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

Nico Castelli[1], Gunnar Stevens[2], Timo Jakobi[3], Niko Schönau[4]

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).

[1] University of Siegen, 57076 Siegen, Germany, nico.castelli@uni-siegen.de

[2] University of Siegen, 57076 Siegen, Germany, gunnar.stevens@uni-siegen.de

[3] University of Siegen, 57076 Siegen, Germany, timo.jakobi@uni-siegen.de

[4] University of Siegen, 57076 Siegen, Germany, niko.schoenau@uni-siegen.de

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

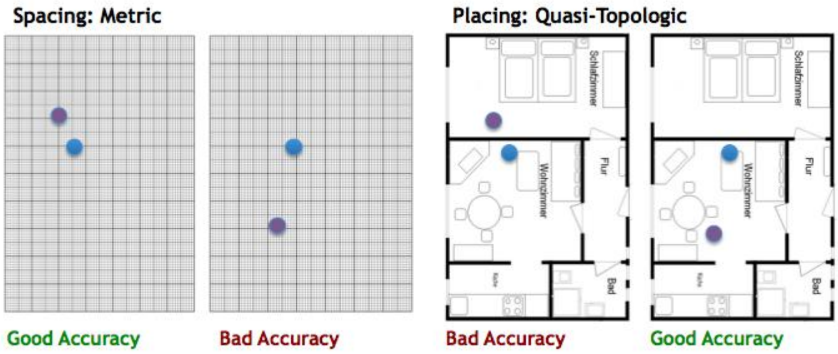

Figure 2 *Difference between "space-oriented" and "place-oriented" localization*

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 smart-watch 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.

References

[1] European Commission, “COM(2008) 772: Energy efficiency: delivering the 20% target.” 2008.

[2] G. Fitzpatrick and G. Smith, “Technology-Enabled Feedback on Domestic Energy Consumption: Articulating a Set of Design Concerns,” *IEEE Pervasive Comput.*, vol. 8, no. 1, pp. 37–44, 2009.

[3] E. Blevis, “Sustainable interaction design: invention & disposal, renewal & reuse,” in *Proceedings of the SIGCHI conference on Human factors in computing systems*, 2007, pp. 503–512.

[4] T. Schwartz, S. Denef, G. Stevens, T. Jakobi, V. Wulf, and L. Ramirez, “What People Do with Consumption Feedback: A Long-Term Living Lab Study of a Home Energy Management System,” 2013.

[5] C. Kelsey and V. Gonzalez, “Understanding the use and adoption of home energy meters,” in *Proceedings of El Congreso Latinoamericano de la Interaccion Humano-Computadora*, 2009, pp. 64–71.

[6] A. Gustafsson and M. Gyllenswärd, “The power-aware cord: energy awareness through ambient information display,” in *CHI’05 extended abstracts on Human factors in computing systems*, 2005, pp. 1423–1426.

[7] V. Sundramoorthy, Q. Liu, G. Cooper, N. Linge, and J. Cooper, “DEHEMS: A user-driven domestic energy monitoring system,” in *Internet of Things (IOT), 2010*, 2010, pp. 1–8.

[8] T. Erickson, M. Li, Y. Kim, A. Deshpande, S. Sahu, T. Chao, P. Sukaviriya, and M. Naphade, “The dubuque electricity portal: evaluation of a city-scale residential electricity consumption feedback system,” in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, New York, NY, USA, 2013, pp. 1203–1212.

[9] M. Weiss, T. Staake, F. Mattern, and E. Fleisch, “PowerPedia: changing energy usage with the help of a community-based smartphone application,” *Pers. Ubiquitous Comput.*, vol. 16, no. 6, pp. 655–664, Jul. 2011.

[10] C. Neustaedter, L. Bartram, and A. Mah, “Everyday activities and energy consumption: how families understand the relationship,” in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2013, pp. 1183–1192.

[11] T. Schwartz, G. Stevens, L. Ramirez, and V. Wulf, “Uncovering Practices of Making Energy Consumption Accountable: A Phenomenological Inquiry,” *ACM Trans Comput-Hum Interact*, vol. 20, no. 2, pp. 12:1–12:30, May 2013.

[12] B. N. Schilit and M. M. Theimer, “Disseminating active map information to mobile hosts,” *IEEE Netw.*, vol. 8, no. 5, pp. 22–32, 1994.

[13] R. Hull, P. Neaves, and J. Bedford-Roberts, “Towards situated computing,” in , *First International Symposium on Wearable Computers, 1997. Digest of Papers*, 1997, pp. 146–153.

[14] J. Pascoe, “Adding generic contextual capabilities to wearable computers,” in *Second International Symposium on Wearable Computers, 1998. Digest of Papers*, 1998, pp. 92–99.

[15] A. K. Dey, G. D. Abowd, and D. Salber, “A Conceptual Framework and a Toolkit for Supporting the Rapid Prototyping of Context-aware Applications,” *Hum-Comput Interact*, vol. 16, no. 2, pp. 97–166, Dec. 2001.

[16] P. J. Brown, “Triggering information by context,” *Pers. Technol.*, vol. 2, no. 1, pp. 18–27, Mar. 1998.

[17] E. Costanza, S. D. Ramchurn, and N. R. Jennings, “Understanding domestic energy consumption through interactive visualisation: a field study,” in *Proceedings of the 2012 ACM Conference on Ubiquitous Computing*, 2012, pp. 216–225.

[18] M. Jahn, M. Jentsch, C. R. Prause, F. Pramudianto, A. Al-Akkad, and R. Reiners, “The energy aware smart home,” in *Future Information Technology (FutureTech), 2010 5th International Conference on*, 2010, pp. 1–8.

[19] Y. Guo, M. Jones, B. Cowan, and R. Beale, “Take it personally: personal accountability and energy consumption in domestic households,” in *CHI’13 Extended Abstracts on Human Factors in Computing Systems*, 2013, pp. 1467–1472.

[20] T. Jakobi and T. Schwartz, “Putting the user in charge: End user development for eco-feedback technologies,” in *Sustainable Internet and ICT for Sustainability (SustainIT), 2012*, 2012, pp. 1–4.

[21] L. Baillie and D. Benyon, “Place and Technology in the Home,” *Comput. Support. Coop. Work CSCW*, vol. 17, no. 2–3, pp. 227–256, Apr. 2008.

[22] S. Harrison and P. Dourish, “Re-place-ing space: the roles of place and space in collaborative systems,” in *Proceedings of the 1996 ACM conference on Computer supported cooperative work*, 1996, pp. 67–76.

[23] T. Schwartz, S. Denef, G. Stevens, L. Ramirez, and V. Wulf, “Cultivating Energy Literacy: Results from a Longitudinal Living Lab Study of a Home Energy Management System,” in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, New York, NY, USA, 2013, pp. 1193–1202.

Like! You saved #energy today.

Fostering Energy Efficiency in Buildings – The implementation of social media patterns as symbols in Building Management Systems‘ Graphical User Interfaces using Peirce's semeiosis as a communication concept

Andreea Tribel[1], Jan Geffken[2], Oliver Opel[3]

Abstract

This paper starts with a short definition of the research field sustainable ambient computing (SAC), which unites ambient intelligence, and ubiquitous computing. SAC takes into account not only the ecological aspects of life cycle assessment and energy efficiency, but also includes HCI as main pillar. Part of SAC is building management systems, which, in their current form, struggle with lacking user integration and rebound effects. The prospect is to build, implement and test a graphical user interface in a new energy efficient building at Leuphana University, which provides a convenient surrounding and an user-friendly system at the same time. According to the pragmaticist approach of C. S. Peirce's sign theory, we propose abduction as a method of inference and semeiosis as a triadic communication process. Regarding the spread of social media usage, we suggest using elementary communication patterns taken from this field for building management systems, because known communication patterns encourage the usage of uncommon ambient computing systems. Hence, acceptance, a major challenge when trying to successfully integrate users, is facilitated. Here fore we looked on typical communication patterns of the most used social media platforms. A successful usage of these patterns in this specific context will raise the perception und knowledge of energy consumption, and can be expected also to change habits on the long run.

Sustainable ambient computing (SAC) reflects the main ICT trend in the societal and industrial development today. Computers have become part of ordinary things like walls, doors or even car seats. They build a surrounding with contactless switches (e.g. light in buildings) or actually invisible things to happen like variable heating and air conditioning in buildings or windows open and closed by smart systems and no longer by humans.

Viewed from a systems point of view, the aim of smart buildings, for example, is balancing convenience and energy efficiency. This should by no means result in using more computers hence more energy. Therefore in SAC the life cycle assessment of the systems to be taken into account is an utterly important part of the sustainability aspect concerning hardware.

[1]Leuphana University Lueneburg, 21335 Lueneburg, Germany, tribel@leuphana.de, Institute for Sustainability Communication

[2]Leuphana University Lueneburg, 21335 Lueneburg, Germany, geffken@leuphana.de, Institute for Sustainable and Environmental Chemistry

[3]Leuphana University Lueneburg, 21335 Lueneburg, Germany, opel@leuphana.de, Institute for Sustainable and Environmental Chemistry

As well as for the hardware part, the software part has to be sustainable by means of anticipating and guiding users and user groups: A successful communication respectively HCI (human-computer-interaction) within BMS (building management systems) or smart buildings fosters not only energy efficiency, but may also change habitual and cultural patterns in the long run.
SAC, therefore, suggests a holistic view on any ICT supported system.

However, whilst computers became a nearly invisible surrounding for us, the usage of smart phones, smart buildings and other smart systems did not fulfil the promise for sustainable nor energy efficient infrastructures yet [1].

Planned as "closed" systems, BMS are often used to rigidly control the indoor climate. They produce a large data stock that is supposed to be used by the manager of the system to control energy efficiency and provide a comfortable ambient, however a purpose that is hardly ever reached. The lacking flexibility and interaction with users and user groups in the room often results in discomfort for the user and users bypassing the rigid BMS regime, resulting in inefficiencies on the system side. In general, "[t]he environmental effectiveness of eco-technologies strongly depends on the way users interact with them" [2].

There are several challenges – the position of the building, the weather, the subjective feel of the user. She might feel cooler in the very early hours of the day, but would love some cooler air after lunch. Also the gradual difference between the outside and inside temperature – a somehow subjective "feels like" for the person in the room. While the user can easily handle brightness in a room because of its visibility, room climate is more challenging from a user's point of view. We conclude therefore that there has to be some communication between the system and the person in the room.

Part of the interaction between user groups and the BMS is the preparation of sampled data for a user-friendly visualization that leads to clear instructions for the BMS. To create user-specific feedback, it is necessary to collect data about the handling of actors like thermostat settings and environmental parameters like humidity and outdoor temperatures.

Because of the otherwise increasing hardware requirements, energy and data, the sampling rate, the resolution and the accuracy of information should be balanced out for the needs of the user and user groups. For a sustainable system the mass of sensors and data has to be minimized to the basic necessary data that enables an interaction between the user and the BMS, e.g. the use of heating energy for the day before compared to a similarly used room. There are three main levels between the user and the system: sensor-actor-level, database and Graphical User Interface. While the development of the GUI is based on the semeiosis as communication method, the development of the level of database and sensors/actors is based on a technical efficiency perspective. Thus the holistic view is given by this interdisciplinary research approach, resuming the idea of sustainable ambient computing.

Regarding the Human-Computer-Interaction, dyadic communication models following the action-reaction syntax are fine for closed systems only. We suggest therefore Peirce's triadic sign model and its semeiosis as methodical concept. Semeiosis uses the sign or the object, respectively representamen and interpretant relation, in analogy to action-interpretation-reaction [3] for any process that brings out another sign. This triadic model is, according to the late Peirce, not an infinite process. Peirce avoids the infinite progression giving „the ultimate logic interpretant the status of a habit or, when the occasion made it necessary, the effect of a change of habit produced by any intelligent mind – not necessarily human" [4] An introduction to Peirce's "way of thinking", his method and the derivative of a process driven communication model will show how social media platforms as genuine communication tools form symbols that can be used to achieve the supposed objectives.

Known as the founder of pragmatism (around 1878), Peirce moved away from his own theory of pragmatism nearly thirty years later in 1905, and renamed it pragmaticism: "Pragmaticism, then, is a theory of logical analysis, or true definition; and its merits are greatest in its application to the highest metaphysical conceptions." [5] Pragmaticism in the Peircean meaning moves away from the ontological question that asks what is existent in a first category, using the term critical common-sense [6]. For Peirce, inference in the scientific inquiry cannot be made without a basic knowledge of the world called (critical) common-sense. Common-sense is indispensable for the scientist assuming a set of inferences that cannot be doubted: "[…] The test of doubt and belief is conduct. No sane man doubts that fire would burn his fingers; for if he did he would put his hand in the flame, in order to satisfy his doubt. There are some beliefs, almost all of which relate to the ordinary conduct of life, such as that ordinary fire burns the flesh, [which] while pretty vague, are beyond the reach of any man's doubt." [6] The term "critical" implies furthermore something crucial for (scientific) inquiry, namely that still any proposition can be object of doubt or can be criticized. This is Peirce postulate on science, called fallibilism. The scientist should doubt any, also later proposed inferences, views or beliefs, until they are proven.

Peirce's theory of signs, called "semeiotic" in his own term, is not meant to be a metaphysical explanation of the world, a philosophy in the traditional meaning [7] nor a solely linguistic method. Although the names and concepts are completely abstract, they are meant to be used on any category of life: "[…] all this universe is perfused with signs, if it is not composed exclusively of signs" [8]. Thus semeiotic is a method used e.g. in medicine, chemistry or jurisprudence. Peirce wanted to overcome the dyadic induction - deduction process of natural science with its strict method and terminology, as the only possible scientific method of inference. He introduced a third form of inference, called abduction. This is regarded as the only logical possibility to develop new ideas by forming an explanatory hypothesis [8]. The abductive rule will be deductively proven and inductively falsified [9] and is considered by Peirce as the only creative method of inference.

Using sign theory means therefore concentrating on processes in a sign-sphere which is called semiosphere [10]; the logic of the sign process forms patterns that allow an usage on any other sign formations, in any other sphere. We will take this approach here for the graphical user interface of a building management system, whose design metaphor follows the logic of social media platforms.

A brief introduction of the sign and a presentation of the three sign classes explain our different take on communication, expanding the dyadic model of input-output, used in communication technology, e.g. Shannon & Weaver's model [11], into the triadic form with an interpretative process. It is from utter importance to distinguish these sign classes, as they show why sign theory is an actual communication theory.

The notation of sign, as Peirce states, is that of a threefold medium with an integrated quality. A sign consists of the representamen, "something which stands to somebody for something in some respect or capacity" [9], of its object, which can be a real-life thing or an idea, and its interpretant, the sign which it creates in the third state. An interpretant does not have to be a person or a mind, but a state where the process of interpretation and sign re-creation occurs. Peirce notion of a "quasi-mind" [5] allows the interpretation and usage of this triadic concept from a calculating machine to a group of humans.

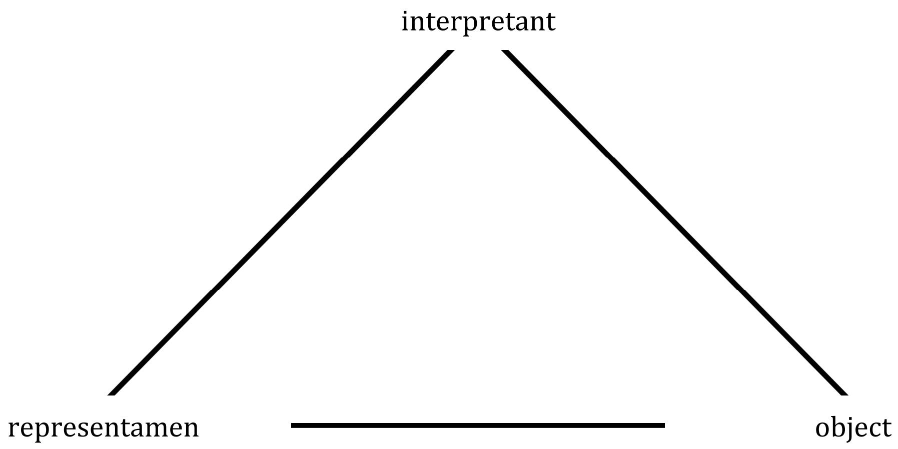

Figure 1: Sign

The existence of a sign is mediated through another sign, e.g. a word through an utterance, and it creates another sign: The same one respectively a lookalike (an iconic sign), an indicative one (an indexical sign) or a sign qua convention, a symbol.

One can be interested in a sign in three different ways, namely on the thing itself, on something the sign is indicating or on an association with the sign, a representation (of something) which calls up an association or an "idea" [12]. The first sign class, icon, is a sign that looks like the represented object, like a diagram in geometry or a portrait [13]. It is a sign that one can directly perceive. The second sign class contains signs that indicate something: an index would be smoke that indicates fire. Symptoms like raised temperature and shivering are indexes for a severe illness. For the third class, the symbolic sign, the relation between its object and representamen is due to a convention. A symbol enables us to "create abstractions" [14, 15];, it exists because it is interpreted in a certain way. The symbol for heart does not look like a heart itself nor does it denote a certain heart, but any heart. Any sign is already a symbol, because we use the concept of language to denote it. Mathematics is a science that is based on symbols.

A symbol contains all sign classes in it, what can be shown on a pictogram of an emergency sign.

Figure 2: Emergency sign

As an icon, it denotes a simplified picture of a human being that runs in the direction of the pointing arrow. The pictogram itself indicates a certain situation, an escape. The emergency sign itself can be only interpreted as a symbol, for which the person that looks at it only knows the interpretation. Without having seen a sign like this before, or without knowing that green as a colour has a positive connotation in our culture, a correct interpretation would not be possible [16].

Supposing communication is a triadic concept mediated through signs in a semiosphere, communication proceeds as following: The iconic sign is also the object, the indicating sign is a representamen and the symbolic sign is the interpretant. Thus communication implies continuous processes that are developed through symbolic signs. Defining communication as an action using and by itself building symbols means we can already take functioning symbols and their patterns and apply them to different semiospheres.

This paper will not examine social media as a communication medium in the sociologic way. The discussion about reasons of usage or impact on people, society or technology shall here be left disregarded, although this is an important part of the discussion. With blogs starting to get common around 1999 [16], the usage of social media platforms like Facebook and Twitter has pervaded everyday life since the spreading of smartphones with mobile Internet access [17]. The most important social media platforms are blogs, Facebook and Twitter. A blog is run by one or more authors who generate content that can be commented by the reader. Blogs became popular for many reasons, like the blog software Wordpress and webhosts like Google's Blogger, which are non-expert systems that do not need programming skills. They also became popular because they enabled people to speedily publish and receive a feedback from their readers [16]. Facebook is a platform that allows the user to connect with friends respectively other users, share activities and e.g. pictures. Facebook's "like" button grew up to the symbol of social media. It gives an instant positive feedback to the posted content. Twitter unites the key functions of blogs and Facebook-like content generation (in 140 signs), feedback in the function "reply to", connection and sharing with other users via the timeline and the positive feedback, the "favourite" button.

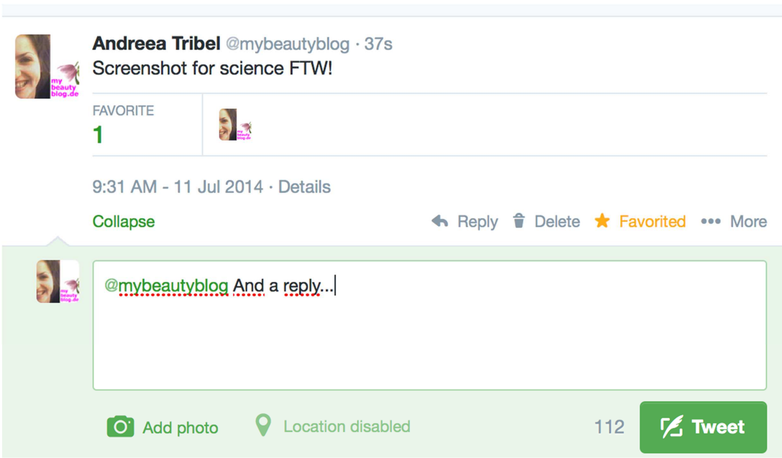

Figure 3: Screenshot of an initial tweet, a reply and a favourite tweet

An overlapping logic or structure, respectively, determines the special semiosphere of social media: the possibility of feedback, interaction with several people and immediate, positive acknowledgement of the utterance (Like and Favourite buttons). Further the usage of the platforms creates symbols, thus signs qua convention, for communication mediated exclusively through computing devices - just like Facebook's thumb and the claim "Like!". These symbols are encoded twice because of their usage in online as well as communication processes solely. It can therefore be supposed that these symbols will be used correctly in a manner that is common for the user, as in any computer mediated communication process, e.g. in a building management GUI (Graphical User Interface).

Introducing the term of sustainable ambient computing SAC, ambient intelligence plus ubiquitous computing, means to bridge the gap from computing as an engineering approach with ubiquitous systems that solve real-world problems [18] to a conception of information and communication systems that are ecological from the perspective of life cycle assessment, user-friendly and have a supportive effect on decision making as well on cultural habitual change. In this research field building management systems can be considered as environmental technology at the intercept between industry and everyday life. Tools and systems in this field are made for different user groups, i.e. experts, engineers and non-experts or everyday users of the building. The latter group shall be enabled to partly take control of the system themselves, so the human-computer interaction becomes a stronger focus in BMS research and development.

A main goal of generating a successful interaction between the BMS and the user is saving a maximum of energy by avoiding rebound effects. Rebound effects are lowered energy savings (due to technical efficiency) by increased usage, often because of less costs or a “greener” feeling [19]. A high degree of automation in the BMS can lead to inefficiencies due to rebound effects in two ways. First, the “efficiency improvements ([...] energy) made possible through technological improvements are counteracted by increasing demand […]” [20]. Second, if users can`t influence the energy demand, e.g. the heating, in a way that fits their requirements, they will find other ways to achieve a better surrounding. This lack of participation could cause a difference up to 70% between the planned and the real energy usage of a building [21]. A difference like this can, for example, be a result of simultaneous opened windows and activated heater. Thus the impact of uncontrolled usage underlines the importance of manipulation possibilities and a resulting satisfying communication between the users and the BMS from both perspectives.

Regarding SAC as a semiosphere allows usage of the triadic conception of signs and their classes on different levels. There are sign processes concerning hardware and machine language, which are related to the engineering part. Another sign process is the communication between the system and the user group, allowing decision making and eventually changing behaviour. Deconstructing the semeiosis (sign processes), these can be regarded the following way: The hardware as a concrete object and technical medium, the software and sampled data as an instrument thus representamen, and the usage or interaction with a user or user-group as interpretant. In the special contextual situation of BMS we gain a sustainable usage in matters of energy consumption qua the hardware and engineering part. Further a successful usage of the interface between system and user is essential, which should result in creating new “symbols”. That is the status of the interpretant, which is not only a habit, but also the effect of a habitual change. This means a successful interaction with the user would minimize the system’s infrastructure, generating a sensibility for energy efficiency, and resulting in more energy efficient behaviour. Supposing BMS data is already processed and filtered thus simplified for the user, the GUI will be convenient to handle if we are using a certain set of symbols that are derived from the usage of social media platforms. Therefore we essentially suggest using common signs already known for communication purposes in a communication context, as we explained before.

The conceptual metaphor for the GUI [22] includes double coded symbols we know from social media usage. We can find them similarly in all proposed three main platforms. First comes the possibility to generate content. This is proposed without any quality nor interpretation. Because the building management system generates the first content, we must regard this in the sense of common-sense as a set of inference or data that already exists. The user should have the possibility to generate “own” content, so not only participating to but initiating (sic!) the communication process with the system. She could choose the components of the information like temperature and humidity to correlate to the felt temperature. Second, different forms of feedback have to be possible. Comments and spreading information could be regarded as indexical signs in the process. The single user might be regarded as peer to a group where, however, information is shared or commented. The possible feedback to the system should further include the possibility to manipulate it to a certain extent, even up to the submission of a first data set initiating the communication process. The communication process continues while setting the object, such as the data, into a context. Here we postulate the interpretant in a way that the symbol that comes out qua convention is able to put its object (the subjective “feel like” in the building) in a solely positive context. This happens in social media activity with the “like” button or the “favourite” star. What differentiates the mentioned symbols from a symbol even more widely known, e.g. a traffic light? For the latter, the convention respectively the interpretant arises not from the user itself, but it is imposed by an invisible authority. The user knows that traffic lights command and forbid certain actions on crossroads based on a societal convention, and also an everyday situation that can be connected to negative notions like prohibits or being late. The positive connotation that involves social media activity becomes apparent in the virtue of the “like” button or thumb symbol, because these terms are used in colloquial language.

We used the method of semeiosis to analyse the social media as a sphere of signs, a semiosphere, and determined three utter important communication patterns. We propose using these symbols, understood as habit changing possibilities, in a case of building management systems. The logic of the elaborated, practical communication process should be able to develop a successful communication between users and the BMS.

The prospect of this analysis follows Peirce’ understanding of science. After having deduced what the requirements for the graphical user interface of the BMS are, a first GUI will be designed as part of an interdisciplinary project. It will be implemented and tested in a new energy efficient building at Leuphana University by an interdisciplinary project team.

We will keep the interdisciplinary perspective and theoretical foundation based on Peirce’s theory and, at the same time, take into account the technical requirements (i.e. the resolution of the sensor system, the monitoring concept and the design of the BMS) and knowledge to create a set of requirements for the design of the GUI. Finally all parts together build the holistic SAC system, however a centralised database will still be needed, as well as data mining, filtering and comparing algorithms to generate content for the user – the informatics part of the concept.

References

[1] Lewis, Simon C. R., Energy in the Smart Home. In: R. Harper. *The Connected Home: The Future of Domestic Life.* London: Springer, 2011, pp. 281-300.

[2] Vlek, Charles, Steg, Linda. Human Behavior and Environmental Sustainability:Problems, Driving Forces, and Research Topics. *Journal of Social Issues 63 (1).* pp. 1–19, 2007.

[3] Sarbo, Janos J. et al., *Knowledge in Formation. A Computational Theory of Interpretation.* Berlin Heidelberg, Germany: Springer, 2011.

[4] Romanini, Vinicius. (2014, July 10). *Scattered Fragments.* [Online] Available: http://www.minutesemeiotic.org/?p=38

[5] Robin, Richard S., *Annotated Catalogue of the Papers of Charles S. Peirce.* Amherst/Mass.: University of Massachusetts Press 1967, CP 6.490; MS [R] 793:1

[6] Peirce, C. S., *The Essential Peirce: Selected Philosophical Writings. Volume VI.* Bloomington: Indiana University Press, 1998, EP 2:432-433

[7] Ketner, Kenneth Laine, *A Thief of Peirce: The Letters of Kenneth Laine Ketner and Walker Percy.* Jackson: University Press of Mississippi, 1995, pp. 234-238.

[8] Peirce, C. S., *Collected Papers of Charles Sanders Peirce. Volumes V and VI: Pragmatism and Pragmaticism and Scientific Metaphysics.* Cambridge, MA: Belknap Press of Harvard Univ. Press, 1979, CP 5.448 FN; CP 5. 171

[9] Peirce, C. S., *Collected Papers of Charles Sanders Peirce. Volume I and II: Principles of Philosophy and Elements of Logic.* Cambridge, MA: Belknap Press of Harvard Univ. Press, 1978. CP. 2.270; CP 2.776; CP 2.228; EP 2:460-461.

[10] Lotman, Yuri Michailowitsch, Universe of the Mind. *A semiotic theory of Culture.* Bloomington: Indiana University Press, 1990.

[11] Shannon, Claude E; Weaver, Warren, *The mathematical theory of communication.* Urbana, Illinois: University of Illinois Press, 1949.

[12] Peirce, C. S., *The Writings of Charles S. Peirce: A Chronological Edition. Volumes 1–6.* Bloomington: Indiana University Press, 1982, W 1:257-258

[13] Freadman, Anne. (2014, July 10). *The Classifications of Signs (I): 1867 – 1885.* [Online] Available: http://www.digitalpeirce.fee.unicamp.br/p-186fre.htm

[14] Peirce, C. S., *The Essential Peirce: Selected Philosophical Writings. Volume II.* Bloomington: Indiana University Press, 1998.

[15] Peirce, C. S., *Collected Papers of Charles Sanders Peirce. Volume IV.* Cambridge, MA: Belknap Press of Harvard Univ. Press, 1979.. CP 4.531

[16] Tribel, Andreea, *Technik, Medium, Kommunikation. Zur semeiotischen Struktur des Blogs.* Saarbrücken, Germany: VDM,2010. (in German)

[17] BITKOM. (2014, July 10). *Soziale Netzwerke. Eine repräsentative Untersuchung zur Nutzung sozialer Netzwerke im Internet.* [Online] Available: http://www.bitkom.org/files/documents/Soziale-Netzwerke.pdf (in German)

[18] Josephson, John R., Josephson, Susan G. *Abductive Inference. Computation, philosophy, technology.* Cambridge: Cambridge University Press, 1994.

[19] Berkhout, Peter H. G. et al., “Defining the rebound effect”, *Energy Policy,* vol. 28(6-7), pp. 425-432, June 2000.

[20] Erdmann, Lorenz et al. “The future impact of ICTs on environmental sustainability.” IPTS, Sevilla, Sci. Rep., Nov. 2004.

[21] Fisch, Norbert, Plesser, Stefan. (2014, July 10). *EVA – Evaluierung von Energiekonzepten für Bürogebäude.* [Online] Available: https://www.tu-braunschweig.de/Medien-DB/igs/Projektarchiv/abschlussbericht_eva.pdf (in German)

[22] Zuellighoven, Heinz, *Das objektorientierte Konstruktionshandbuch nach dem Werkzeug-Material-Ansatz.* Heidelberg, Germany: D.punkt Verlag, 1998. (in German)