panel to the devices of the actual room
- Make aware about spenders outside the room

One of the current problems of control panels is the large number of switching options that can lead to a cluttered design. Architectures solve, for example, the problem of complex control panels by making use of rooms as a domestic order system: *A room only includes the controls for the room*. This is a smart choice as people most often are interested in controlling activity-related devices, which typically are in the person's current surrounding. Room context information helps to adopt this strategy by showing only controls of the actual room on the user interface. This radically simplifies the complexity of home control panels.

An exception to the rule above, are devices outside the room that have been forgotten to be switched off, e.g. because of laziness, so they still consumes energy. To nudge people to switch off these devices, the control panel should make aware about these spending devices. Figure 1, right, presents our solution for this demand, where we split the control panel into two sections: The top section shows the controls in the actual room. The bottom section shows the detected spenders outside the room. By focusing on the controls that are important in the current context, the panel is more structured and the number of switching options is greatly reduced.

4. Placing and spacing: A new view on domestic indoor location

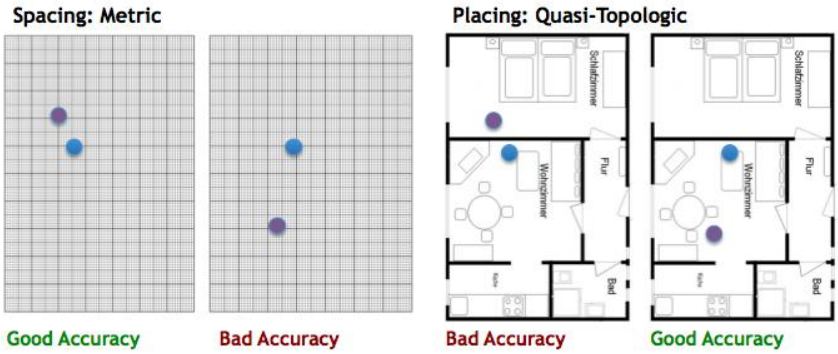

Figure 2 *Difference between "space-oriented" and "place-oriented" localization*

The distinction between place- and space-oriented approaches leads to different requirements for locating in domestic environments. The major difference between common indoor localization solutions and room localization is that *space-oriented* approaches are relying on metric error measures, commonly defined by the distance between the actual and the estimated position. In opposite, *place-oriented* approaches rely on a quasi-topologic error measure defined by the ratio whether the actual room is estimated correctly or not. Figure 2 gives an example that good space accuracy does not necessarily imply good place accuracy. Yet, until we have specially optimized place-oriented localization techniques, existing space-oriented techniques could be used as a heuristic.

Concerning the various localization techniques, we principally can distinguish between four classes: The first group are beacon-based approaches that use proximity detection with short-range radio communication, for example RFID or NFC. Based on a globally unique identifier, e.g. a smartphone can look up the position of the beacon (e.g. [1]). But these approaches depend on additional hardware to locate the position of the user. The second group are geometry-based approaches estimating the position e.g. by triangulation and trilateration, determining positions from measurements of angle of arrival or distance between sender and receiver. The intersection of lines or radii respectively provides the current location (cf. [2]). One disadvantage is that conventional WiFi-routers are hardly suitable, because they either need special antennas allowing angle-measurement, or, for trilateration, a much more precise measure of distance than can be provided by electromagnetic waves. The third class of indoor-positioning approaches use accelerometers and gyroscopes of a device to log the movement: speed and direction, starting from a given position to calculate a new position. Such dead reckoning techniques suffer from a fast increasing inaccuracy as small errors add up every step [3]. The fourth group is based on fingerprinting the signal strength of e.g. WiFi routers at different places. One disadvantage is that such a system must be trained beforehand [4]. Yet, it has the great advantage that existing router infrastructures in domestic settings could be reused for the positioning.

5. *MyLocalEnergy* - a prototype of a room-context aware HEMS

We have developed a fully functional room-context aware home energy management system prototype called *MyLocalEnergy*. The system was realized as a server-client architecture with a low-power home server where the energy- and position-data is stored in a local database. The client was implemented as a native app for Android devices that communicates with the home server via web-services. Although the client could be used on smartphones, it was optimized for Android Tablets.

The positioning is mainly computed on the Android client, which tells the home server in which room the person actually is. We therefore use a fingerprinting approach based on available WiFi network signals as WiFi routers are available in most domestic environments and no additional hardware is needed. Furthermore, a combination of multiple Received Signals Strengths (mRSS) provides relatively unique fingerprints. Reducing the error rate can be handled by setting up additional WiFi AP [4]. We also minimized the mentioned training problem by providing a user interface, where users iteratively can add, edit and delete multiple measurement points and assigns them to a room. The users themselves can improve system accuracy by adding additional measurement points at places that are important from their perspective. We further implemented some filters that validate the results.

Through smart plugs and a smart meter we measured the overall electricity consumption of the household as well as the individual consumption of appliances (cf. [4] for more details on this "traditional" part of our HEMS system). A tomcat webservice is running on our server, which provides energy consumption services, e.g. *getActualConsumption(deviceID)*, position services e.g. *getCurrentRoom(personID)*, as well as additional fusion services understood as a logical linkage of positioning and energy data e.g. *getConsumptionInCurrentRoom(personID)*.

On the user interface we provide, among others, a room-context aware time series consumption graph, which either displays current live consumption or historical values together with information about the users' presence. Based on feedback from our living lab participants, we added additional statistical information about the potential wastage. This information includes, for example, how much the potential wastage would cost per hour.

Furthermore, we implemented control/assistance features, too. Like in figure 1 on the right, the Android client provides a context-adaptive display showing the home devices in two groups: The primary group includes all devices in the immediate environment of the user (room); the second includes all other devices. This slightly differs from the concept outlined above as some of our users wanted to switch on devices in other rooms as well that is why we display more than the appliances in the room in this view. Yet, to ensure that users still get aware about spenders, they are marked with an extra symbol in the list. In addition, an Android application notification is sent to the user if a spender is detected. We further have included a programmable timer function. This feature, e.g. allows switching off a VCR after recording the television program in order to save stand-by consumption.

6. Evaluation

We split our evaluation in a technical and a conceptual part concerning overall user experiences. For the technical evaluation of the position service we use a test routine asking the user at random selected points in time, whether the actual recognized room is correct or not. We have run this routine in two different households with three WiFi networks available and collect overall 29 measuring points in two days. We achieve a correctness of about 85%, which means that with an optimal establishment of the position service a good accuracy could be achieved. The accuracy of the position determination, however, depends on the existing WiFi infrastructure and the structural conditions of the household. The WiFi networks should have sufficient signal strength and the routers should be placed in different corners and floors to get best results. The use of repeaters/extenders can distort the results, since in this case the distance to the router cannot be recognized. For the prototypical implementation, the position recognition is sufficiently accurate to examine the usefulness of the system in terms of supporting the user within a sustainable use of energy. We have not carried out a major technical evaluation, since the position determination is not the focus of this work.

We evaluated the user experience by conducting interviews and workshops with seven private living lab households [23] concerning the perceived usefulness and shortcomings using room-context to make the consumption feedback more meaningful and how such concepts should be realized. Overall, our participants appreciate the design concept and said that additional context information would help them to get a more profound understanding of their domestic consumption. Additionally, the participants agree, that their room-based position is a useful information, especially in the historical consideration of consumption data to inference on ineffective behaviour. A further aspect that people regarded as practical was the better clarity by the distribution of the devices in two categories in the control panel. Due to the fact that we measure up to 18 single devices four households, the usual control-panel become cluttered. The people also noted that with an accurate detection of the position, some device could automatically be switched on or off, e.g. lamps. However, there were several points of criticism and detail improvements like that participants sometimes felt disturbed when there always receive notifications when they just leave a room with active devices for a short time to make a coffee or something.

7. Discussion and Outlook

The first energy monitors simply feedback more or less the raw measured energy data. Today real-time, disaggregated consumption measurement is reality. The major challenges in domestic settings concerning lowering the energy consumption are:

- How can we prevent an information overload given the vast amount of raw data
- How can we make consumption feedback more meaningful

We contribute to this challenge by outlining the concept of room as a context and how it could be implemented. Concerning other approaches on context-aware consumption feedback in literature [10, 17, 18], we do not think that room as a context will replace them, but supplement them. For instance, room-context complements the device context and visa versa. E.g when a user comes near a device, our room context-aware user interface could be adapted to a device context-aware one as outlined in [18].

In summary, this paper has outlined the potential of room-context aware HEMS. However, for the practical use several challenges have to overcome: Firstly the practical value of the positioning must be studied under realistic conditions with a larger sample and in long term. Secondly, while people always take the smartphone and the tablet with them when they leave the home, they often put the device on a desk, a sideboard, etc. when they are at home. Concerning this, future smartwatch based positioning services have a great potential. Thirdly, we got aware that our solution is implicitly optimized for single households. Hence, in future we have to investigate how multi-person households appropriate such design concepts and if, in which way the concepts must be extended.

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