'Just Enough' Sensing to ENLITEN

A preliminary demonstration of sensing strategy for the 'ENergy LIteracy Through an Intelligent Home ENergy Advisor' (ENLITEN) project

Tom Lovett
Department of Architecture and Civil Engineering
University of Bath
Bath, UK
t.r.lovett@bath.ac.uk

Elizabeth Gabe-Thomas
Department of Psychology
University of Bath
Bath, UK
e.g.thomas@bath.ac.uk

Sukumar Natarajan
Department of Architecture and Civil Engineering
University of Bath
Bath, UK
s.natarajan@bath.ac.uk

Eamonn O'Neill
Department of Computer Science
University of Bath
Bath, UK
eamonn@cs.bath.ac.uk

Julian Padget
Department of Computer Science
University of Bath
Bath, UK
j.a.padget@bath.ac.uk

ABSTRACT

The ENLITEN project aims to reduce carbon emissions attributable to energy use within buildings – particularly homes – by understanding and influencing occupants' habits and behaviours with respect to energy use. To achieve this we are developing a system based on a whole building energy model that, uniquely, integrates (i) a thermal model, (ii) a model of occupants' habits and requirements and (iii) a disaggregated model of energy use in the dwelling. A "minimal sensor set" is being identified for delivery of the live data feed to the whole building energy model. This will be complemented by collection and analysis of occupant data that will be used to construct a model of occupants' energy-related attitudes, behaviours and habits. The whole building energy model will contribute to an interactive in-building tool to help occupants identify and break poor energy habits, form better ones and reduce energy demand and carbon emissions. This system is to be deployed in 200 homes for a period of 2 years in the city of Exeter (UK). This poster and demo presents our prototype sensor deployment and the visualisation of live data collected from the trial home group, through which the minimal sensor set is being developed.

Categories and Subject Descriptors

H.4 [**Information Systems Applications**]: Miscellaneous

Keywords

ENLITEN; Energy use; sensing; intelligence; interaction

1. INTRODUCTION

Buildings are the single largest contributors to UK carbon emissions (greater than transport) [3] with a total footprint of about 34%. To meet the UK's national target of 80% emissions reductions by 2050 [1], energy use in buildings has to be reduced. It is clear that savings from efficiency improvements alone (e.g. insulation, more efficient boilers, etc.), while substantial, will not achieve this target. Micro-generation and improvements to building design will be important, but none of these factors are likely to work unless we have a deeper understanding of how occupants interact with their internal environments, the buildings they occupy and the systems they use within the buildings. Furthermore, the occupants themselves require a better understanding of their energy use and the implications – both environmentally and financially – of their energy-related behaviour.

Current work into this problem has concentrated on various factors [8], including: (i) thermal properties of buildings, i.e. understanding thermal models of buildings and heat loss reduction through improved building and heating, ventilation and air conditioning (HVAC) system design [2] (ii) inference of energy use from appliances, e.g. using disaggregation of sensed electrical data [5, 7] and (iii) occupant behaviour, e.g. inferring occupants' energy-related activities from automatically sensed data [6], providing occupants with information on energy use and its implications [4], and attempting to intervene in energy-related behaviour.

This poster and demo describes the ENLITEN[1] project, which aims to understand these factors better and to use sensing technology to inform occupants both about their energy use and actively encourage them to change their energy-related behaviour. Unlike previous work, which explores sensing capabilities and occupancy inference, e.g. [5, 8], we concentrate on the trade-off between sensing capability and *affordability*, i.e. an appropriate sensor choice for energy-related sensing applications.

2. APPROACH

Figure 1 illustrates the conceptual architecture for the ENLITEN project. We are developing a building *energy model*, which comprises of a thermal model and occupant model, both of which actively configure and adapt themselves through the inference and learning of incoming data. The *thermal model* is concerned with heat generation, control and loss within each home. Based on real time modelling of buildings' thermal responses [2], the thermal model will capture and learn about environmental behaviours

[1] http://cs.bath.ac.uk/enliten

.

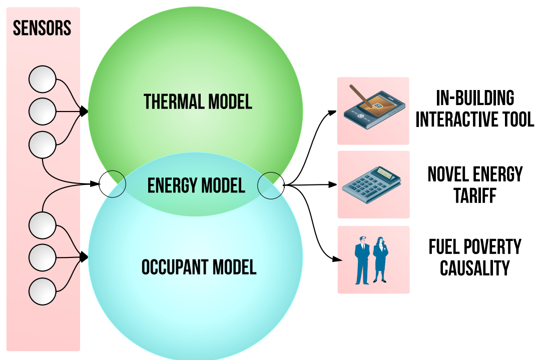

Figure 1: ENLITEN conceptual architecture

in order to inform occupants about areas of concern or potential improvement. The *occupant model* is concerned with occupants' energy-related activities within the home. Using a combination of electrical load monitoring [5, 7], gas sensing, occupancy detection and qualitative survey data, the model will build a representation of occupants' behaviour to auto-suggest changes to their energy-related behaviour.

3. CURRENT WORK

The initial goal for ENLITEN is to deploy an *affordable* sensor set in a sample of $\approx$ 200 homes (from a candidate set of 5000 homes) in the city of Exeter in the UK. The key challenge is the design of a sensor set that trades off data value – that is, the importance of each sensor to the set value – against the set cost – that is monetary and energy consumption costs.

Sensing equipment can be expensive, particularly for high-precision sensing [5], leading to a trade-off between data quality (and therefore cost) and scalability. If sensors are too expensive, it limits the number of deployments. Moreover, an expensive system will have little impact in the real world where consumer affordability is a major issue. Conversely, if the sensing equipment is of low quality, we risk compromising on data integrity and our understanding of energy consumption. Given the fundamental contribution of data sensing to the energy reduction problem and to ENLITEN, low integrity data is likely to have a negative impact on higher-level thermal and occupancy modelling.

Our current work, and the focus of this poster and demo, is a study of energy-related sensing requirements and the identification of a "minimal sensor set" to sense 'just enough' about each of the 200 buildings and their occupants. The first step in this process is comprehensive sensing in a small group of trial homes ($\approx$ 5), in order to identify superfluous sensors and proxy sensors to achieve both sufficient coverage and redundancy at low cost. Table 1 lists the sensors and the relevance of each to the 3 models described above. Following deployment of a large sensor set in each of the trial homes, occupants will undertake scripted events so that we can compare sensor data against ground truth and measure sensor subset information. This will be combined with a measure of subset cost in order to analyse the value-cost trade-off of each subset. The demo visualizes this sensor deployment and demonstrates how varying sensor subsets affects the trade-off between sensor value and cost using appropriate measures.

Sensor	**Model relevance**		
	Thermal	**Energy**	**Occupant**
"Environmental" sensing			
Temperature	x		x
Temperature (water pipe)	x	x	x
CO_2	x		x
Air pressure	x		x
Humidity	x		x
Internal light		x	x
Insolation	x		
Sound level			x
"Energy" sensing			
Gas usage		x	
Real power (appliance)		x	x
Reactive power (appliance)		x	x
Real power (circuit)		x	x
Reactive power (circuit)		x	x
Real power (household)		x	x
Reactive power (household)		x	x
Other sensing			
Passive Infra Red (PIR)			x
Window open/close	x		x
Water flow		x	x

Table 1: List of sensors and model relevance

4. SUMMARY

We have presented the ENLITEN project, outlining its high level architecture, key project components and planned outputs. In particular, we describe our current work on sensor set design, which will be presented in the demo. Full scale deployment is scheduled for 3Q2013.

5. REFERENCES

[1] Climate Change Act 2008. Retrieved from `http://www.legislation.gov.uk/ukpga/2008`, 20130122, 2008.

[2] D. Coley and J. Penman. Second order system identification in the thermal response of real buildings. Paper II: recursive formulation for on-line building energy management and control. *Building and Environment*, 27(3):269–277, 1992.

[3] Committee on Climate Change. Meeting Carbon Budgets – ensuring a low-carbon recovery. Retrieved from `http://www.theccc.org.uk/reports`, 20130122, June 2010.

[4] E. Costanza, S. Ramchurn, and N. Jennings. Understanding Domestic Energy Consumption through Interactive Visualisation: a Field Study. In *Proc. Ubicomp '12*, pages 216–225, 2012.

[5] J. Kolter and M. Johnson. REDD: A public data set for energy disaggregation research. In *Workshop on Data Mining Applications in Sustainability (SIGKDD), San Diego, CA*, 2011.

[6] S. Mamidi, Y. Chang, and R. Maheswaran. Improving building energy efficiency with a network of sensing, learning and prediction agents. In *Proc. AGENTS '12*, pages 45–52, 2012.

[7] O. Parson, S. Ghosh, M. Weal, and A. Rogers. Nonintrusive load monitoring using prior models of general appliance types. In *Proc. AAAI '12*, 2012.

[8] R. Zhang, K. Lam, Y. Chiou, and B. Dong. Information-theoretic environment features selection for occupancy detection in open office spaces. *Building Simulation*, 5(2):179–188, 2012.