DEFINING CONTEXT FOR HOME ELECTRICITY FEEDBACK SYSTEMS

Fatima Abdallah[1], Ali Abdallah[1], and Shadi Basurra[2]
[1]Faculty of Computing, Engineering and the Built Environment, Birmingham City University, Birmingham, UK
[2]Faculty of Arts, Design and the Media, Birmingham City University, Birmingham, UK
Email: fatima.abdallah@bcu.ac.uk, ali.abdallah@bcu.ac.uk, shadi.basurra@bcu.ac.uk

ABSTRACT

Existing electricity feedback systems provide home occupants with real-time consumption data to enable them to control their consumption. However, these systems provide abstract consumption data that is not related to the occupants surrounding. Although there are some attempts to enrich consumption data with some context information, the presented feedback is not enough to inform decisions of how to conserve electricity. Therefore, this paper provides a rich definition of electricity consumption context, which can be used to provide sensible feedback to users. The obtained context elements can be categorized into three context types: User Context, Appliances Context, and Environment Context. Finally, different implications for the application of a context-aware feedback system are presented showing how the obtained context definition could be used to provide understandable feedback.

INTRODUCTION

Greenhouse gas emissions caused by global energy use and supply will increase by 25-90% in 2030 compared to year 2000 (Barker et al., 2007). This high amount of emissions is having environmental effects such as climate change, air pollution and a scarcity of energy resources (Neustaedter et al., 2013). In response to this dangerous climate change, the European Commission adopted the energy efficiency action plan which is enacted by improving energy end-use efficiency (European Commission, 2011). In the same report, the European Commission stated that buildings account for nearly 40% of the total energy consumption in the EU, and recommended that consumers will have to play a major role in applying energy efficiency.

Besides using energy efficient devices and enhancing building design, end-use energy efficiency can be applied through controlling energy consumption by consumers (Boshell & Veloza, 2008) thus contributing to the zero carbon buildings target. For this purpose, several Electricity Consumption Feedback (ECF) systems were proposed to make home occupants aware of their usage, which will assist them to take control actions. However, these systems either provide abstract consumption data which does not allow full understanding of consumption (Karjalainen, 2011), or relate consumption data with one or two context information (Costanza et al., 2012) which is not enough to inform users' decisions of how to conserve electricity. In this paper, context is defined as the information that is relevant to characterize the surrounding situation, and is used to interpret consumption data. The context information is used by context-aware ECF systems to enable the consumer to relate his electricity usage with the surrounding (Castelli et al., 2014), and may provide the appropriate control recommendations.

This paper attempts to provide a richer definition of electricity consumption context through a literature review survey that identifies the context factors that affect electricity consumption. These context factors are obtained from several domains of research studying domestic energy consumption for different purposes. The identified context factors are then used to specify the context information (which are the elements of the context definition) that is needed by a context-aware ECF system to provide understandable feedback and customized control recommendations, ultimately helping home occupants control their consumption in an effective way.

RELATED WORK

As energy consumption is untouchable and invisible (Fischer, 2008), households need tangible information about their consumption (Froehlich, 2009). This will enable users to be aware of their usage and take actions to control and ultimately reduce their consumption. For this purpose, several ECF systems have been proposed and studied quantitatively and qualitatively. Studies have shown that providing real-time feedback to users normally reduces 5-15% of the consumption (Darby, 2006) . For example, Yun (2009) investigated how a simple portable and stationary energy consumption display affects energy awareness and consumption, and resulted in an average of 11% reduction of consumption. In a similar approach, Hargreaves et al. (2010) qualitatively assessed the efficiency of commercial in-home display systems studying the motivation of earning display systems, way of usage, and behaviour change.

However, research has recently found that these systems are not able to inform users' decisions of how to control consumption. A major challenge has emerged about how to enable users to make informed decisions based on consumption feedback (Castelli et al., 2014). In his investigation into the best way to present electricity feedback to users, Karjalainen (2011) found that although people are motivated to conserve electricity, they are short of information that is needed to take the most appropriate action. Sterengers et al. (2011) also found that people are not able to understand the displayed data. Even when they understand it, they miss apply it by changing visible wasteful practices rather than changing resource intensive practices (Strengers, 2011). Similarly, users of a pilot feedback system, that was studied to know how people change their behaviour in response to electric consumption feedback, reported that they need more context to understand energy use and take actions (Erickson et al., 2013). Therefore, although currently presented feedback enables users to view their consumption, it is sometimes not understood and not enough to take control actions.

Context and Energy Feedback

In response to the lack of understandable information in ECF systems, a number of attempts have been proposed to provide more sensible feedback to users. Building their argument upon the conclusion that existing eco-feedback systems do not tie consumption information with occupants' everyday routine and activities, Neustaedter et al. (2013) interviewed people to study how they understand their energy consumption and relate it to their everyday activities. Based on the results, the authors assessed and recommended the usage of calendars to make sense of consumption data. In this way, calendars can be used as memory triggers of what activities people have undertook and how these activities affect energy consumption, especially that it was remarkably hard for people to remember events at a particular period. However, not all activities that consume energy are included in personal and family calendars (Neustaedter et al., 2013), therefore, there is a need to investigate more what other activities and information are needed to get a full understanding of consumption.

A similar conclusion was found in Costanza et al., (2012), who proposed and evaluated a system that allows home occupants to annotate and manipulate consumption data. The results showed that users labelled the consumption events with activities they were undertaking instead of just labelling it with the devices they were using. The annotation method has helped users make sense of their consumption, but still, consumption data could be supported with more context beside everyday activities because there are other factors that could affect consumption.

Location data was also used to make consumption feedback meaningful. With the aim of providing simpler information display, Castelli et al., (2014) proposed and evaluated the usage of room context (user location and presence) to make sense of consumption data. Room context was found to be useful. It has also shown that context information is needed to interpret consumption data and make a connection between the abstract usage of electricity and the surrounding environment.

In addition to room context, Bonino et al., (2012) disaggregated consumption data in a room level when attempting to evaluate goal setting and direct feedback interfaces. Room level disaggregation, which uses devices location context, allows users to identify the room that is mostly consuming energy and maybe discover the device or activity that is causing the room consumption.

Context information has also been used to achieve automatic energy efficiency and power management. For example, users' presence was used to control lighting consumption (Delaney et al., 2009). User location, devices usage, and face and voice detection were used for managing devices power consumption (Harris & Cahill, 2005, 2007).

Although these works show how to leverage context to make sense of consumption data (or sometimes implement energy efficiency), they only consider specific aspects of context. Therefore, this paper investigates other context information that can be added to consumption data to produce sensible consumption feedback.

CONTEXT OF ELECTRICITY CONSUMPTION

There is a need for a more comprehensive definition of context in order to make sense of electricity consumption. The previous section has shown that current context-aware ECF systems employ a small number of the available consumption context; however, it is important to consider all relevant context information to ensure a complete specification of context and proper adaptivity of the system (Benou & Vassilakis, 2010). Moreover, in order to use context effectively, context-aware application developers will need to spend a significant amount of time studying the situation where the application will be used, to develop a good understanding and definition of context (Dey & Abowd, 2000). Therefore, and through a literature review, the context factors that affect electricity consumption are explored, which will be used to extract the context information/elements that needs to be collected by a context-aware electricity feedback system.

The context factors collected in this paper comes from different kinds of studies including:

- Social research that studies electricity consumption at home.
- Human-computer interaction research that studies electricity feedback.
- ECF systems research that attempts to relate some context data with consumption data.

- Machine learning and scheduling algorithms that analyse consumption data.
- Economic statistical research that studies economic factors which affect consumption at national level.

Elements of the context definition

From the literature explained above, '*User Location*' (Castelli et al., 2014), '*Appliances Location*' (Bonino et al., 2012), and '*Everyday Activities*' (Costanza et al., 2012) can be considered as important context elements of the context definition for electricity consumption.

Many other research works have also mentioned everyday activities as a significant factor, which shows that it is one of the most influential context elements in the context definition. This is because people consume energy to carry out their everyday activities like showering and laundry (Strengers, 2011). Therefore, energy consumption is a by–product of doing different everyday activities (Froehlich, 2009). Based on the fact that everyday activities are meaningful and useful for people, Wilson et al. (2015) developed a methodology to infer everyday activities of home occupants from electricity consumption data as a first step to provide understandable and meaningful feedback. Furthermore, Neustaedter et al., (2013) found that cooking, showering, working at home, watching television, and doing laundry are activities that people noticed to be affecting their consumption.

Neustaedter et al. (2013) also described how peoples' activities vary between the different seasons. Some activities might be performed more or less in hot or cold seasons, such as showering more in hot seasons. Even holiday periods may influence consumption as it affects the devices being used and activities being done. Furthermore, travelling is one of the seasonal activities that also affects consumption because it changes the occupants' presence at home. These facts established in Neustaedter et al. (2013) enrich the context definition with '*Seasonal Activities*' (besides everyday activities), '*Existence of Occupants*', and '*Time of Year*' which can be used to determine the season and holiday period. Along these lines, Erickson et al. (2013) concluded that it was difficult for people to compare their current consumption with historical ones unless they were provided with occupancy data (because they have noticed that during travelling periods they consumed less electricity) and temperature data (to know whether savings were due to cooler weather or efficiency applications). This supports the inclusion of time of year, seasonal activities, and existence of occupants to the context definition, and adds environmental conditions as a further group of elements into the consumption context.

In addition, Beckel et al. (2014) were able to infer the household employment status, number of occupants, and appliances stock from consumption data with high accuracy. This was concluded when they were developing a machine-learning algorithm that reveals the socio-economic and dwelling characteristics of the household from electricity consumption patterns. This conclusion shows that '*Employment Status*', existence of occupants, and '*Appliances Ownership*' may be used to understand electricity consumption. Employment status is an important piece of information since it is a major factor that affects occupants' presence at home, and can also be used to anticipate users' presence and provide devices scheduling plans (Bassamzadeh et al., 2014). Moreover, Yun (2009) observed that energy consumption has increased for some participants, although they were using electricity display systems, because they had a new born baby and a temporary roommate, which supports the need for information about the existence of occupants at home.

Furthermore, environmental conditions are one of the critical factors that influence electricity consumption and can be divided into '*Internal Temperature*', '*External Temperature*', '*Weather Condition*', and '*Length of Day*'. According to Neustaedter et al. (2013), nearly all participants noticed a variation in consumption due to changes in external temperature, weather, and amount of daylight. In addition to these environmental elements, the time factor is a crucial information, which includes '*Time of Day*', and '*Time of Week*' besides 'time of year' mentioned before. The time of day information enables users to compare their consumption among the hours of the day to figure out their daily pattern of use. As well as the time of week context which shows the variation between the days of the week and could be related to the employment status if the user has regular work shifts (for example working four days a week out of home and two days from home).

Furthermore, changing '*Electricity Price*' has an influence of users' consumption. This conclusion was found in Cao et al. (2015) when developing a model of household energy consumption to get the socio-economic factors that affect consumption. Electricity price information can be used to detect how the consumption is distributed over the different energy tariffs and put plans to schedule heavy consumption devices in low prices periods.

Finally, '*Appliances Usage*' is a useful piece of information as it can be used to detect heavy consumption devices and background usage. It can also be used to detect activities going on in the house and most importantly standby consumption which is one of the major energy waste sources (Corucci et al., 2011).

Table 1 summarizes the context elements found in this review with the corresponding references where each element was obtained.

Table 1 Context elements with their references

Context Element	Reference 1	Reference 2	Reference 3	Reference 4	Reference 5
User Location	Castelli et al. 2014				
Everyday Activities	Froehlich, 2009	Strengers, 2011	Costanza et al., 2012	Neustaedter et al., 2013	Wilson et al., 2015
Appliances Location	Bonino et al., 2012				
Internal Temperature	Erickson et al., 2013				
External Temperature	Erickson et al., 2013	Neustaedter et al., 2013			
Time of Year (season and holiday period)	Erickson et al., 2013	Neustaedter et al., 2013			
Seasonal Activities	Erickson et al., 2013	Neustaedter et al., 2013			
Existence of Occupants	Erickson et al., 2013	Neustaedter et al., 2013	Bassamzadeha et al., 2014	Beckel et al., 2014	Yun, 2009
Weather Condition	Neustaedter et al., 2013				
Length of Day	Neustaedter et al., 2013				
Appliances Usage	Corucci et al, 2011				
Employment Status	Bassamzadeha et al., 2014	Beckel et al., 2014			
Electricity Price	Coa et al. 2015				
Appliances Ownership	Beckel et al., 2014				

DISCUSSION

Existing context-aware ECF systems take into account either user context (user location in Castelli et al. (2014) and user activities in Costanza et al. (2012)), or appliances context (appliances location in Bonino et al. (2012)). However, the presented review has shown that there are much more elements that can be used to provide more understanding of electricity consumption, such as users' existence at home and environmental factors among others.

The obtained context elements can be categorized into three groups: User Context, Appliances Context and Environment Context as shown in Figure 1. This categorization shows the entities that are involved in electricity consumption at the home, which are home occupants (whom are the users of the feedback system), electric devices present at home, and the surrounding environment. The consideration of these different entities in the context definition provides more sensibility to the abstract consumption data that is currently provided by existing feedback systems. This will enable the users of these systems to relate the consumption data with what is happening around them, thus providing more perception of consumption and informing users' decisions of what actions to take to reduce electricity consumption.

This context definition can be used in many ways depending on the service specification of the context-aware feedback system. Unlike typical feedback systems that display abstract consumption data (Hargreaves et al., 2010), an effective ECF system needs to display consumption data relating it to the collected context information. This will enable home occupants to make connections between their consumption and the different factors that affect it. The consumption data can be disaggregated in different dimensions (for example, devices consumption, location consumption, activities consumption, consumption based on temperature and weather, etc.) and users can then drill up and down in the data to interpret it. In this approach, simple and straightforward interfaces need to be created to make sure that the presented information are not complicated and can be used by non-expert users.

Alternatively, historical data can be automatically analysed by the ECF system, and instead of giving feedback on the amount of electricity the house is consuming, feedback can be given on how to avoid energy waste. By using the defined context

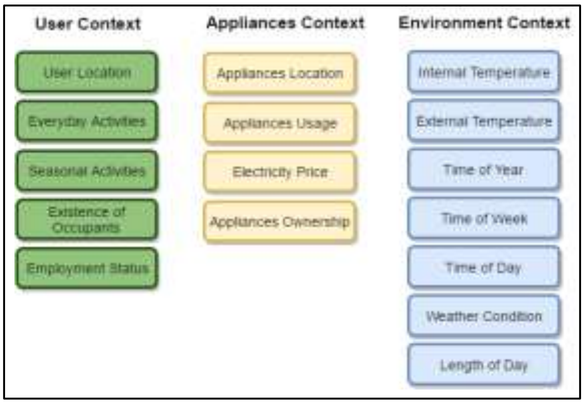

Figure 1: Elements and categories of the context definition

information, the system can specify if electricity is used when it is not needed, or suggest how to optimize the scheduling of appliances based on the situation of the house. For example, the feedback might be as follows: "*The television was left on standby mode in the children's room between 9pm and 7am while the kids were sleeping. You may save £1 a month if you turn it off before they sleep*", or "*The washing machine was turned ON from 8am to 9am yesterday while there was 5 occupants at home and the electricity price was high! You may turn ON the machine between 12pm and 2pm when everybody is out of home and the electricity price is low. This will save you £3 a month*". Compared to the abstract feedback provided by existing ECF systems, these forward control recommendations are more meaningful and actionable for home occupants. Therefore, it is obvious that these customized services that needs to be provided by an ECF system are not be possible without collecting information about the listed context elements.

Another entity that also affects electricity consumption is the house infrastructure (in case the house was heated by electricity instead of natural gas). This context entity can be studied to provide permanent retrofit solutions. Although the house infrastructure plays a major role in home energy consumption, this factor was not considered in this paper. This is because the purpose of an ECF system is to provide real-time feedback to users and change their behaviour of consumption, and since electricity consumption changes continuously, the context information needed to understand it and act on it in real-time are dynamic context information which are causing these changes. House infrastructure context is considered as an important but static factor that can be used to provide permanent energy efficiency advices.

CONCLUSION AND FUTURE WORK

This paper has defined the context that can be used to make sense of electricity consumption at home. The resulting context elements were categorized into three context types: User Context, Appliances Context, and Environment Context. It is not assumed that this list and categorization of context is comprehensive, but provides a rich list of the context that is useful for making energy-related control action. The obtained context definition will provide rich and understandable electricity feedback to users thus enabling them to control their consumption, which will surely contribute to the world's goal of cutting carbon emissions and reserving energy resources.

The obtained list can be extended through a scenario analysis method based on the specification of the services to be provided by the feedback system. In the scenario analysis method, different scenarios of the system usage are generated and the information requirements for each scenario are identified (Benou & Vassilakis, 2010). Furthermore, context modelling methods can be used to ensure that the obtained definition is rich enough and guarantee the adaptivity of the system (Bauer, 2012; Bauer, 2014). After obtaining a satisfactory definition of context, the future work will be to implement a prototype of the system and test how understandable and useful is the feedback provided by the system. This also opens the door to propose and test different analysis methods to obtain the most appropriate interpretation of consumption and recommendations of actions.

REFERENCES

Barker, T., Bashmakov, I., Bernstein, L., Bogner, J.E., Bosch, P.R., Dave, R., Davidson, O.R., Fisher, B.S., Gupta, S., Heij, G.J., Ribeiro, S.K., Kobayashi, S., Levine, M.D., Martino, D.L., Masera, O., Metz, B., Meyer, L.A., Najam, A., Nakicenovic, N., Roy, J., Sathaye, J., Schock, R., Shukla, P., Sims, R.E.H., Smith, P., Tirpak, D.A., Zhou, D., Davidson, O.R., Bosch, P.R. & Dave, R. (2007) "Technical Summary", in: Metz, B., Davidson, O.R., Bosch, P.R., Dave, R. & Meyer, L.A. (Eds.), *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, UK.

Bassamzadeh, N., Ghanem, R., Lu, S. & Kazemitabar, S.J. (2014) "Robust scheduling of smart appliances with uncertain electricity prices in a heterogeneous population", *Energy and Buildings*, **84**, pp. 537–547.

Bauer, C. (2012) "A Comparison and Validation of 13 Context Meta-Models", in: *Proceedings of the European Conference on Information Systems (ECIS)*, p. Paper 17.

Bauer, C. (2014) "A framework for conceptualizing context for intelligent systems (CCFIS)", *Journal of Ambient Intelligence and Smart Environments*, **6**(4), pp. 403–417.

Beckel, C., Sadamori, L., Staake, T. & Santini, S. (2014) "Revealing household characteristics from smart meter data", *Energy*, Elsevier Ltd, **78**, pp. 397–410.

Benou, P. & Vassilakis, C. (2010) "The conceptual model of context for mobile commerce applications", *Electronic Commerce Research*, **10**(2), pp. 139–165.

Bonino, D., Corno, F. & De Russis, L. (2012) "Home energy consumption feedback: A user survey", *Energy and Buildings*, Elsevier, **47**, pp. 383–393.

Boshell, F. & Veloza, O.P. (2008) "Review of developed demand side management programs including different concepts and their results", in: *Transmission and Distribution Conference and Exposition: Latin America*, IEEE, Bogota, pp. 1–7.

Cao, K., Mathews, R. & Wang, S. (2015) "Modelling Household Energy Consumption Using ABS Survey Data", *Economic Papers*, **34**(1-2), pp. 36–47.

Castelli, N., Stevens, G., Jakobi, T. & Schönau, N. (2014) "Switch off the light in the living room, please ! – Making eco - feedback meaningful through room context information", in: *Proceedings of 28th EnviroInfo 2014 Conference*, Oldenburg, Germany, pp. 589–596.

Corucci, F., Anastasi, G. & Marcelloni, F. (2011) "A WSN-based testbed for energy efficiency in buildings", in: *Proceedings of IEEE Symposium on Computers and Communications*, pp. 990–993.

Costanza, E., Ramchurn, S.D. & Jennings, N.R. (2012) "Understanding Domestic Energy Consumption through Interactive Visualisation: a Field Study", in: *Proceedings of the 2012 ACM Conference on Ubiquitous Computing*, ACM, Pittsburgh, USA, pp. 216–225.

Darby, S. (2006) *The effectiveness of feedback on Energy Consumption: A Review for Defra of the Literature on Metering, Billing and Direct Displays*, Environmental Change Institute, University of Oxford.

Delaney, D.T., Hare, G.M.P.O. & Ruzzelli, A.G. (2009) "Evaluation of Energy-Efficiency in Lighting Systems using Sensor Networks", in: *Proceedings of the First ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Buildings*, ACM, Berkeley, USA, pp. 61–66.

Erickson, T., Li, M., Kim, Y., Deshpande, A., Sahu, S., Chao, T., Sukaviriya, P. & Naphade, M. (2013) "The Dubuque Electricity Portal: Evaluation of a City-Scale Residential Electricity Consumption Feedback System", in: *CHI '13 Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM, Paris, pp. 1203–1212.

European Commission. (2011) *Energy Efficiency Plan 2011*, European Commission, Brussels, available at: http://ec.europa.eu/clima/policies/strategies/2050/docs/efficiency_plan_en.pdf, Accessed: 23 May, 2016.

Fischer, C. (2008) "Feedback on household electricity consumption- a tool for saving energy", *Energy Efficiency*, **1**(1), pp. 79–104.

Froehlich, J. (2009) "Promoting Energy Efficient Behaviors in the Home through Feedback : The Role of Human-Computer Interaction", in: *Proceedings of Human Computer Interaction Consortium Workshop*, Colorado.

Hargreaves, T., Nye, M. & Burgess, J. (2010) "Making energy visible: A qualitative field study of how householders interact with feedback from smart energy monitors", *Energy Policy*, Elsevier, **38**(10), pp. 6111–6119.

Harris, C. & Cahill, V. (2005) "Exploiting user behaviour for context-aware power management", in: *International Conference on Wireless and Mobile Computing, Networking and Communications*, IEEE, pp. 122–130.

Harris, C. & Cahill, V. (2007) "An Empirical Study of the Potential for Context-Aware Power Management", *UbiComp 2007: Ubiquitous Computing*, Springer Berlin Heidelberg, pp. 235–252.

Karjalainen, S. (2011) "Consumer preferences for feedback on household electricity consumption", *Energy and Buildings*, Elsevier, **43**(2-3), pp. 458–467.

Neustaedter, C., Bartram, L. & Mah, A. (2013) "Everyday activities and energy consumption: how families understand the relationship", in: *ACM annual conference on Human Factors in Computing Systems (CHI 13)*, ACM, Paris, pp. 1183–1192.

Strengers, Y. (2011) "Designing Eco-Feedback Systems for Everyday Life", in: *CHI'11 Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM, Vancouver, Canada, pp. 2135–2144.

Wilson, C., Stankovic, L., Stankovic, V., Liao, J., Coleman, M., Kane, T., Firth, S., Hassan, T. & Hauxwell-Baldwin, R. (2015) "Identifying the time profile of everyday activities in the home using smart meter data", in: *European Council for an Energy Efficient Economy (ECEEE) 2015 Summer Study*, pp. 933–945.

Yun, T. (2009) "Investigating the Impact of a Minimalist In-Home Energy Consumption Display", in: *CHI'09 Extended Abstracts on Human Factors in Computing Systems*, ACM, Boston, USA, pp. 4417–4422.