Towards an Ambient Awareness Interface for Home Battery Storage System

Eiman Y. Elbanhawy
The Open University
Milton Keynes, UK
eiman.elbanhawy@open.ac.uk

Andrew F. G. Smith
The Open University
Milton Keynes, UK
Andrew.F.G.Smith@open.ac.uk

John Moore
The Open University
Milton Keynes, UK
John.moore@open.ac.uk

Ubicomp/ISWC'16 Adjunct Proceedings, September 12-16, 2016, Heidelberg, Germany
ACM 978-1-4503-4462-3/16/09
DOI: http://dx.doi.org/10.1145/2968219.2968557

Abstract
Roof-mounted photovoltaic (PV) generation is becoming more prevalent within the domestic setting. Recently battery systems have enabled households to store excess self-generated electricity for subsequent use. However the associated user-interfaces and displays can be hard to understand, potentially preventing households from optimizing their solar usage. This paper introduces a known method being deployed in a new context. It reports on on-going research that investigates the effect of in-home ambient light displays linked to the home battery system. The paper covers the design stage and potential feedback solutions to raise awareness and influence consumer behaviour to promote energy conservation. An Ambient Light System is proposed to enable better user feedback. The study outlines the design recommendation for an ambient light display to be used in an energy consumption context. Using such a display, households can optimize use of low Carbon solar energy within the home, thus minimizing grid electricity usage.

Author Keywords Ambient display; Solar energy storage; Calm technology, Behaviour change.

ACM Classification Keywords H.5.2 [User Interfaces]: Information and presentation

Home Solar System

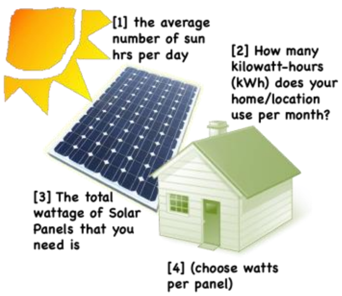

Figure 1:A diagram shows a house with a solar panel and the four steps needed to calculate the amount of kWh will be generated.

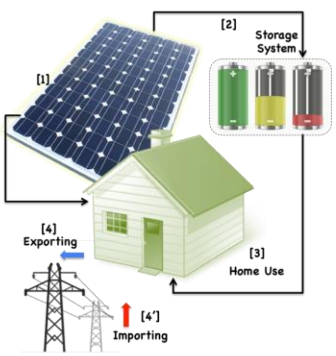

Figure 2:A diagram shows a house with a solar system (PV and Battery storage system) and the two possible cases (importing/ exporting to the grid)

Introduction

Technology for both generating *and* storing self-generated energy for domestic use is becoming increasingly prevalent. Most people lack awareness of how their daily behaviour impacts excessive energy use. The technology to increase awareness is called eco-feedback and traces its origins to environmental psychology. It is implemented to support self-awareness regarding energy consumption [6]. In return, the end-user needs appropriate guidelines in order to determine their energy consumption. In order to support increased awareness, people need to learn about the energy they are using and their associated carbon footprint so they may gain control over their own behaviour and resources[7]. By automatically sensing these activities, technology can bridge the gap through a sustainable HCI lens. Ambient displays (AD)s [6], engaging objects, and visualisation tools have been used in different domains [8].

Battery Storage System

Battery storage for domestically generated photovoltaic (PV) electricity is a growing technology, and likely to significantly alter the way in which domestic-scale renewable energy integrates with grid, see Fig. 1. With recent reductions in battery systems costs, the number of home battery systems is increasing. Battery systems allow people to store PV electricity for subsequent use, and be much less dependent on the grid electrical supply, see Fig. 2. To the householder wishing to minimize their usage of grid electricity, there are many variables to consider. These include being conscious of:

1) the maximum power that the battery can receive (2.5kW in this trial), beyond which the system will export excess PV power to the grid;
2) the maximum output power of the batteries, beyond which will entail import from the grid.

A further complication is that the system will supplement its battery output with whatever PV power is being generated at a given instant. At night, the PV power will of course be zero, however during the day this will vary according to solar intensity. This latter factor varies considerably with weather and seasonal changes. For the systems used in this trial, the current interface used to convey the information is a screen-based graphing system, available through internet-connected devices, Fig. 5.

Research Aim

This study proposes condensing the pertinent elements of the data into a more easily understood system namely an AD. This would enable the householder to make more effective use of their direct solar electricity and their stored energy.

Related Work

In energy consumption related matters, many studies were carried out to make the people conscious about the implications of wasteful behaviour, using a number of techniques [2]. Some of them relied on large-scale information campaigns pointing out financial advantages [12]. Others focused on the efficiency improvements and controlling the behaviour via persuasive techniques (e.g. having a reminder next to the object/ place being used) [10]. As in some studies, simple visualization of daily usage may need specific recommendations about efficiency to complement it (e.g. quantifying the amount of money that could be saved by installing a low-flow showerhead) [6], Togler et al. 2009 presented an ambient interface for water

Ambient Intelligence (AI)

It is a vision of environments in which electronics are sensitive to people’s needs, personalized to their requirements, anticipatory of their behaviour and responsive to their presence [4], see Fig. 3

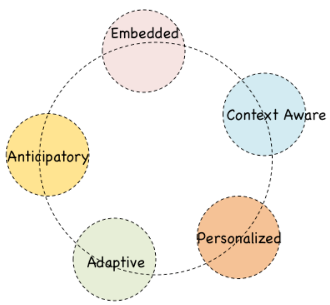

Figure 3: AI Technology Features [4]

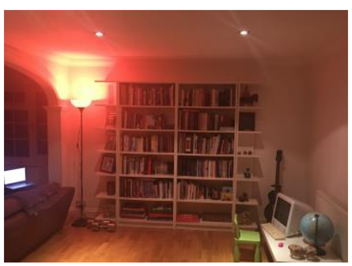

Figure 4: Ambient display: It is an example of an ambient light display in the living room with a red colour as the battery is empty.

consumption to increase awareness [13].Other approaches were to deploy the technology (Intermediary role) by restricting the use (e.g. restricting fixtures, automatic control with no user control over the resource). Feedback was also achieved by creating a psychological sense of the importance of behaviour change such as by applying a persuasive energy monitoring technology (e.g. displaying consumption on a dashboard). Ethnographic studies can help in providing full insights and reporting the level of engagement and interrogating the reflective learning approaches [10].

Ambient Display (AD)

The initial idea of ADs and calm technology was introduced by Weiser and Brown [14]. It is designed to provide feedback to the users in the periphery of their attention. Ambient displays rely on pre-attentive processing of information as these displays do not show text or numbers, but simply alert the householder to the fact that something relevant to their electricity supply has changed or is about to do so [9].

Ambient Light System (ALS)

The process of designing an ALS is complex and challenging due to the various conditions and factors affect the periphery. For a specific objective, a single display may not be applicable to all surroundings [11]. The AD has been used in the context of energy consumption as a way to raise awareness, such as by communicating the current consumption to inhabitant to bring attention to excessive use. An ambient light display was designed by Muller et al., 2012 [11] to reflect the household energy consumption using colours and pulses. The visualisation designs were developed and tested, but brightness was difficult to deploy as it depends on the surrounding, and pulses may annoy the users. Changing colour shades seemed to be the most reasonable visualisation technique. ALS is defined by Matviienko, 2015 as: “A system positioned in the periphery of a person's attention that conveys information using light encodings in a non-distracting way most of the time” [9].

Method

The ongoing research is case-study based with the aim of designing and experimenting with a prototype that provides stored solar energy feedback for households, see Fig. 4. The study is to run for a total of six months and it has four main stages: 1) design stage (brainstorming), 2) pre-trial interviews, 3) trial, and 4) post-trial interviews. The pre-trial interview feeds into the design phase as both phases are run in parallel. This paper is presents the design phase and sheds light on the pre-trial interviews. The recruitment process of participants has two main requirements: 1) a household with a solar panels (mandatory but capacity is irrelevant) and 2) energy storage system (mandatory with no minimum time of installation). The participants were named anonymously (PVH1, PVH2…etc.) where the interview is taking place with all the household.

The Importance of the Research

The need of having improved design solutions for feedback stems from the difficulties the users found dealing with the existing system. The lack of awareness and ambiguity of the battery storage system may lead to inefficient utilisation of resources. Whilst the information on the graphs (battery is provided by Solax Power Europe Ltd., see Fig. 6.) may be intelligible to an engineer, to the bulk of the population, these displays are confusing and very hard to understand, see Fig. 5.

Solax System Software

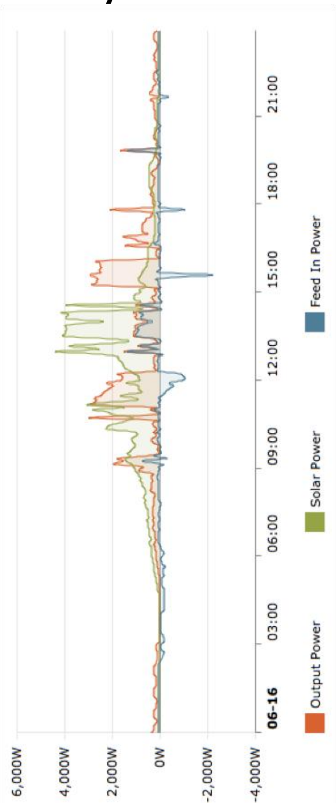

Figure 5: Existing complex UI

Figure 6: Solax trademark

Technology Affordance

As Norman (1988) [12] simplified its meaning as "to give a clue". Affordance as a term has been used in the interaction design and is being used to describe how interfaces should make it obvious as to what can be done using them. The UI, is conceptualised as a perceived affordance, it is a screen-based interface, which is different than real affordance of physical objects. Applying this in the e-home energy context, carrying out user studies and analysing real information, provides insights into the energy-related behaviour and the use and usability of battery storage system (PV and battery, connection to the grid).

System in Detail: Battery Storage Installation

While PV installations have proliferated in recent years, if a householder is not at home during most of the daylight hours, much of the electricity generated by the home is exported, rather than used within the home for domestic benefit. Battery systems are now emerging as an affordable option for storing PV for subsequent use. Once installed, the battery systems can also be effective at buffering the short-term intermittency of PV generation. Thus when passing clouds reduce PV generation, the operation of appliances can still occur on stored PV rather than having to draw on grid electricity during the cloudy period. The existing display of the battery storage, PV generation and household demands are hard to understand. They typically update on a relatively low frequency (~ every 5 min for Solax). Higher frequency updates in power import / export are required if the AD system is to provide timely information to the householder. High frequency feedback will arguably assist the householder in identifying which items within the house are causing the most significant loads. For example, they would be able to rapidly see the impact of say switching on an electric oven, and whether this is causing a draw from the mains electricity. Equally the householder can be informed in close to real-time on whether the charge controller is exporting to the grid. Timely knowledge of this will allow decisions to be taken that could lead to this energy being used with the home, rather than exported. An example could be the running of an appliance or the plugging in of an electric vehicle. High frequency feedback is achieved in our work by the integration of Current-Transformer (CT) systems on the domestic mains electricity supply than can provide a readings every 12 seconds.

Method I: The Design Stage

In this study we are developing an adaptive AD which provides help for homeowners to better understand their energy data.

System Architecture

The typical operation of the system is shown in Fig. 7. Central to the systems operation is the Charge Controller. This receives input from PV and directs electricity to where it is most needed. The priority will be to satisfy domestic demands, and any excess will be stored within the home battery (any excess electricity beyond this is exported to the grid). Equally any demands that can't be satisfied by the battery + PV generation, will be imported from the grid.

Level A: Battery level (Colour as a metaphor)

The colour is deployed in our study as a metaphor to reflect the state of the stored energy. The colour spectrum has designed to denote the solar energy, warm colours representing the solar energy stored in the battery. The spectrum starts with a dark red when

System Architecture

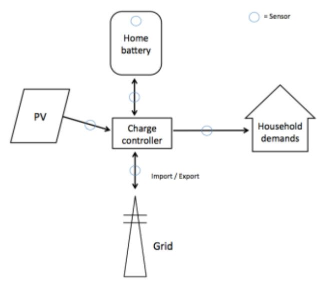

Figure 7: System architecture

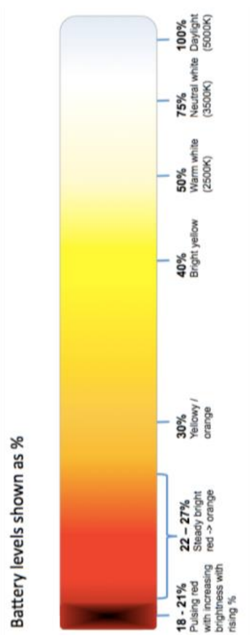

Figure 8: Colour scheme

the battery is almost flat (up until it is 21%). The colour keeps changing until it is very bright yellow reflecting the maximum capacity that can be stored in the battery (Full battery), see Fig. 8.

Level B: Degree of grid Import/ export level

At very low battery levels, the system's capacity for buffering household electrical loads is at its minimum. If the resident is able to allow the stored energy to build up to a higher level (via PV input), then the house will be less likely to have to draw power from the mains. The system used in this study has a minimum battery level of 18%. As such, we propose using a pulsing system to attract attention when batteries are very low at between 18 and 21% charged, see Fig. 9. Appliances powered up during this period would most likely have to draw from the grid. However if the batteries are allowed to charge until above 21% (ie: when the pulsing stops), the degree of buffering will be improved, and the home will improve it's PV utilization.

Method II: The Pre Trial Stage

As a part of the methodology, pre-trial interviews were conducted with early recruited participants (with a link to the design phase for participatory design approach). The interviews were conducted at the participant's house, see Fig 11, semi structured; questions are mainly about the purchase of the PV and the battery system, the behaviour change (before and after the battery storage system), the motivation behind having home solar system. The whole household is interviewed, so we can depict both adults' opinions and perceptions

> *"We have double the capacity of PVs. We got the 1st roof covered in 2011 (3.3 kW), the 2nd in 2013 (4.3 kW) and in 2016 the battery" [PVH1, Male, 51]*

> *"I knew about the possibility to have a battery storage system. I started to use my kettle more economically" [PVH1, Female, 52]*

The participants were asked about the current UI of the battery system and how easy it is for them and we introduced some AD ideas to get feedback, see Fig. 10.

> *" We are so aware of the energy we are generating; however, it is not easy to get information needed". [PVH2, Female, 39]*

> *"After the battery being installed…I became aware of what the battery delivers… how if you cannot have several heavy appliances to keep yourself off the grid". [PVH2, Male, 42]*

Method III: Trial

The AD (using a LIFX Color 1000 IoT light bulb) will be located somewhere in the house, see Fig. 4. It is up to the participant to choose the preferred location and light shade. The trial will be running for eight consecutive weeks with an ad-hoc call interviews with the participants to observation and better understanding of their behaviour.

Reflection and Design Requirements

This paper reported on an on-going research project, which naturally leads into designing an ALS to give eco-feedback of home battery storage systems. The key design requirements are:

1) Colour Parameters: potentially, colour is an effective way to reflect the use of green home energy. Based on the literature review and interviewing participants, there is a common agreement that a changing light may better

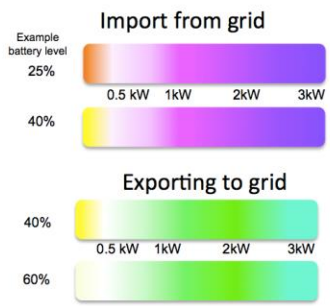

Figure 9: level 2 visualisation

Figure 10: personalised choices

Figure 11: Battery storage unit

communicate the information needed with regard to the battery storage system.

2) The two levels of communication: the ALS can convey both the state of the battery as well as the state of the house's interaction with the grid (importing/ exporting).
3) Personalised and embedded (AD intelligence): The display has be both ambient and efficient in conveying key information. Ideally it should also be personalised (via participatory design) and embedded within the home to be most accepted.

Conclusion and Future Work

Conveying a lot of information in a complex system is difficult. Our proposed system will turn the complex graphs into a simple and easier to understand interface for householders. We propose an AD approach to make it easier for people to understand how much of their PV generation and battery storage is available on a day-to-day basis, and thus make better-informed decisions. The paper proposes an approach for eco feedback; it presents the design process of a simple AD to reflect the state of the solar energy being stored in home battery system. The next step is to conduct the study by installing the AD in participant homes: 1) Measuring the changes that we noticed in terms of energy use (minimizing grid use, utilizing export (potential export) in the home), 2) Behaviour, and 3) End user feedback.

References

[1] Aarts, E. and Marzano, S. *The New Everyday: Views on Ambient Intelligence.* 2003.

[2] Bonanni, L., E., A., Chia-Shun Lee, J., and Selker, T. Waterbot:Exploring Feedback and Persuasive Technology at the Sink. *Interactions*, (2005), 25–28.

[3] Bourgeous, J., Foell, S., ElBanhawy, E., Price, B., and Van der Londend, Janet, Kortuem, G. Harvesting green miles from my roof: an investigation into self-sufficient mobility with electric vehicles. *UbiComp 2015*, (2015).

[4] Brey, P. Freedon and Privacy in Ambient Intelligence. *Ethcis and information Technology 7*, (2005), 157–166.

[5] Costanzo, M., Archer, D., Aronson, E., and Pettigrew, T. Energy conservation behavior: The difficult path from information to action. *American Psychologist 41*, (1986), 521–528.

[6] Froehlich, J., Findlater, L., and Landay, J. The Design of Eco-Feedback Technology. *CHI 2010*, (2010).

[7] Gustafsson, A. and Gyllensward, M. The Power-Aware Cord: Energy Awareness through Ambeint Information Display. *CHI*, (2005), 1423–1426.

[8] Holmes, T. Eco-Visualisation: Combining Art and Technology to Reduce Energy Consumption. *ACM Creativity and Cognition*, (2007), 153–162.

[9] Matviienko, A., Rauschenberger, M., Cobus, V., et al. Towards New Ambient Light Systems: a Close Look at Existing Encodings of Ambient Light Systems. *Interaction Design and Architecture*, (2015), 10–24.

[10] Midden, C.J., Meter, J.E., Weenig, M.H., and Zieverink, H.J. Using feedback, reinforcement and information to reduce energy consumption. *Economic Psychology 3*, (1983), 65–86.

[11] Muller, H., Fortmann, J., Pielot, M., et al. AmbiX: Designing Ambient Light Information Displays. *Designing Interactive Lighting at DIS, ACM*, (2012).

[12] Norman, D. *The Design of Everyday Things.* Basic Books, New York, US, 1988.

[13] Togler, J., Hemmert, F., and Wettach, R. Living Interfaces. *TEL*, (2009), 43–44.

[14] Weister, M. and Brown, S. The Coming Age of Calm Technology. In *Bits flowing through the wires of a computer are invisible*. 1996.