Abstract—A lot of research has been carried out on the energy consumption of buildings and appliances. Very little has been conducted into how people use energy, especially in the home where they are difficult to observe. This paper presents an outline of the SUMMER project. SUMMER (Salford University Monitoring and Management Energy Research) involves devising a method of gathering data on who uses energy within the home and how they do it. The technology will be tested in the University of Salford Energy House before being rolled out to living lab field trials of individuals and families.

Keywords—energy monitoring; domestic; tracking; tagging; behaviour; the everyday; quotidian.

I. INTRODUCTION

Today in the UK more energy is used in homes than by either road transport or industry, accounting for nearly a third of total energy use [1]. Between 1970 and 2009, energy use in housing rose by 17%. Over the same time the number of homes increased by a fifth, and crucially the number of energy consuming appliances increased radically. Unless domestic energy demand is cut dramatically and rapidly the UK will neither achieve the 2020 carbon emissions targets nor the fuel poverty reductions required by legislation [2].

A household is said to be in fuel poverty if it needs to spend more than 10% of its income on fuel to maintain satisfactory conditions. In 2009, the number of fuel poor households in the UK was estimated at around 5.5 million, representing approximately 21% of all UK households. Fuel poverty particularly affects low income households and those who spend a lot of time at home, such as the long term sick, disabled people, young families, the unemployed and the retired [3].

The introduction of tracking to monitor the interactions between people and appliances in their homes is novel, and has the potential to recognise patterns of energy consuming behaviour. This knowledge can help to identify who uses the most energy, and contribute to a more effective way of targeting energy efficiency advice and support.
One of the findings that emerged very clearly from DEHEMS was the lack of knowledge that users had about their own energy consumption. They wanted to reduce their consumption, but to do this effectively they needed to know how much individual services and appliances cost to run. At the start of the project 1000 people were asked to rank the household services that used most energy if left on at full capacity from a list of typical appliances. 83% failed to identify the most power hungry services. Initial results from Living Labs were broadly in line with findings. Most users had little idea of how much individual appliances consumed and when asked to guess were frequently wrong, despite being from a cohort whose interest in the subject probably predisposed them to agree to participating in a Living Lab in the first place.

III. THE EVERYDAY

The SUMMER project will investigate the way people use electricity and gas in their homes. Very little is known about the patterns of domestic energy-consuming behaviour. One of the reasons for this is the difficulty and ethics of observing people at home. Another reason is that the everyday is often considered to be mundane and without value and so is often ignored. Lefebvre argues that in order to bring about transformation, everyday life has to be properly observed and analysed [9].

Additionally, De Certeau suggests that inadequate assumptions are made about the nature of the way things are done, that the everyday is considered merely to be the ‘obscure background of social activity’ [10]. To De Certeau the everyday is ‘elusive yet fundamental’ and only by fully understanding and appreciating the significance of the seemingly insignificant will we really see the habits and rituals of the everyday. The SUMMER project will use the concept of the everyday in order to identify quotidian energy behaviour.

IV. TRACKING

In order to observe domestic quotidian energy behaviour it is necessary to devise a methodology for tracking an individual’s interaction with energy consuming appliances within their home. Therefore it is necessary to have tracking devices on the individuals as they move around their home and tags on the appliances they interact with. There are many tracking technologies currently in use in a multitude of environments and for many purposes. These technologies and their potential limitations are briefly discussed here. GPS (Global Positioning System) is excluded because although it can be used for tracking this only works when there is an unobstructed line of sight to four or more GPS satellites, and therefore is not reliable indoors.

A. ZigBee

ZigBee is a low-cost technology that is widely used in wireless control and monitoring applications, such as home energy monitoring and domestic automation systems. An advantage of ZigBee is the low power consumption that can allow a longer battery life of wireless elements [11]. Direct use of ZigBee for object tracking without the use of additional technologies is problematic. A system can be implemented using signal strengths but the accuracy is poor.

B. RFID

RFID (Radio Frequency Identification) tags are very widely used all over the world everyday. Marathon runners, shopping trolleys, livestock, luggage and merchandise are routinely tagged and tracked. RFID tags can be active or passive, depending on whether they have an internal power source, and can not only provide locational data, but additional data such as price, sell-by dates, maintenance logs. Passive tags are dependent on the transceiver’s power source, have a limited range, do not need a ‘line of sight’ to the transceiver and are much cheaper than active tags. There is a large body of research into maximising the effectiveness of RFID systems and the optimum RFID antenna positioning. A recent study guided visually impaired people around an obscured indoor environment using RFID tags in a grid [12].

C. Motion Imagery

With the increase of people working alongside robots, there are very important safety concerns that require a system of human recognition. Motion imagery and motion-based recognition systems are often used and can be very accurate [13]. Despite the ability to use non-visual sensors to track humans it is highly unlikely that these would be socially acceptable to the participants or acceptable within an ethical framework.

D. DECT

DECT technology is a wireless technology and most widely known for use in cordless home telephones. DECT has also been used in a wider variety of products including audio/video monitors, wireless microphones and home care pendants. A DECT home network could potentially provide energy
monitoring and be integrated with Wi-Fi for remote monitoring [14]. Advantages to DECT include the wide distribution of the technology already, the good range available and compatibility with other standards. The power consumption is heavily influenced by the frequency of wake-up events and this could have serious negative consequences for the practicality of use in the device due to the likely high incidence of trigger events.

V. BEACON LOCATION

One of the more accurate ways to track objects in confined indoor environments is to use beacon location. This would require additional hardware, but can yield centimetre accuracy.

Beacon location systems for use in tracking require a number of sensing nodes to be placed at pre-determined physical coordinates within the area where tracking is required. These coordinates can be global, or relative, meaning that they are an arbitrary coordinate system related to the tracking area. At a minimum, three non-collinear sensor nodes are required to completely define a coordinate system in two dimensions. If three dimensional coordinates are required, then at least four non-coplanar nodes must be used. The methods for establishing the location of the tracked object from the nodes fall into three main areas;

A. Received Signal Strength

This method uses the property that the energy of a radio signal diminishes with the square of the distance from the signal’s source. As a result, a node listening to a radio transmission should be able to use the strength of the received signal to calculate its distance from the transmitter. In practice however, signal strength ranging measurements contain noise on the position accuracy of the order of several metres. This noise occurs because radio propagation tends to be highly non-uniform in real environments. Physical obstacles such as walls, furniture, etc. reflect and absorb radio waves. As a result, distant predictions using signal strength have been unable to demonstrate the precision obtained by other ranging methods.

B. Time Difference of Arrival

Time Difference of Arrival (TDoA) is a commonly used hardware ranging mechanism. In TDoA schemes each node is equipped with a timer and a mechanism for detecting an emitted pulse from the tracked object. The difference in propagation time from the tracked object to each of the nodes forms the basis for calculating the position of the tracked object. In order to produce a measurable time differential between the received pulses a radio pulse is used for synchronisation followed by an acoustic pulse to provide ranging information. Other methods are available depending on the range involved but the general mathematical technique to obtain the position is independent of particular hardware.

TDoA methods are impressively accurate under line-of-sight conditions; however, they perform best in areas that are free of echoes. Close to centimetre accuracy can be obtained without calibration over ranges of up to ten metres in indoor environments. The downside of TDoA systems is that they inevitably require special hardware to be built into sensor nodes, require calibration if using acoustic methods and generally only work well when line-of-sight between the tracked object and the sensor nodes is not obscured.

C. Angle of Arrival

Angle of Arrival (AoA) systems normally use some form of optical or radio beacon on the tracked object. The sensor nodes will then have a system that can determine the direction of a transmitting beacon. Simple trigonometry then allows the calculation of the ranges to the tracked object and hence the position. Generally the hardware used with these methods can obtain accuracy to within a few degrees. Unfortunately, AoA hardware tends to be bulkier and more expensive than TDoA ranging hardware and good spatial separation along known axes is required between the sensor nodes to ensure good accuracy.

VI. WEARABLE TECHNOLOGY

Tagging systems are currently used for a wide variety of purposes, from monitoring compliance with Home Detention Curfews to health traceability of livestock and improved stock control and logistics. Competitive runners can purchase commercial RFID wristbands that not only accurately log their timings, but also store their bib number, name, gender, age, medical information and emergency contacts. Wearable tags can be used in medical setting to both give a quick and accurate identification of patients, their medical history and allergies, etc. but also to give warnings when they are leaving the environment. This has been successfully used to reduce instances of potentially life-threatening cases of confused patients leaving hospital grounds.

There have also been several attempts to develop technologies that can accurately locate and track people and objects within closed environments. These systems frequently use triangulation and multi-lateration methods using light, ultrasound or radio signals. The purpose of indoor positioning systems is to locate people and/or objects in large buildings, such as offices and hospitals.

The Active Badge system was the first indoor location sensing system developed by AT&T [15]. This is an infrared positioning system as every person wears a small infrared beacon that emits a unique code identifier every 15 seconds. The network of IR sensors within the building detect these transmissions and sends the information to a central data bank. In contrast the Active Bat system is an ultrasonic system and
the users are tagged with ultrasonic tags that emit signals that are picked up by receivers. Active Bats performed better than Active Badges but required a large number of sensors mounted in the ceiling.

Wearable RFID is increasingly being developed to increase interactivity with computer gaming. Two wearable RFID systems developed by Intel Research Seattle include the iGlove and the iBracelet [16]. While the iGlove has the electronic components mounted on the hand of the glove and the antennae wire sewn into the palm, the iBracelet has everything encased in a hard plastic shell around the wrist of the wearer. The technology is being developed to reduce the size and there are several games already being developed specifically for RFID interaction.

VII. PROPOSED METHODOLOGY

The SUMMER project aims to identify patterns of domestic energy consuming behaviour. In order to do this it is necessary to devise a method of collecting three distinct types of data:

- Interactions between people and energy consuming appliances, such as turning appliances on and off;
- Locational data of the individuals in the home – in order to determine who is benefiting from the appliance, such as watching the television or using the computer;
- Energy data consumption patterns, so that confirmation of energy interactions can be made and energy consumption can be attributed to the correct individuals.

To collect the data the project will require the use of wearable technology on the participants, energy monitoring equipment and an appropriate sensor network.

The SUMMER project can be split into four main stages. The first stage consists of devising the technology to monitor the interactions of participants with their energy consuming appliances at home. This will be followed by extensive testing in the University of Salford Energy House. The Energy House is a traditional pre-1920’s Victorian terrace house that has been reconstructed using reclaimed materials in a fully environmentally controllable chamber.

Following testing in the Energy House there will be a period of refinement to ready the technology prior to rollout to the participants in the living lab field trials. Living Labs in the UK are communities of volunteers in Birmingham, Bristol and Manchester who test technology, give feedback and exchange experiences with other participants.

VIII. CHALLENGES, ISSUES AND CONSTRAINTS

Lefebvre discusses the differing responses to the introduction of technology in the everyday. There can be suspicion and paranoia and this must be dealt with sensitively. The tracking methodology that is selected must not only be acceptable to the participants of the study, it must also be unobtrusive. Previous research for the DEHEMS study observed a ‘dehems effect’ whereby participants were aware of the data collecting technology and changed their behaviour as a result. The dehems effect made a marked difference in the data for approximately two weeks before the effect lessened. The practical design of the tagging devices must therefore simultaneously consider the following:

- Safety – for the wearer and the wearer’s family and pets. Therefore no sharp edges or small removable parts;
• Robustness – the device must be able to withstand an expected range of conditions likely to be met within the home environment;
• Allowing free movement of the wearer so as not to alter the behaviour of the observed;
• Stickiness – the device must be worn in order to observe the behaviour. The awareness of needing to wear the device must be balanced with the need for wearing the device to become everyday in itself.
• In multiple occupancy houses is essential that each person’s device is easily identifiable to ensure consistent and reliable data.
• Social acceptability – the method of monitoring must be acceptable to all the residents within the house, and not cause any distress with regard to concerns over privacy.

It will be necessary for participants to complete a diary throughout the living lab field trials to record when non-everyday occurrences happen, such as parties, so that the non-everyday data can be identified and removed.

Previous energy monitoring research projects have resulted in a very large amount of data. An appropriate data management system must be implemented before any data is collected.

Due to the complex nature of the project, it will be necessary to have a comprehensive structure of the rules of responsibility and attribution of energy consumed in advance of any data acquisition. Key questions include at what age children should be monitored and the fairness of attributing to one person energy that is used to benefit the whole household. care-giving energy consumption, such as cooking, washing and most of the energy consumed by kitchen appliances. Rules of handover will dictate who is responsible for the energy consumption of appliances left on when no-one is present, and at which point energy should be shared between all the people present.

**IX. CONCLUSION**

The potential benefits of the SUMMER project are numerous. Firstly, creating the method of observing energy consuming behaviour within real domestic settings could potentially be transferred to research into other domestic behaviour. Secondly, a much clearer picture of the patterns of energy behaviour will assist policy makers to address the main users and uses of energy within homes. Thirdly, the insight could prompt more successful devices and appliances to be developed by entrepreneurs and industry.

Successful tracking technology and appropriate use of the information gained could fill a significant gap in the current understanding of domestic energy. This knowledge could have a notable impact on reducing fuel poverty rates and carbon dioxide emissions.

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**REFERENCES**