Turning Up the Heat on Energy Monitoring in the Home

Fitton[1] D., Horton[1] M., Guo[2] Y., and Read[1], J.C.

[1]School of Computing Engineering & Physical Sciences, University of Central Lancashire, Preston, PR1 2HE, UK
[2]Department of Computer Science, University of Swansea, Swansea, SA1 1XW, UK

ABSTRACT: The use of domestic electrical energy monitoring systems is becoming more common however gas usage has received comparatively little attention. This paper presents a new technique for monitoring gas-powered heating and hot water usage in the home integrated into a prototype energy monitoring platform. Compared to usual meter-based approaches this technique provides finer-grained usage data and uses simple temperature sensors. The main motivation for this work is to provide more meaningful energy information to users for inclusion in novel mobile and embedded applications. This is part of ongoing work which aims to reduce energy use among teenagers in the UK and make lasting attitude changes. The development and findings from a prototype deployed in a typical UK house over 7 days are presented. The findings highlight the utility of the technique and simplicity of the sensing approach. The novel requirements that inspired the development of this technique are also presented.

Keywords – Sensing, Energy Monitoring, Human-Computer Interaction, Child-Computer Interaction

1. INTRODUCTION

Governments across the world are now committed to reducing CO2 emissions and one key area for improvement is reduction in domestic energy usage. Much work to-date has focused on monitoring and making visible electricity usage in the home and several inexpensive commercial products are available (e.g. AlertMe www.alertme.com, Current Cost www.currentcost.com) with services such as Google PowerMeter (www.google.com/powermeter) becoming popular. This is, of course, very important given the massive growth in ownership of energy hungry electrical devices within the past 20 years (DEFRA, 2007). However, in the UK approximately 70% of home energy CO2 emissions are from space and water heating (DEFRA, 2007), primarily though gas powered boilers providing heating and hot water. Gas usage monitoring has received comparatively little attention (Cohen et al, 2010). This disparity may, in part, be due to the fact that it is more challenging to monitor gas than electricity, but also due to the 'invisible' nature of gas usage. While electrical appliances can easily be unplugged or turned off, gas appliances such as a domestic boiler generate hot water on demand and automatically provide space heating within pre-set parameters.

Where energy consumption information is provided to users the visualization of this information is challenging to correlate with consumption behaviour (Chetty et al, 2008). This is either because the units of measurement are relatively meaningless to users or the information is irrelevant to their interests (e.g. cost information may not mean much for teenagers who do not pay the bills). Furthermore there is a common lack of awareness about the amount of energy consumed by devices in the home and energy-saving options (Read et al, 2011).

In this paper we present a new technique for monitoring gas-powered heating and hot water usage in the home using simple temperature sensors. Compared to usual meter-based approaches, this technique provides finer-grained usage information which can be used in improved energy usage visualization. This work is part of a larger project that targets teenagers to reduce energy use with the aim of producing attitude changes that will last through to adulthood. The sensing technique is integrated into a low-complexity and low-cost energy monitoring platform prototype to be deployed in the homes of participants in the project. The data will be used in a set of engaging 'teen' energy applications to run on mobile, wearable and situated devices designed and developed in collaboration with the teenage participants in the project.

The remainder of paper is structured as follows. Section 2 provides an overview of related work in energy monitoring tech and energy monitoring apps and also looks into the use of such apps to promote behavioural change. Section 3 introduces the new monitoring technique and findings from a prototype deployment. Section 4 discusses the broader application of the sensing platform and Section 5 presents concluding remarks.

2. RELATED WORK

Although there are very few smart gas meters installed in domestic properties in the UK, there are products that are commercially available to record gas usage (Darby, 2006). Domestic gas meters are predominantly mechanical (using a diaphragm) due to their simplicity and low cost, however, their disadvantage being they produce a mechanical output and have the inability to indicate an instantaneous flow rate value (Buonanno, 2000). Ultrasonic flow meters measure the time of an acoustic wave across a moving gas or fluid using transducers installed in the flow line (Drenthen and de Boer, 2001). The advantage being these meters, and other flow meters, have the ability to record data and perform diagnostics that can be easily integrated with electronic output sensors (Buonanno, 2000). It would be possible to retrofit a significant number (65%) of mechanical gas meters in the UK with data logging equipment as, as these gas meters have built in pulse capabilities that could be recorded and transmitted to a computer or smart display (Pierce et al, 2010). Research by van Houwelingen & van Raaj (van Houwelingen and van Raaij, 1989) found the use of such equipment did have a positive effect on reducing gas usage in homes in Holland. Finer-grained domestic gas usage sensing has received relatively little attention apart from the appliance-level GasSense device by Cohn et al (Cohen et al, 2010), GasSense is designed for gas meters in US and utilized a relatively complex sensing configuration.

As previously discussed, electrical energy monitors are becoming more common in the UK through companies such as AlertMe and Current Cost providing electricity meters and displays. There is also considerable research into enhancing and augmenting energy data to assist and improve consumer energy usage but all of which focuses on electricity sensing as this is both easier and less expensive. Devices such as the Energy Orb provide consumers with information such as when peak energy times are occurring in the form of colour changes to the orb (Owen and Ward, 2007). The power aware cord (Gyllensward and Gustafsson, 2005) acts similarly changing colour depending on the amount of electricity flowing through it.

2.1 Inducing Behavioural Change

As previously highlighted, the work on this paper is intended to reduce energy use in teenagers and through this their parents by changing their energy behaviour. For this to be successful these changes need to be long term by consolidating and re-inforcing good behaviour whilst addressing bad behaviour (Collier et al, 2010). Education and understanding of energy saving is important in this goal however the financial incentives for energy saving appear to be the greatest motivators for most. Care needs to be taken in addressing barriers that exist to energy saving such as habitual actions that are hard to change, financial constraints whereby families cannot afford to buy the most energy efficient appliances (Wood & Newborough, 2003), social pressures or norms which require the use or more energy or family commitments that force bad energy use (Collier et al, 2010). Emotional engagement is also an important factor, particularly when targeting teenagers, as behaviour change is more effective, engaging and productive if there is an emotional engagement between the technology and the user (Beale and Creed, 2009).

3. THE 'HEATER METER'

As discussed earlier, monitoring domestic gas usage in the home is usually achieved though augmenting the gas meter on the incoming supply with a counter or by adding acoustic sensing. In this work we wished to provide a finer-grained use sensing than simply measuring overall supply but without the complexity of acoustic sensing. We therefore considered adding simple sensors to the usual combination ('combi') domestic gas boiler that heats water and provides central heating for the majority of homes in the UK. Aside from the gas feed, four copper pipes exit a combi boiler and are accessible below the unit, the cold water feed, the hot water exit (to taps, washing machine, etc.), the return feed from the radiators and the hot feed to the radiators – these are shown in Figure 1.

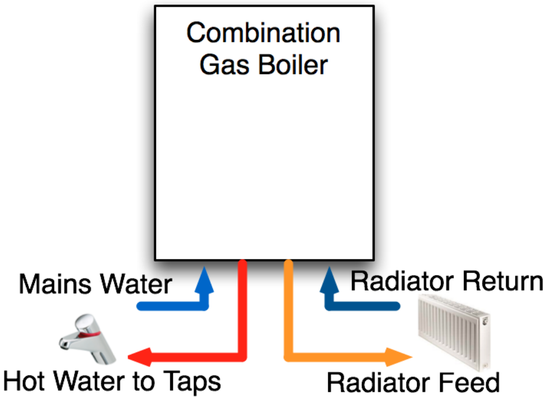

Figure 1. Combination ('Combi') Gas Boiler

The initial hypothesis was that by measuring the temperature difference between the exterior of the cold feed/hot water exit pipes and the radiator feed/return pips it should possible to accurately determine whether the boiler is heating water or heating radiators. In this work it was important that the sensing be low-cost, have high reliability and be easy to deploy. To test the hypothesis a prototype was created using an Arduino Duemilanove (Atmega 328-based prototyping platform), with an 'Ethernet Shield' for network connectivity. For temperature sensing 4 identical thermistors were used, heat transfer paste was applied before being securely (but temporarily) fixed to pipes using cable ties (see Figure 2).

Figure 2. Prototype System including Arduino (top left), temperature sensors (top right), sensors affixed to pipes (bottom left), and feed from gas meter camera (bottom right).

Every 3 seconds the Arduino measured the temperature of the pipes, using the Steinhart-Hart Thermistor Equation to find a result in degrees Celsius, which was then sent to a PHP script on server via a HTTP POST request and logged in a database (along with other debugging information). Temperature values were recorded to 3 decimal places. The accuracy of the temperature sensing in the prototype was compared to a more complex (and expensive) temperature sensing IC (a Maxim DS1621, accurate to +/- 0.5°C) and while the thermistor appeared less accurate, reading between 0.5-1.5°C lower than the DS1621 in the temperature ranges involved in this application, the response times were very similar.

In order to verify gas usage a wireless camera was used to take pictures of the gas meter and upload these to a server when movement of the rotating dials of the meter was detected (see Figure 2). The prototype was also integrated with a Current Cost ‘CC128’ device which sensed electricity usage and room temperature. The CC128 provides a serial connection over which data (in XML format) is sent approximately every 5 seconds, the Arduino parsed the XML and sent the additional information to the server.

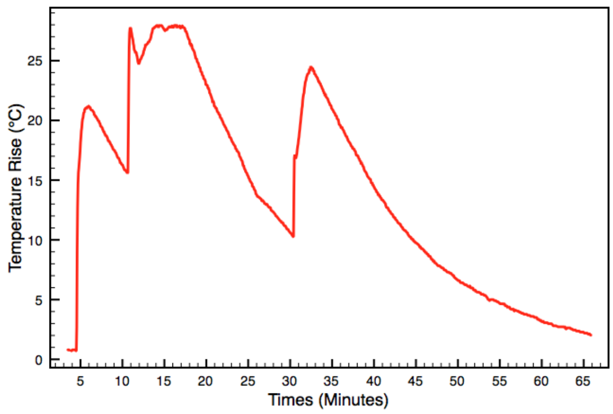

Figure 3. Hot Water Outlet Pipe Temperature Rise

3. FINDINGS

The prototype was installed in a mid-sized 3 bedroom detached family home in the UK and left to collect data for 7 days. The prototype proved reliable and data (at 3 second intervals) over the whole period was collected. Figure 3 shows a typical temperature response for heating hot water and Figure 4 for radiators. The initial finding was that when the boiler began heating an associated increase in temperature of the pipes was sensed within the 3 second sampling interval. As shown in Figure 3, the rise in pipe temperature is clearly apparent. When heating stops the temperature immediately begins to drop and this is clearly distinguishable from the minor fluctuations which occurred during heating. Figure 3 shows 9 minutes of hot water usage in total, 2 short bursts of hot water use (e.g. washing hands) at approximately 5 minutes and 10 minutes, then a shower from approximately 15 minutes to 20 minutes, and another short burst of use at around 30 minutes. As Figure 3 shows, the increase in temperature difference (rise) between the cold feed and hot water outlet pipes is dramatic when the water is being heated, initially rising quickly (3.8°C minimum over each 3 second interval) then slowing (0.08°C minimum over each 3 second interval). When heating has stopped the temperature drops at an average of 0.21°C over 9 seconds.

Figure 4 shows the radiator outlet temperature over a period of 210 minutes when the boiler was actively heating the radiators. This data proved more useful than the temperature rise (between radiator feed and return) to determine if the boiler is heating the radiators, as when the house has become warm relatively little heat is lost though radiators. The temperature change in the radiator feed and return pipes was far slower for the hot water, with the temperature rising between 0.4°C and 0.2°C over a 9 second interval. The radiator pipes also reached a far higher temperature, 45°C compared to 23°C for the hot water.

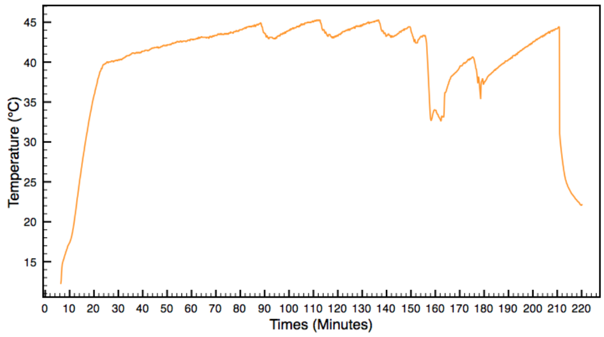

Figure 4. Radiator Outlet Pipe Temperature

When heating has stopped the temperature dropped at an average of 0.12°C over 9 seconds. The change in slope at around 20 minutes (see Figure 4) occurred when the return feed from the radiators reached 18°C (no significant change to room temperature was seen). The dips in the graph around 90, 110 and 140 minutes do not correspond with significant changes in return feed temperature or room temperature. These patterns were seen repeatedly and are attributed to the boilers own internal control program moderating the heating system when the radiator outlet temperature reaches 40 then 45°C. Between 140-160 minutes demand in hot water (for taps etc.) meant that heating of radiators was stopped, this occurred again around 180 minutes (a combination boiler can only heat hot water or radiators exclusively).

4. DISCUSSION

The key finding from this work is that the sensing approach can be successfully applied to gather usage information relating to hot water and space heating for home with a gas combination boiler. The interpretation of the sensor data (detecting changes I temperature over time) is relatively easy and could easily be performed on the Arduino. This sensing approach could also be applied to measure the hot water usage of any individual appliance supplied by accessible copper pipes, such as a bath, shower or washing machine.

The prototype will now be subject to extended testing and refinement in a range of different size of homes with different manufacturers of boilers before deployment with participants in the project. While gas boilers have differing heating capacities, energy efficiencies and installation configurations (differing number of radiators, use of room thermostat, timing configurations etc.) the actual boiler always functions in the same way. We are therefore confident that this sensing technique will be widely applicable. The prototype will be modified to carry out usage detection on the Arduino, sending only summary results to the server, and measuring pipe temperature more frequently. We expect to monitor a sliding window of temperature measurements to determine change. Key areas for consideration in detecting usage will be the boundary conditions of cold weather, where the boiler will working a maximum capacity to produce maximum possible temperature increases, and hot weather where high ambient temperatures will heat the pipes and their contents.

4.1 Using the Data: Teen Energy Apps

The motivation for this work on energy monitoring in the home is to support applications to reduce teen energy use. Our studies have shown that teenagers have an awareness of environmental issues, as this is part of the school curriculum in the UK, but have very limited knowledge of the energy consumption of devices in their environment and pragmatics such as the cost implications. The energy applications we are designing will include mobile, wearable devices technologies that educate teens about choices they can make to reduce energy use and provide feedback on energy usage. A key challenge of this work is not only the design of highly usable technologies to provide access to energy usage information presented in a meaningful way for teenagers, but also to ensure that these technologies that are sufficiently ‘cool’ that they are desirable and socially acceptable (Read et al, 2011). The technologies will make personalised and aggregated energy usage information accessible in meaningful ways to enable comparison and competition between peers to foster an active community of teenagers interested in reducing energy use. We therefore require energy usage information of a finer granularity than a household meter, and personalized energy usage wherever possible.

While the sensing infrastructure will eventually be installed in the homes of teenagers participating in this project we will employ a phased deployment process. The next phase of this work is a small-scale deployment at the homes of researchers involved in the project. These ‘friendly’ users will be tolerant to any failure and simplify modifications required during the initial testing phases. Once the sensing infrastructure has proven to be robust, applications will then be created that analyse and utilise the data. Initially this will be simple visualizations based on the raw data (graphs of energy use over time), following this we will analyse the data in more detailto infer context such as the periods during a day when the central heating is active and predictions of the number of baths/showers during a day based in the hot water usage.

The project team will then be able to design and prototype applications utilising this data in collaboration with the teenagers involved in this project.

5. CONCLUSION AND FUTHER WORK

This paper has presented a new low-cost and low-complexity technique for measuring space heating and water heating in homes in the UK. Thermistors used on the 2 pairs of feed/return pipes from a combination boiler make measurable temperature changes in the pipes made boiler activity quickly and unequivocally apparent. The approach used makes a compromise between the simple house-level sensing (ie the meter reading) and more complex but fine-grained device-level acoustic approaches.

The sensing platform described in this paper combines COTS household and appliance-level electricity usage sensing (using the Current Cost device) with support for novel sensing technologies, using the Arduino board, to fulfill our specific requirements. The requirement in the case of this paper was finer grained sensing of domestic hot water and central heating use. While we have presented the simplest method of utilizing this information it could be used, for example, to determine what actions are taking place (e.g. running a bath, running a shower etc.) and these could then be placed in further context (e.g. who is in the house at that particular time). This method provides evidence that it is possible to create an inexpensive domestic monitoring space and water heating in the home that could run alongside electrical meters to provide families with a greater understanding of their household energy consumption. The exact requirements for this research project will be guided by the novel application designs created in conjunction with our users.

6. REFERENCES

Beale, R, and Creed, C (2009), Affective Interaction: How emotional agents affect users. *International Journal of Human-Computer Studies*, Vol. 67, No 9, pp. 755-776

Buonanno, G (2000), On field characterization of static domestic gas flowmeters, *Measurement* Vol. 27, pp. 277–285

Chetty, M, Tran, D, and Grinter, R.E (2008), Getting to green: understanding resource consumption in the home, *Proceedings of the 10th international conference on Ubiquitous computing*, New York, pp. 242-251

Cohen, G, Gupta, S, Froehlich, J, Larson, E, and Patel, S (2010), GasSense: Appliance-Level, Single-Point Sensing of Gas Activity in the Home. *Pervasive*, pp. 265–282

Collier, A, Cotterill, A, Everett, T, Muckel, R, Pike, T, Vanstone, A (2010), Understanding and influencing behaviours: a review of social research, economics and policy making in Defra. Retieved from http://archive.defra.gov.uk/evidence/series/documents/understand-influence-behaviour-discuss.pdf (accessed June 2011)

Darby, S (2006), The Effectiveness of Feedback on Energy Consumption, *Environmental Change Institute— Univ. Oxford, for DEFRA*, UK

DEFRA (2007), Act on CO2 Calculator: Public Trial Version Data, *Methodology and Assumptions* Paper 6

Department of Energy & Climate Change (2010), Energy Consumption in the United Kingdom. Retrieved from http://www.decc.gov.uk/en/content/cms/statistics/publications/ecuk /ecuk.aspx (accessed January 2011).

Drenthen, J.G, and de Boer, G (2001), The manufacturing of ultrasonic gas flow meters. *Flow Measurement and Instrumentation* Vol. 12, No 2, pp. 89-99

Gyllensward, M, Gustafsson, A (2005), The Power-Aware Cord: Energy Awareness through Ambient Information Display. *Proceedings of CHI2005*, Portland

van Houwelingen, J.H, and van Raaij, W.F (1989) The effect of goal-setting and daily Electronic Feedback on In-Home Energy Use. *Journal of Consumer Research*, Vol. 16, pp. 98–10

Martinez, M.S, and Geltz, C.R (2005), Utilizing a pre-attentive technology for modifying customer energy usage. *Proceedings of European Council for an Energy-Efficient Economy*, Summer Study 2005

Owen, G, and Ward, J (2007), Smart meters in Great Britain: The next steps? *Sustainability First*, London

Pierce, J, Schiano, D.A, and Paulos, E (2010) Home, habits, and energy: examining domestic interactions and energy consumption, *Proceedings of the 28th international conference on Human factors in computing systems*, New York,pp. 1985-1994

Read, J.C, Fitton, D, Cowan, B.R, Beale,R, Guo, Y, and Horton, M (2011), Understanding and Designing Cool Technologies for Teenagers, *CHI'11: Proceedings of the 29th international conference on Human factors in computing systems*, Vancouver

Wood, G., & Newborough, M. (2003). Dynamic energy-consumption indicators for domestic appliances: Environment, behaviour and design. *Energy and Buildings*, Vol. 35, No 8, pp. 821–841.