An Analysis Approach for Context-Aware Energy Feedback Systems

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Abstract. Several energy systems have been developed and studied to help occupants reduce energy usage by providing feedback about their consumption. But recently, a major challenge has emerged about how to enable users to make informed energy efficiency decisions based on consumption feedback. This is because existing systems only present abstract consumption data that are not related to the surrounding energy consumption context. This paper proposes a novel energy data analysis approach which leverages context-awareness to support users to take actions that improve energy efficiency. The approach consists of two stages: multidimensional analysis followed by case-based reasoning. The anticipated output of the analysis approach will be understandable and actionable feedback that helps occupants control their energy consumption.

Keywords: Context-Aware Applications, Energy Consumption Feedback Systems, Multidimensional Analysis, Case-based Reasoning

1 Introduction

The world concern has been more and more concentrated on using energy efficiently since greenhouse gas emissions are expected to increase between 25-90% by 2030 [3]. The European Commission considers that end users will have to play a major role in reducing energy consumption [7]. For this purpose, several energy systems exist to help users reduce their usage by providing information about their energy consumption [2]. However, the information that is provided by existing systems is not enough to inform energy efficiency decision making. This is because these systems only display abstract consumption data which do not allow the users to interpret and understand their consumption [10]. Therefore, an effective energy system needs to integrate energy data analysis capabilities which include: detecting energy waste, providing the reason of the waste, and helping to take appropriate actions [13].

In order to overcome this limitation, we propose the use of context awareness in energy feedback systems. Context awareness involves 3 stages that are referred to as the context life cycle [12]: 1) *context acquisition* which involves collecting different contextual data from physical and virtual sensors, 2) *context* *modelling* that is putting the collected data in appropriate repositories, and 3) *context reasoning* which involves analysing the collected context data to provide customized services to the users. Context awareness helps provide understandable and actionable feedback instead of giving abstract feedback. The expected feedback may be of two forms: 1) detailed reports that consist of rich feedback that is supported by context data, and 2) description of energy waste incidents and recommendations that help overcome the waste.

In order to get the desired feedback, we propose an analysis approach that models and interprets energy consumption data using energy related context data. The approach combines multidimensional analysis which integrates the different context data with the consumption data, and case-based reasoning that is used to detect energy waste scenarios and suggest the appropriate energy efficiency advice.

This document is organized as follows: Section 2 highlights limitations of existing energy systems, Section 3 explains the proposed analysis approach with examples of understandable and actionable feedback, and finally Section 4 presents the future work.

2 Energy Systems Related Work

To make occupants aware of their energy consumption, several Energy Consumption Feedback (ECF) systems have been proposed and studied (such as [9]). But recently, a major challenge has emerged about how to enable users to make informed decisions based on consumption feedback [4]. In his investigation into the best way to present electricity feedback, Karjalainen [10] found that although people are motivated to conserve electricity, they are short of information that is needed to take the most appropriate action. Similarly, users of a pilot feedback system reported that they need more context to understand energy usage or take actions [6]. These studies indicate that merely showing the consumer the amount of energy they are using may not be enough to make them understand their consumption and take action to control it.

Another type of energy systems, besides ECF systems, are Energy Management Systems (BEMS) which were thoroughly reviewed in [5]. The review identifies the main components of an ideal BEMS which is expected to monitor energy consumption, sense environmental conditions, detect user presence and preferences, and ultimately help reduce energy consumption. These specifications show that context awareness is one of the core parts of energy systems.

Therefore, there is a need for a context-aware analysis approach that enhances the feedback compared to typical energy feedback systems, and leverages a variety of context data that affects energy consumption.

3 The Energy Analysis Approach

As a first step for context-aware applications development and in order to use context effectively we have defined energy consumption context for context-aware energy feedback systems in a previous work [1]. The work has found that energy consumption context consists of *User Context*, *Appliances Context*, and *Environment Context* (Fig. 1). These context data are, along with the energy consumption data, the input for the proposed analysis approach (Fig. 2). The context and consumption data can be collected by a smart home technology (sensors) and smart meters.

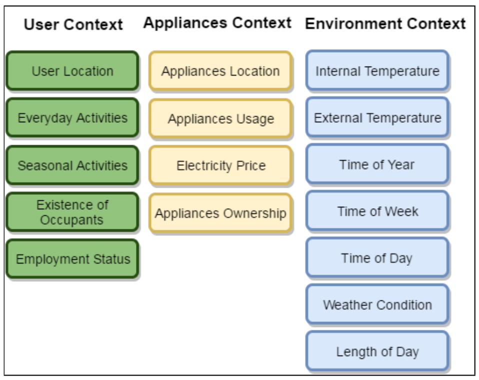

Fig. 1: Elements and categories of the energy consumption context [1]

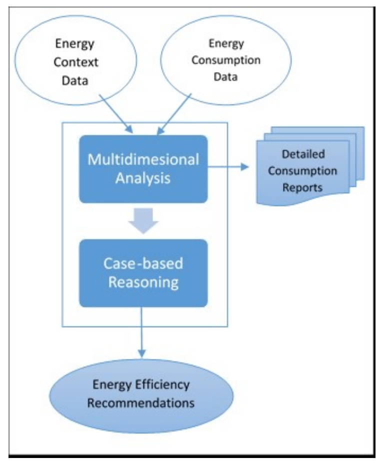

Fig. 2: The proposed energy data analysis approach

Since these data are from different sources, with different formats, and of huge amounts, we propose Multidimensional Analysis (MDA) as the first stage of the analysis approach. MDA can be used to provide detailed consumption reports consisting of rich feedback that is the consumption data supported by the energy consumption context. Therefore, the user can view the consumption data disaggregated in multiple dimensions: room level, user activity level, time dimensions levels (workdays, holidays, weekends), appliances level, or based on outside temperature and weather. These details help the users gain a better understanding of their energy usage, hence, determine practices/conditions that mostly affect it. A similar MDA approach was proposed in [8], which presents a system design that leverages MDA for building management systems to reduce energy consumption. They showed that MDA can support decision-making and provide actionable information for users by combining data from sensors, data from building management systems and data from building information modelling tools [8].

Although detailed reports provide more understanding of consumption, it may not be effective to inform decision-making and implement energy efficiency. Therefore, an automated reasoning method is required to analyse the collected data. For this purpose, the second stage of the analysis approach is a Case-Based

Reasoning (CBR) that detects energy waste, and suggests energy efficiency recommendations. CBR is an artificial intelligence methodology that solves problems based on past experience. Given a current problem with no solution, CBR remembers problems similar to the current situation, and adapts previous solutions to new problems. The adapted solution is then evaluated in order to improve the system's experience [11]. Therefore, through context awareness, CBR detects energy waste incidents by retrieving similar cases based on similar context, and suggests adapted solutions based on the current context. In a similar way, CBR was used for a context-aware healthcare system in [14] and have shown its adaptability compared to traditional rule-based reasoning methods.

The suggested CBR analysis can detect the following energy waste incident: *"The television was left on standby mode in the childrens room between 9pm and 7am while the kids were sleeping. You may save £1 a month if you turn it off before they sleep"*. A similar energy waste case may involve a different device and may be in a different location, at a different time, or with a different occupant activity. CBR is able to detect these similar cases, calculate the amount of wasted energy and forward a notification to the user. Another example that include solution adaptation is as follows: *"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 on weekdays when everybody is out of home and the electricity price is low. This will save you £3 a month"*. The suggested solution is to schedule the washing machine in a time when the electricity price is low and the occupants are out of home. Therefore, if a similar case is detected, CBR will search for a suitable time to turn ON the device thus avoiding the detected energy waste.

The difference between a typical CBR system and the proposed analysis approach is in the query initialization. In a typical CBR system, the query is initiated by the user of the system. However, in a context-aware ECF system, which is deployed in a smart home environment, the sensors and smart meters data are streamed continuously. For this purpose, MDA serves as the repository that unifies the formatting of the collected heterogeneous data, synchronizes the data in a specific time interval, and provides the query, which contains all the measurements in the current time, to the CBR for energy waste detection.

4 Future Work

The future work of this proposal is to collect the data needed to test the approach. Real data will be collected through a commercial IoT[1] smart home tool. The data include individual devices energy consumption, occupants motion and presence, temperature, etc. In addition, a smart home simulation software will be used to produce other kinds of scenarios. The simulation tool generates the heating and lighting energy consumption of the house along with sensors data such as temperature and brightness. The approach will then be implemented to test its efficiency and compare it with previous systems.

[1] Internet of Things

References

1. Abdallah, F., Abdallah, A., Basurra, S.: Defining Context for Home Electricity Feedback Systems. In: Proceedings of 2nd International Conference on Zero Carbon Buildings Today and in the Future. Birmingham City University, Birmingham, UK (2016)
2. Aman, S., Simmhan, Y., Viktor K. Prasanna: Energy Management Systems : State of the Art and Emerging Trends. IEEE Communications Magazine 51(1), 114–119 (2013)
3. Barker, T., Bashmakov, I., Bernstein, L., et al.: 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 (2007)
4. Castelli, N., Stevens, G., Jakobi, T., Schönau, N.: Switch off the light in the living room, please!-making eco-feedback meaningful through room context information. In: 28th EnviroInfo Conference. pp. 589–596. Oldenburg, Germany (2014)
5. De Paola, A., Ortolani, M., Lo Re, G., Anastasi, G., Das, S.K.: Intelligent management systems for energy efficiency in buildings: A survey. ACM Computing Surveys 47(1), 13:1–12:38 (2014)
6. Erickson, T., Li, M., Kim, Y., Deshpande, A., Sahu, S., Chao, T., Sukaviriya, P., Naphade, M.: The dubuque electricity portal: Evaluation of a city-scale residential electricity consumption feedback system. In: Proceedings of the 13th SIGCHI Conference on Human Factors in Computing Systems. pp. 1203–1212. ACM, Paris (2013)
7. European Commission: Energy Efficiency Plan 2011. Tech. rep., European Commission (2011), http://ec.europa.eu/clima/policies/strategies/2050/docs/efficiency_plan_en.pdf, accessed: 23 May, 2016
8. Gökçe, H.U., Gökçe, K.U.: Multi dimensional energy monitoring, analysis and optimization system for energy efficient building operations. Sustainable Cities and Society 10, 161–173 (2014)
9. Hargreaves, T., Nye, M., Burgess, J.: Making energy visible: A qualitative field study of how householders interact with feedback from smart energy monitors. Energy policy 38(10), 6111–6119 (2010)
10. Karjalainen, S.: Consumer preferences for feedback on household electricity consumption. Energy and Buildings 43(2-3), 458–467 (2011)
11. López, B.: Case-based reasoning: a concise introduction. In: Synthesis Lectures on Artificial Intelligence and Machine Learning, pp. 1–103. Morgan & Claypool Publishers (2013)
12. Perera, C., Zaslavsky, A., Christen, P., Georgakopoulos, D.: Context aware computing for the internet of things: A survey. IEEE Communications Surveys & Tutorials 16(1), 414–454 (2014)
13. Piette, M.A., Granderson, J., Wetter, M., Kiliccote, S.: Intelligent Building Energy Information and Control Systems for Low-Energy Operations and Optimal Demand Response. IEEE Design & Test of Computers 29(4), 8–16 (2012)
14. Yuan, B., Herbert, J.: Context-aware hybrid reasoning framework for pervasive healthcare. Personal and Ubiquitous Computing 18(4), 865–881 (2014)