Energy-Aware Systems for Improving the Well-Being of Older People by Reducing Their Energy Consumption

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***Abstract*—Fuel poverty is becoming a problem amongst the older community in the UK. To help reduce the anxiety that fuel poverty places on older members of the community, this paper will first address why such systems are necessary before introducing a system and various interfaces for engaging and promoting better energy usage. Key areas of the proposed prototype will be discussed which focuses on a recommender and behavioural change system which enables older people to improve their energy footprint through energy-aware systems. Using systems to help reduce fuel poverty will invariably improve their general well-being. Results show how this technology can be accepted and act as an enabler in improving the overall well-being of older people as well as other system considerations. In addition, a number of subsequent phases of the project will be detailed which will discuss a longer test duration, an analysis of the data harvested and future directions.**

***Keywords-* energy-efficiency; energy-awareness; intelligent sensor systems; recommender systems; well-being; internet of things; big data.**

I. INTRODUCTION

This paper is based on [1] and provides more detail regarding the prototype system and results as first presented at the 2017 International Conference on eHealth, Telemedicine, and Social Medicine.

At present, older people within the community face a host of technological and perceptual problems, which can inhibit their interaction and well-being while using information and communications technology (ICT) solutions to improve their lives. This is especially relevant when considering Internet of Things (IoT) based systems to improve their well-being within their home environment [17], dealing with heating and reducing costs. Fuel poverty is a key societal problem that impacts on large numbers of the older community within the UK [2] as older people tend to fall into the low-income range due to low pensions and rising energy costs. The worry and anxiety concerning their limited financial resources results in 20,000 – 25,000 deaths in the UK [4]. This is due to reducing their dependency on heating their homes as they are not financially secure enough to afford or pay for their monthly household heating or cooling bills [5]. The use of technology to help older people reduce costs is constrained by their fear and distrust of technology. To enable older people to accept ICT solutions, the UK government has a number of initiatives in place to help reduce this fear (e.g., digital by default [3]), which aims to provide them with skills to use modern technology. However, figures show that high numbers of individuals are still susceptible to fuel poverty which is not only reducing their well-being but also putting their lives at risk [4].

Compounding the issue of fuel poverty, older members of the community also fear the use of technology which can impact on the successful deployment and adoption of technology to address the issue of fuel poverty. Other issues relating to the acceptance of technology and the security of personal information also factor into the distrust of ICT, which is there to help improve their well-being.

In this work a prototype system is introduced to show how unobtrusive and intelligent technology can help reduce the energy consumption of older people and how this can impact on their behaviour by adopting more energy conscious patterns through a real-time responsive recommender system. Therefore, this work will examine whether an *intelligent recommender system can reduce the energy consumption of older people by predicting and modifying their daily patterns and behaviours so that they minimise their energy needs*. The first phase of this work is to address the aforementioned requirement and expand on this by considering large scale data collection for more in-depth analysis and system considerations that need to be taken into account.

The rest of this paper is structured as follows: Section II provides an insight into existing systems; Section III discusses the design considerations that need to be taken into account when considering energy-awareness as a whole; Section IV introduces our proposed system and its key components; Section V discusses user interaction issues and factors that can deter engagement; Section VI provides initial results; Section VII provides results gathered from the second phase of system development; Section VIII discusses what will be considered in the next phases;

Section IX provides a short discussion and finally, the conclusion is presented in Section X.

II. Related Work

Reducing the energy consumption of individuals has been widely tackled by a variety of commercial and academic systems. An approach taken by some commercial systems is to view each room as a separate entity and give contextual information regarding the state of the room. Some systems require user intervention in the control of the ambient energy consumption. For example, with the *Hive* system [11], to adjust or improve the heating within a room, a separate mobile based application is required which can lead to problems when considering older people. Although additional sensors and smart plugs are available to provide the ability to turn on and off devices [22], these still need to have some form of user intervention. Voice control or a mobile phone application is required to govern their operation. However, this forces the user to actively monitor, respond and modify temperatures rather than allow the system to proactively shape the energy use of the home. IFTTT (IF This, Then That) [12] is another system which allows IoT integration within the home by providing users with a simple rule-based approach for governing the operation of smart devices. Devices are linked to a web based system which can then control the devices within the home. Systems like this would fail to address the needs and anxiety encountered when older people interact with technology [6] due to mobile technology and applications not being accessible to all older people which also increases their fear of technology. Another similar system is the Honeywell *evoHome* system [13] which provides users with contextual information about the room temperature and provides them with a digital thermostat to control ambient temperatures. The *Heat Genius* system [14] is another commercial product which uses motion control to determine whether heating is required in a particular room. This system also provides the ability to learn and adjust room temperatures based on the life-style of the users. However, these commercial systems do not address the issue of reducing energy consumption as a whole but instead focus on one specific problem i.e., heating.

Smart energy meters have been used extensively in the home and in some cases have targeted low-income and older users. In [16], a number of smart energy systems and the interactions with users are discussed. Here, users used the *Duet* and *Trio* devices in a bid to monitor their real-time energy consumption over a one year period. Smart home and assistive technology can also play an important part in monitoring and adapting the environment to best suit an older person. Kim et al. [15] discuss the *U-Health* system for monitoring and supporting the older person within their home. Wireless sensor technologies embedded within appliances in the home allow for the collection and mining of information regarding the habits of the older user, as well as providing decision-making capabilities to allow the system to adapt to the users' needs.

In [23] Granados et al. proposed an IoT architecture for healthcare applications based on an energy-efficient and resilient gateway design taking advantage of some characteristics of many home and hospital environments. Their architecture focuses on enabling wide-spread data collection from medical and structural sensors. Similarly, Rahmani et al. [24] presented a fog computing-based solution to enhance different characteristics of IoT architectures used for healthcare applications in terms of energy-efficiency, performance, reliability, and interoperability. Their fog assisted system was targeted at monitoring patients with acute illnesses.

Leandro et al. [26] proposed a smart architecture for In-Home Healthcare, based on the use of IoT for smart and individualised monitoring of elderly patients in their homes. The system has two units, a sensory unit for capturing images and a decision unit for inferring the user's health from the images.

Zhou et al. [25] presented an architecture and a set of functional modules for a smart home energy management system, with the aim of implementing an optimal demand dispatch system. The system relies on the smart grid paradigm to collect real-time electricity consumption data from in-home appliances, including schedulable and non-schedulable appliances. The main focus of the work in [25] was on the utilisation of building renewable energy in support of energy savings rather than fuel poverty.

The issue of fuel poverty is a multi-dimensional one which covers more than just the heating of homes. To provide a representative picture of how energy-awareness impacts older people, all aspects of energy consumption need to be considered. When looking at the problem of fuel poverty, any savings of an older person's energy expenditure must result in financial benefits. In turn, for a technological solution to fully address the issue of fuel poverty it must holistically look at energy-awareness as a whole, and provide ways in which behaviours and usage patterns can be altered to improve energy expenditure through an unobtrusive and proactive system which does not require constant user interaction to govern the control of the environment.

III. Design Considerations

Older people face a number of challenges in today's society which can impact their lives and well-being. Fuel poverty is a major societal challenge which affects significant proportions of the society. With limited financial resources available to older people who are reliant on state pensions, paying for fuel (i.e., electricity and gas) becomes a major concern for their well-being [4]. Within the UK alone, a high number of unnecessary deaths are caused each year due to weather concerns [2]. This can be due to excessively hot weather during the summer months or excessively low temperatures during the winter. In circumstances like this, which require a higher expenditure, it is common for the older person to go without basic heating or cooling due to limited financial resources, which enables them to focus on other costs (e.g., food and rent) [5]. However, this has a detrimental impact on their well-being due to the suffering involved, and possible death, during low or high temperature times during the year. Not only does it impact older people, but the costs to healthcare for dealing with emergencies relating to the admission and care of older patients at these times, places stress on services which are already over-stretched.

Communities and community care offer care services where carers or social workers visit the older person to ensure that they are coping and not suffering. However, with finite resources, only so much is able to be done. To help in the care of older people, smart technology has been employed quite extensively. For example, in [16], smart devices help monitor the older resident. However, relying on technology can introduce other challenges. More specifically, older people distrust and fear the use of technology [6]. This often leads to technology being ineffective due to the lack of engagement from the older person, especially if they are required to interact and engage with the technology in some way. Davis [6] introduces the Technology Acceptance Model which impacts on the perceived usefulness of technology by the older person which can introduce barriers for adoption. However, older users also encounter problems with a general lack of understanding of ICT which introduces barriers to the user as it impedes them from making strategic decisions when managing fuel costs [10]. This lack of understanding needs to be addressed for the system to be effective and allow seamless interaction with the user. For instance in [15][16] mobile technology is used but can introduce problems with engagement due to the fear of technology whereby the older person has to interact not only with an unknown and unfamiliar device but also some form of application and visual interface. If the interaction between the system and older person is perceived to be too difficult then a lack of engagement usually results [6][9]. Therefore, intelligent devices need to be unobtrusive as well as the system offering a less technological way of interacting with the older person to minimise the impact of the fear of technology.

Behavioural change is another key consideration for such systems as the technology would also have to monitor and determine if there are better behaviour patterns when interacting with energy-reliant devices within the home. For example, making a cup of tea or cooking dinner relies on some form of energy consumption (either electricity or gas) to complete the task. However, energy tariffs can change through the day and can impact on the total expenditure over a month. By modifying the behaviour of the older person to a more cost-conscious time can have benefits over the long term.

Therefore, when designing effective systems for reducing the energy consumption of older people, a number of design considerations have to be taken into account. Namely, the use of unobtrusive technology which is embedded within the environment; simple interaction devices which promote trust; behaviour modification and prediction to reduce or better manage the use of energy reliant devices within the home; and, systems to recommend changes to patterns.

This work proposes to address the question of whether an intelligent recommender system can reduce the energy consumption of older people by predicting and modifying their daily patterns and behaviours so that they minimise their energy needs to ensure an improvement in their general well-being by reducing anxiety associated with fuel poverty. Anxiety has a clear detrimental effect on the well-being of an older person [9], which will hinder their interactions and acceptance of technology. Improving the quality of life of older users is difficult to gauge as different people assign different values to things [8]. For that reason, the proposed system aims to reduce the fear of poverty and improve the quality of life for older users by providing them with guidance and options on how to change their behaviour so that they are more energy-conscious and aware of what they are doing through a simple house model interface. More detailed feedback can be given to those users who feel comfortable with technology or to carers, or family members who are actively helping the older user. By providing them with a more holistic and wide-ranging understanding of the energy-consumption which takes into account not only their heating but also their activities during the day can help them improve their overall energy consumption. By looking at the whole, more substantial savings can be made which in turn reduces their chances of falling into the fuel poverty trap.

An addition technical design consideration is due to the heterogeneous nature of the devices necessary to perform all the tasks necessary to monitor people in their home. No single commercial company yet provides lighting, power sockets, motion sensors and the other devices necessary for such a task. As such, it is necessary to create a technical solution that integrates the data from a range of available devices. This can be achieved in different ways, including runtime transcoding [20], brokers [21], architectures [18], cloud based solutions [19] and proxies. However, because of the relatively small scale of the required deployment, the data integration will be done in phase two which looks at data collection (see Section VII).

Therefore, in summary, this paper is intended to address the issue of the acceptance of technology as well as factors relating to the trust of intelligent systems and improving well-being by reducing fuel poverty. This will be through simple, trusted and unambiguous human-computer interfaces, behaviour and activity analysis; and, recommender systems to help promote more informed energy-aware decisions. This will allow older people to consider all aspects of their energy consumption, rather than focusing on one single aspect (e.g., heating) as their overall energy-footprint will be made of many different components. For example, heating, cooking, recreation, etc., which complements their potentially sedentary life-style. In addition, other system considerations when collecting telemetry from within the home on a more permanent basis will be looked at.

IV. Proposed System

The development of the system has been split into three distinctive phases. The first phase of development focused on the initial system development and interactions with the end user (see Section V). The second phase focused on providing more energy-aware devices for monitoring the usage patterns of older people (or test candidates) and system related issues. The final phase will be to deploy multiple sensors and interfaces into the houses of test candidates.

From a conceptual perspective, the system (see Fig. 1) will process sensor telemetry from devices located within the environment, determine if the behaviour of the person can be changed based on the task activity they are performing, which includes using tariff information gathered from energy suppliers through IoT devices and then facilitate in providing feedback to the older person.

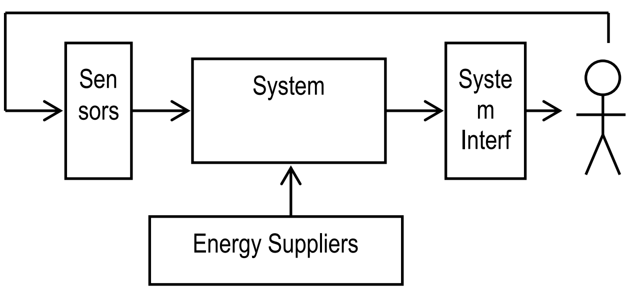

Figure 1. Overview of the proposed system.

The guiding principle in the design of the prototype is to determine if the energy consumption of the user can be reduced by determining the behaviour and patterns they are exhibiting. This builds on our existing energy-aware work which is looking into energy-aware programming languages and middlewares. The system relies upon a number of key components that deal with the interactions with energy suppliers to provide information, which informs the recommender system; activity/task detection and interfacing with the user through an unobtrusive interface. A system prototype has been developed which allows the seamless interaction with an older person, which could reduce their energy consumption. For this prototype iteration the full system was implemented but deployed within an idealised test environment to capture telemetry. The system was also able to save and playback telemetry for user evaluation. In the second iteration, data has been collected from a variety of energy-aware plugs, wireless enabled light bulbs and motion sensors. Information was collected over a seven-day period to give a richer data set of an occupant's activity, and how best behaviour and activity levels can be analysed for energy-aware decisions.

A. Sensors

A variety of off-the-shelf sensors have been used to provide contextual information regarding the state of the environment, the location of the older person, and what they are interacting with in the home environment. Sensors that provide telemetry on light, motion, pressure, electricity use, sound, as well as other sensors providing contextual state information of the environment, have been used. Sensors were typically subsumed within the appliances which consumed energy. This was mostly electrical appliances but scope for gas based appliances will be incorporated in a later phase. Sensors can be added seamlessly to the system by simply plugging them in and informing the software that a particular type of sensor has been added. Different sensors can be dynamically added, along with information which provides contextual information regarding how telemetry can be analysed and interpreted during the behavioural analysis phase. During the first phase, environmental and power usage sensors were based on Phidgets technology and were used to record and forward telemetry using an event system that had been developed (details in Section IV. B).

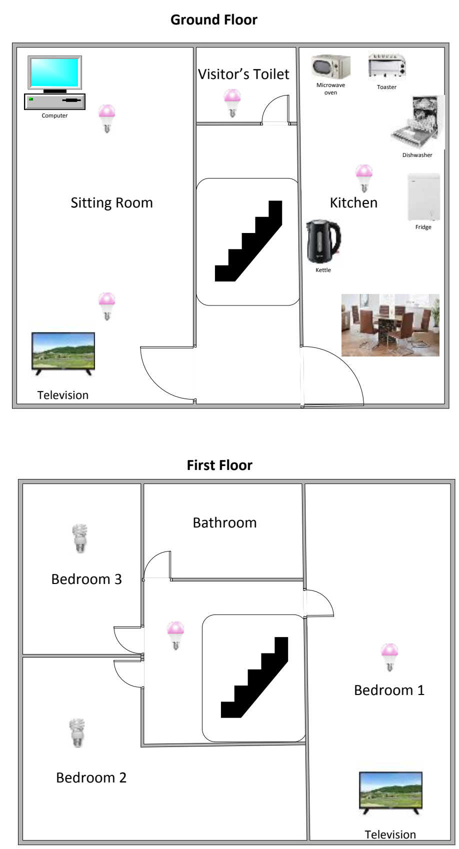

Figure 2. Deployment of wireless sensors.

Building on the first phase, a combination of smart Wi-Fi enabled energy plugs and other Wi-Fi enabled technology (motion sensors and wireless enabled light bulbs) were used. These are currently outfitted within a test house which is also being used for other work that is being currently investigating on energy-aware programming languages. Each room of the test house has a combination of motion, energy aware plugs and Wi-Fi enabled light bulbs. The present deployment consists of 8 energy aware plugs, 8 wireless light bulbs and three-in-one motion sensors for recording ambient temperature, light levels and motion environmental state information.

The test house has 7 rooms (including two toilets / bathroom) and a hall way spread over two floors. For the toilets / bathroom, only lighting levels were monitored. Sensors have been placed so that minimal occlusion occurs. Fig. 2 provides an outline of the deployment of wireless enabled sensors within the environment. There are a number of issues that will not be considering in this phase. This is principally dealing with privacy, occlusion and identify resolution issues.

B. Behavioural Analysis

To aid in the process of determining how much energy is being consumed within the house and whether a better alternative is available, telemetry from sensors are aggregated and processed within the behavioural analysis component of the system. An overview of the activity, behaviour and recommender stages is outlined in Fig. 3.

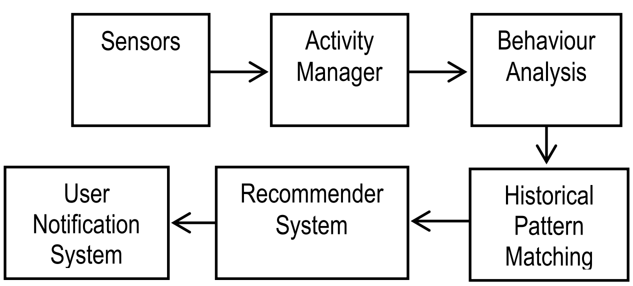

Figure 3. Activity, behavioural and recommender stages.

Activities are used to identify what task the user is performing within the home. For example, making a meal would involve using a variety of sensor equipped devices within the kitchen, each of which will be generating telemetry. In a typical use case, the oven, along with the cooker and supplementary devices (e.g., kettle) could be used. Combined with environmental state information originating from embedded sensors in the home, additionally telemetry regarding light, sound and motion information would be generated and be contextualised within the kitchen environment.

Activities are generated by end-users and allow the association between different telemetry and devices and a given activity. The approach that has been taken is to offer a simple means for users to define an activity and then to associate device combinations to that activity. These activities will then form the basis of the behavioural analysis and pattern-matching functionality whereby the system will be able to determine what type of activity is being performed by the user.

Raw sensor telemetry is tagged with additional meta-information regarding the device type, timestamp and location and is consumed by the system within an event message. For the first development phase, as the types of sensors were limited, events contained all contextual information which was needed to be consumed and processed correctly. During testing, this did not provide sufficient granularity for the types of devices used within the second phase of the system. Here, events became aggregates of the principle device types (e.g., plugs, lights and motion detectors, as outlined in the data structure behind the system in Fig. 4). Events are captured and processed within the behavioural component during the activity identification process. To aid in providing an environmental snapshot of what is happening within the environment, a window of applicability is used which allows events to be received over a short period of time. This populates activity states which are triggered when all associated sensor telemetry has been received during a set period. When this has been satisfied, activities trigger notifications, which in turn are processed by the analysis component. At this point, a decision can be made on what to do next. The first option is to process an associated action which causes the system to perform some form of real-world action which impacts the end-user. Alternatively, notifications can be used to build up composite events which provide more complex combinations of activities to be associated with each other. This allows the system to provide a richer and more complex activity detection process.

The system was enhanced in the second phase to capture more detailed information from each of the devices. This then interfaces with the rest of the system developed previously. The notable extensions in this phase are to allow for richer devices to be used. Namely, Hue and TP-Link based light bulbs which can provide contextual information regarding their intensity/brightness and, in the case of the Hue bulbs, different colours/shades. The latter can also be used to indicate mood information and will be incorporated in to the third phase of development and testing. Motion sensors have been used which expands on the coarse motion information which was available in the first phase of the system. Wireless based sensors which can record temperature, lighting and motion information are now used and provide contextual information which was spread over a variety of other sensors in the previous iteration. The system stores information (as outlined in Fig. 4) and links to the rest of the system developed in stage one.

Historical information regarding past activities is used to provide the ability to determine if activities have occurred during similar times in the past. For example, cooking food

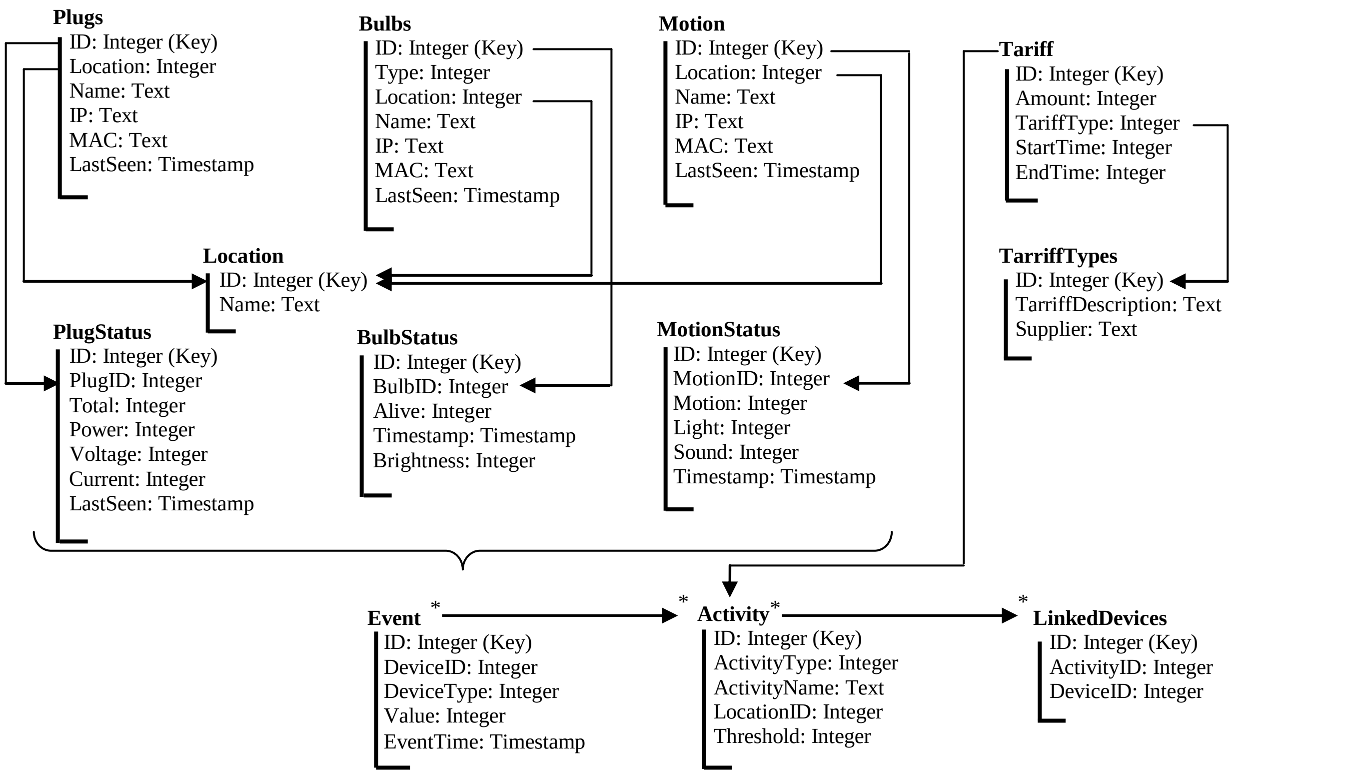

Figure 4. System data structure and relationships.

at specific times; use of kettle to make drinks; and activities that relate to their life-styles. This information is used by the recommender system to determine if user activity patterns can be modified to help improve the energy use within the home based on their occurrences. For instance, when coupled with tariff information, the recommender would be able to inform the user that by changing their pattern to do a particular activity by a few minutes could result in a tangible energy cost saving over a period of time. In the first phase of development, only small data sets were collected over a two day period, and then based on information generated on several devices. With the introduction of the second development cycle, devices were polled each second and data was stored. The number of devices was increased to incorporate the energy-aware plugs and light bulbs which were not used in the previous iteration. Because of this, it was found that the processing of historical information introduced additional issues (as discussed in Section VII). This was mainly due to the large size of data sets collected over the test period (now one week) where the method in which historical behaviours were identified and analysed would require more efficient storage and processing algorithms for them to work effectively in real-time.

C. Recommender System

The purpose of the recommender system is to provide end-users with feedback on their energy consumption performance or provide alternative actions. To best inform end-users of any energy cost savings, tariff information is used from the electricity supplier that they are signed up with. By analysing their past behavioural patterns, the recommender system will determine if any energy savings can be made by suggesting to the end-user how best to alter their habits. For instance, as a profile of the user is generated, any patterns or behaviours they exhibit will be identified and any improvements will be suggested. This information can be conveyed in a number of ways to the end-user. Notification messages detailing the current cost and potential savings can be shown to the user, whilst real-time feedback is given through a physical prototype system, which allows users to instantly see how much energy they are consuming within different rooms in the house.

An administrative component is provided which allows carers or family members to configure the system and provide guidance on what levels of energy expenditure the older user should use on average. This information is used to inform the older user that targets are not being met and to keep the carer or family member informed and involved in the care of the user. Additionally, these set targets also allow carers/family members to closely monitor that the older user is using a minimum threshold amount of energy, thereby ensuring that they are not suffering from the lack of heating or cooling.

V. User Interaction

Compounding the problem of fuel poverty, older users also suffer from technology acceptance. This adds additional constraints in which electronic systems subsumed within the home impact the experience and engagement of the older user. If the technology with which the older user has to interact is complicated or non-intuitive, this can lead to users disengaging with the system put there to improve their well-being and causes an opposite effect so that the user is even more isolated and stuck within the fuel poverty trap. The issue of reducing a lack of understanding and purpose of the system [10] needs to be considered to allow the prototype to be effective with users. In turn, Leonardi [7] highlights that the interactive medium needs to consider the "*motor and cognitive capabilities*" [7] of the older user. When considering the perceived usefulness of the system [6] to promote older users to engage and trust the system and recommendations, a clear simple interface is required. These issues are important when considering how the older person interacts with the prototype system. However, it does pose challenges when considering the acceptance of the interface as it must not rely on something that might cause confusion or anxiety when interacting with the system. Therefore, some form of mobile device or interface would pose significant challenges to older people.

Different interfaces were constructed and evaluated to determine which one offered the older user with the best way to interpret energy usage information. One method of conveying information was through a clock metaphor where LED's indicated the general energy usage within the home. However, this did not prove to be too useful or popular with older-users.

The approach, which ended up being taken, was to provide the older user with a simple, non-technical interface which does not rely on any interactive technology (e.g., mobile phones or smart televisions) but instead uses a simple traffic light metaphor. A mock-up miniature house was provided which uses a traffic light system located in each of the rooms within the model. Instant visual feedback is provided to the older end-user by indicating their power consumption in each room. Red indicates that they are excessively using energy within that room, amber indicates they are using more than they should but there is room for improvement with a few recommendations, while green indicates that they are using energy within the guidelines, or what the carer/family member might have specified.

Fig. 5 shows the model house prototype interface. Each room of the house contains a set of LED's which indicates the real-time use of energy within that room. This was found to be the most successful of the prototypes for conveying straight forward energy usage information to older users.

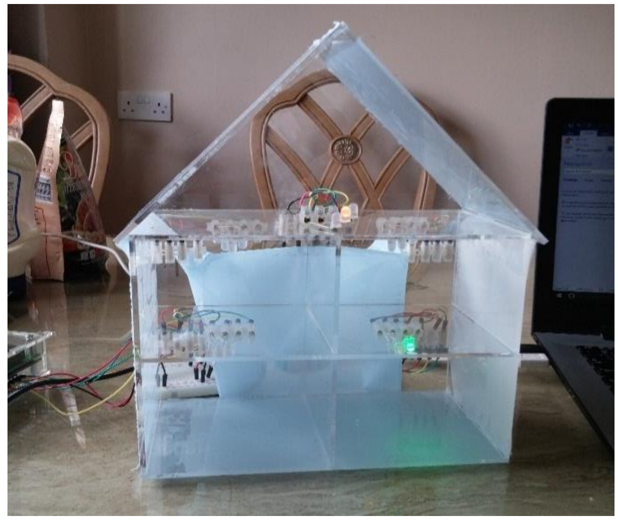

Figure 5. Model house prototype.

A. *Administrative interfaces*

The administrative interface provides carers or family members with cost saving's information either on a day-by-day basis or over a projected month. If older users felt comfortable with the technology they were also provided access to this information, rather than simply relying on the model house. For example, Fig. 6 shows the costs incurred for a number of monitored appliances within the home environment during the first phase of testing. Information is outlined, based on the activities that have been detected during the day and shows a comparison of their energy use. Both carers/family members and the more technically confident older user can utilise this information to determine how many times a day they perform specific activities with a view to reducing the frequency over time or to more suitable times which reduces their energy costs.

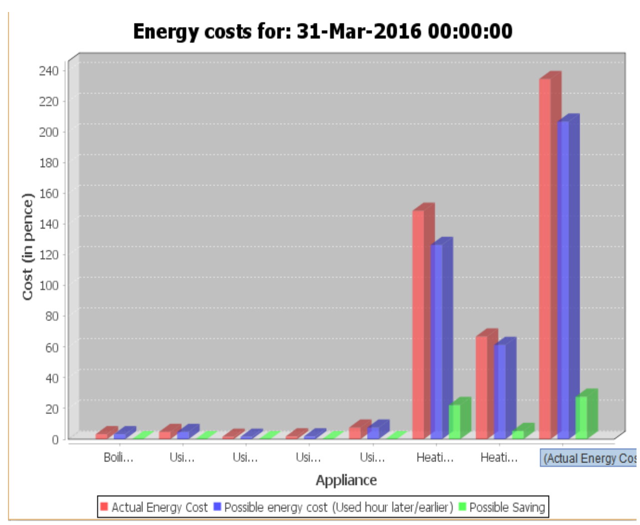

Figure 6. Savings graph (phase 1 of system).

Another way in which financial information can be conveyed to the user is through a monthly chart outlining the costs that have been incurred for each of the activities during that particular period. Fig. 7 shows how information can be presented to end-users regarding the total costs incurred and by activity during the first phase of testing.

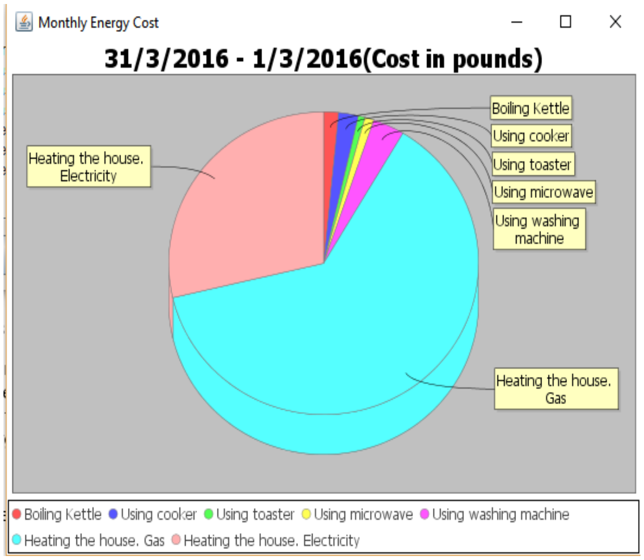

Figure 7. Monthly energy costs (phase 1 of system).

Recommendation notifications were also provided to end-users and carers/family members to allow them to determine where savings could be made by changing habits. For example, recommendations could be made to change the time of morning snacks and eating times to make best use of energy costs by moving these occurrences by a few minutes. For phase two, users were presented with different graph information representing their energy expenditure (examples of these are included in Section VII).

VI. Phase One Results

There are three principle phases to our testing of the system. The first phase was to collect basic data over a short period and test the effectiveness of the user interface (phase one). Phase two required spending a week within a test house monitoring energy, activity patterns and identifying system considerations e.g., storage and processing (phase two) while phase three will look at deploying within a number of homes for a longer period and expose users to the full monitoring system.

To combat fuel poverty, older users have to overcome issues with anxiety caused from the distress of lack of finance to pay for energy bills and also the fear of technology, which impedes the adoption of technology to help them become more energy efficient. Data was collected from an idealised test environment and played back through the system for evaluation purposes. The prototype was evaluated by 10 older users, whose ages ranged between 50 and 70 and were used to measure their technological fear and acceptance of using this technology. This was to determine whether monitoring energy use and recommending more efficient use of energy through modifying activity patterns, would improve their well-being by reducing their overall energy costs.

Preliminary testing was conducted using 10 users to determine the effectiveness of the model house prototype. Older users were asked to answer a questionnaire after evaluating the usefulness of the interface. The data collected represented activities spread over several days from the test environment and was played in compressed form for them to evaluate the prototype. Activities were highlighted and explained during the playback of telemetry to help identify what was being done. 100% of the respondents identified with what the model house prototype was attempting to do by making them more aware of their energy consumption patterns. It was found that 80% of users were able to interpret the real-time information with ease while 20% of the respondents had difficulty when the system detected an increase or decrease in the energy use and notified them through flashing LED’s. When addressing the question of technology acceptance and the fear of using new technology which can beset an older user, 100% of respondents said that they did not feel anxiety or fear regarding accepting information generated through the model house prototype. When asked if the prototype provided them with a way to monitor and adjust their habits during the day to make better use of energy, all respondents replied favourably (100%). In fact, it was discovered at this point that a number of users would like even more information presented to them on improving their energy expenditure. This proved to be encouraging and a validation that the model house improved their energy awareness and reduced their anxiety from worrying about fuel costs. Another group of 10 users (aged between 20 and 50) were used to evaluate the usability and functionality of the backend functionality of the system. This type of functionality would be used by carers or family members to help advise the older end-user on how to improve their energy-use by exposing them to fine-grained data regarding which activities were done and how potential savings could be made. The types of questions asked to these participants were predominantly focused on activity management, savings information, monthly projections and recommendations. The results from this evaluation showed that 100% of participants understood what the activities were and how they related to the system and data while 70% of participants were able to deal with, and manage, activity related features. The remaining 30% required extra guidance before they felt fully comfortable with the back-end system. When addressing the usefulness of the recommendations and potential financial savings, all participants agreed that the system was easy to use and offered important and helpful information on how to improve energy usage.

VII. Phase Two Results

Our second phase of development and testing was spread over a seven-day period and collected data from a test house (see Fig. 2). This phase primarily focused on the integration of heterogeneous IoT devices, collection, storage, processing and administrative analysis graphs. An expansion on the number the monitoring capabilities of the initial system was undertaken by incorporating off the shelf components that are readily available instead of relying on specialist hardware. More devices would be monitored, as well as lighting patterns and other information. This phase also considers the additional system based issues that were not encountered in the first stage due to the limited data collection and primary focus of interacting with the older user.

Electrical appliances were plugged into energy monitoring wireless plugs, while standard light bulbs were replaced within the house environment with equivalent wireless light bulbs. Complementing the environment, each room had a wireless motion sensor (which recorded motion, lighting and temperature telemetry) in the main living areas (front/living room, kitchen and bedroom). Telemetry was captured over a 24-hour, 7-day period. Each wireless device was given unique identifiers so that energy use could be tracked for each associated electrical appliance as well as the occupancy of the room. The house is occupied by two people (male and female) and ages range from 40's to 60's. The selection of the appliances to monitor was based on the availability of energy-aware plugs. The rooms with high energy use and occupancy were identified as the kitchen, front room and bedroom. Therefore, the appliances that were chosen were located within these rooms. The devices monitored in the kitchen were: microwave, kettle, toaster, fridge/freezer and dish washer. Ideally, the cooker and washing machine would have been monitored but these were found to be wired directly into outlets rather than being plug based. These will be monitored when running the third phase in three separate homes. In the front room, the devices which were monitored were the TV and computer. In the bedroom, a TV was monitored.

The purpose of this stage was to collect telemetry which can then be used to test system and data integration more fully before monitoring the usage of a number of older people. As telemetry was collected during the summer months, devices which aided in cooling the occupants down (i.e., fans) would have been ideal. However, the test home did not contain these. At colder times of the year, other devices that provide heat (e.g., electric blankets, central heating) would be considered and will be monitored during phase three. Motion sensing was limited to the main areas of the home (front room, kitchen, and main bedroom) and provided contextual information regarding light and temperature levels.

The results for each monitored room are shown in Fig. 8 for the Kitchen, Fig. 9 for the main living room and Fig. 10 for the bedroom. It was observed that an issue occurred during day 5. This was down to the Wi-Fi router becoming unavailable and was spotted by one of the occupants who reset it. The subsequent figures highlight the loss of telemetry during this time.

Fig. 8 shows the energy usage of the monitored devices located within the kitchen for a 7-day period. The monitored devices consist of a microwave, kettle, a fridge/freezer, toaster and dishwasher.

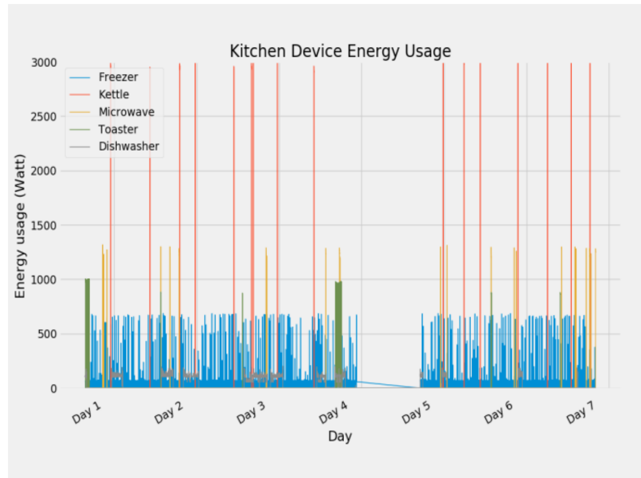

Figure 8. Kitchen device energy use.

The usage patterns and properties of each device are correctly identified for the room. The freezer has a constant load of around 50 Watts, with regular peak loads of around 600 Watts – as expected when the cooling circuits are in operation. The microwave is generally not used heavily, mainly just for preparing evening meals, so only appears at its peak load of 1200 Watts. The kettle is likewise not used regularly, appearing when used at a load of around 3000 Watts for short amounts of time. The toaster is used intermittently during the day and usually at the same time as the microwave. These times are around the time that food is prepared in the morning and afternoon/evening. The peak load of the toaster is 1000 Watts. The dishwasher is used once or twice a day and peak load is up to 250 Watts. Based on the results, and the frequency of the more commonly used items (i.e., kettle, and microwave), the system would be able to suggest times at which energy costs are lower and thereby, reduce overall costs by time-shifting to more affordable time periods. The same applies to the frequency of the dishwasher activity, where changing the times of day can result in cost savings. On the other hand, the fridge freezer which is on continuously due to the nature of the appliance would not be something that can be time-shifted. However, information would be available to provide whether the appliance is indeed energy-efficient to help identify cost savings if a newer, energy-efficient appliance was used instead.

Fig. 9 shows the energy use of the monitored devices located within the front room for a 7-day period. The monitored devices consist of a TV and a computer. The TV tends to be used briefly in the morning and lunch, and more extensively in the evening. It has a relatively high standby of around 15 Watts, and an on-power usage of around 150 Watts. The computer is mainly switched on in the evening. It has a very low standby power usage and an on-power usage of between 100 and 180 Watts.

As only two devices were monitored in the living room, the most commonly used electrical appliances in use were the TV and computer. It can be seen from fig. 9 that the TV is in use at different times of the day where it is mainly used towards the morning and early afternoon. The associated energy costs for this would be higher due to the higher energy costs from the supplier, so changing habits could result in savings. In the afternoon and evenings, both the computer and TV were in operation, although on some days, their usage was spread more evening across the day rather than clustering exclusively in the morning / afternoon / evening areas. Changing the habits of the user could result in cost savings when considering that both devices are used extensively during the day, and at times, concurrently.

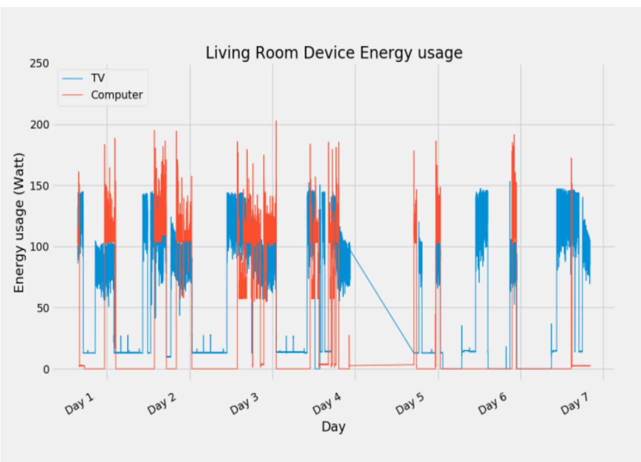

Figure 9. Living room energy use.

To enable further analysis of energy usage, the cumulative power usage of these two rooms can be plotted based on the collected data. Fig. 10 shows the cumulative energy usage in Watt-hours (Wh) of the devices in the kitchen. It shows the cumulative power usage from the devices being generally steady. This information would provide the user with an idea of the total energy consumption for the duration through the administrative interface. The accumulated energy use of the toaster shows that there was an issue with the plug storing the daily energy totals. It does match with the activity patterns in Fig. 8 where the toaster was used on day 1 and day 4 with no activity between those days.

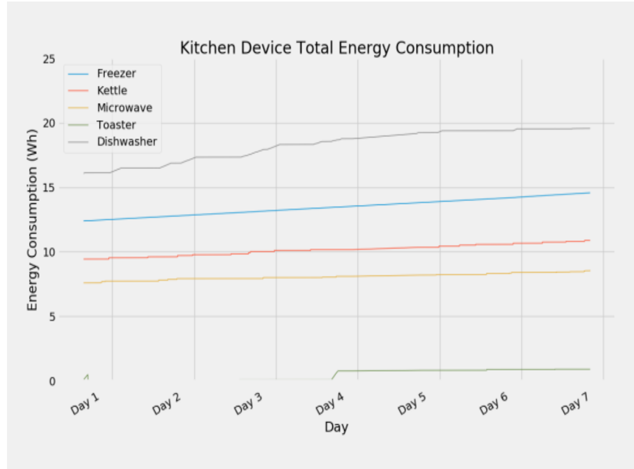

Figure 10. Cumulative kitchen device energy usage.

Fig. 11 shows the cumulative energy usage in Watt-hours (Wh) of the devices in the living room. It shows a steady increase in power usage.

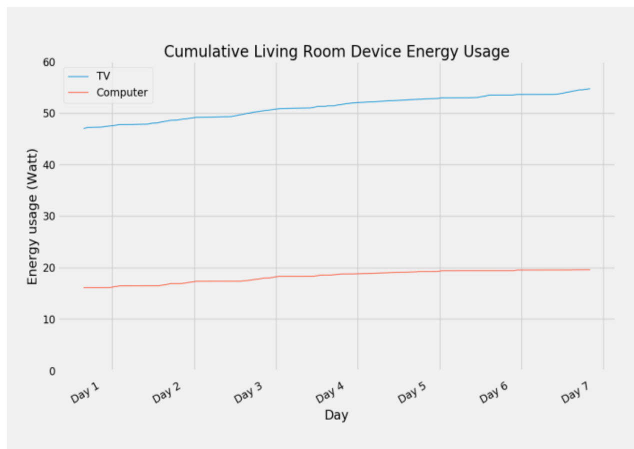

Figure 11. Cumulative living room device energy usage.

Fig. 12 shows the cumulative energy usage in Watt-hours (Wh) of the device(s) in the bedroom. Although only one device in the bedroom was monitored, the usage activity of the TV indicates rough times at which the occupants are occupying the room. This also can provide loose information about the times at which they sleep (before and after activity through TV usage). The peak load of the TV is around 80 Watts when in use for short periods of time.

Utilising more devices located within the bedroom would provide more contextual information regarding the habits of the occupants.

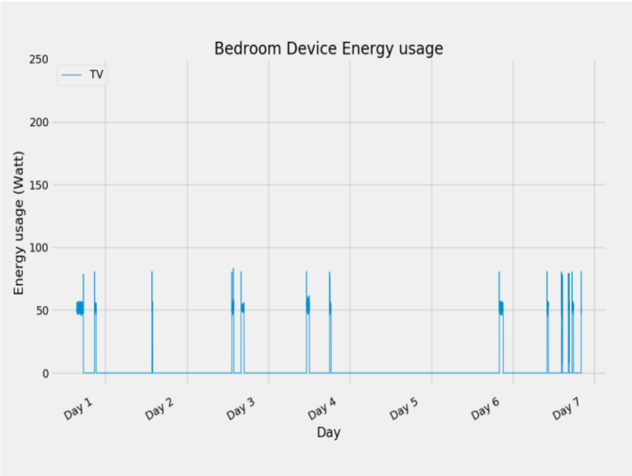

Figure 12. Bedroom energy use.

As well as monitoring the energy usage from electrical appliances, the lighting in the house was also monitored. The use of lights during the test period is shown in Fig. 13. Two types of bulbs were utilised within the home. Five TP-Link Wi-Fi enabled light bulbs were used in the main living areas. Three Hue bulbs were used in addition in the bathroom, and as supplements to the other rooms. Fig. 13 shows only the TP-Link bulb usage during the test phase as the information gathered from the Hue bulbs indicated that while not in use, energy was actually being expended.

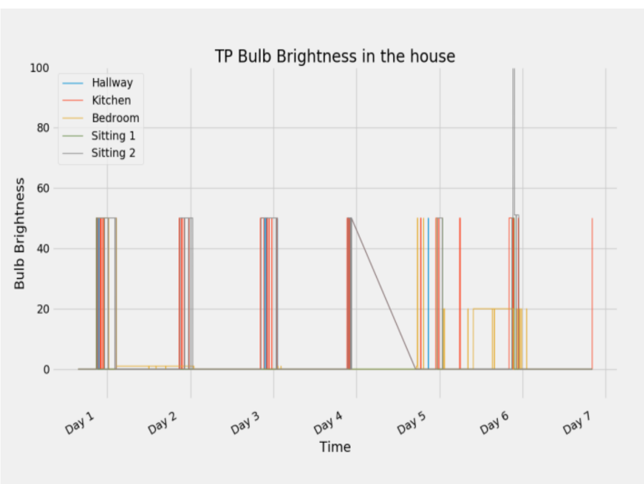

Figure 13. Light usage across the house.

In Fig. 13, it was decided to layer all the TP-Link lights in the household on the same figure, as it illustrates an important point. The household lighting is almost always switched off. There is a narrow window of 2-3 hours a day when the lights are activated which correlates with the longer days during the summer months when the data was collected. This would be greater during the winter months due to the shorter daylight hours and would suggest even more power usage efficiency. The diagonal lines represent data collection issues due to the bulbs dropping the Wi-Fi and presenting erroneous results. It is believed that the most efficient approach to reducing lighting waste is to install cheap motion sensors that activate, and de-active lights based on movement and ambient lighting. It is worth noting that the lighting data was also collected over summer, hence their minimal usage.

During this phase of testing, other issues outside of energy-awareness have been shown to be important and need to be addressed further. Issues concerning the size of the data set generated from a variety of devices and lights resulted in a database exceeding 124MB in size for the one week of testing (8 devices & 8 lights). Based on this, for a system running realistically over a year, the amount of data generated would be in the range of 6448MB. With more devices being added which are polled for telemetry, this would increase the amount of information generated. This would mean that efficiency and storage issues would come into play which was not considered in the first phase of development. The time to process information to present to end users via the administration interfaces would take considerable time and as a result, would need to implement more efficient ways on processing vast amounts of information. The same can be said when it comes to analysing behaviours and activities over a period of time for the system to provide useful recommendations. As the second phase was within a closed system (i.e., all devices were connected to a Wi-Fi router with limited internet access), any information requiring being stored on the cloud and its subsequent processing would become an issue. Another Wi-Fi related issue observed from the test data is the intermittent nature of the router itself. The one used was a fairly cheap off the shelf device but did show that the Wi-Fi signal dropped at different times. This would introduce the problem of lost telemetry which could potentially have a bearing on the recognition and analysis components. Making the collection and aggregation of this information from devices more resilient and able to cope with periods of no connectivity would need to be addressed. However, it is envisaged that the system will store and process information locally within the house. Issues regarding the privacy ~~of~~ and security of this information also pose an interesting dilemma. The information collected provides a very fine snapshot on the behaviours and activities of the occupants, and thus, privacy and the safeguarding of this information is paramount. These issues will be considered in phase three of the system development.

VIII. Phase Three Results

The final phase of testing will be conducted over the next several months with live participants. A small number of candidates will be selected which will allow us to analyse the effectiveness of the system. Both male and female test subjects will be selected so that analysis of the differences between genders, age, disability (both physical and cognitive related) and living status can be considered. In addition, system based issues regarding storage, processing, resiliency and privacy will be explored to best protect the end user from potential abuse of information. The intention is to outfit three homes with larger numbers of energy-aware plugs, motion detectors and wireless light bulbs over at least a two-month period.

IX. DISCUSSION

The goal of this work is to look at energy-awareness and how this impacts older users. Our intention was to produce a simple ICT system which would attempt to reduce the anxiety that older people experience in relation to fuel poverty as well as address the issue of accepting technology. It was found that the prototype system promoted the perceived usefulness of the system to older users. This is in addition to other areas of our research into energy-aware programming languages and runtime systems.

By focusing on the energy-awareness of everyday use from the start, the prototype system was able to successfully improve the energy use of a user over the initial trial period. The behavioural analysis and recommender systems were found to accurately identify activities which in turn aided in recognising and highlighting the cost awareness of what users were doing in association to their activities. By increasing this cost awareness of their actions, users were found to be more aware of how to reduce their energy costs by changing times or common activities to more cost-effective times of the day. Carers/family members would be able to help by raising awareness of what the older user was doing on a day-to-day basis by showing them how simple changes to their daily patterns could result in tangible cost savings as well as improved health.

In the second iteration, the primary focus was on collecting richer data sets with off the shelf sensor technologies that are commonly available. The devices that were used during this process were TP-Link energy aware plugs, TP-Link bulbs, Hue bulbs and motion sensors. A test house was outfitted with a number of rooms containing these smart devices and data was collected over a 7-day period. The energy use of the test subjects in the principle living areas (kitchen, front room and bedroom) was monitored. Although only 8 electrical appliances were monitored, usage showed basic patterns and activities during the day and night. Light usage was also monitored but as the experiment was performed during the summer months, limited lighting patterns were shown. The amount of data collected over one week showed that additional investigation is required in the storage and processing of large data sets to provide a responsive system, as well as the privacy and safe guarding of intrusive information and resiliency of transmission / reception of information.

The next phase is to introduce more technology into three homes and monitor more electrical appliances. This is currently underway, and with the intention to capture several months of usage data to validate the system and house interface. Experiments on how the system affects the overall well-being of the older person will also be conducted as well as the impact of gender, disability (both physical and cognitive related), living status and age on their acceptance and use of the technology.

X. CONCLUSION

This paper has argued the case for simpler interaction and energy-aware systems for helping older members of the community to be aware of, and monitor their energy expenditure. This is a relevant societal problem which is addressing the anxieties of fuel poverty facing vulnerable groups of individuals as well as their acceptance of technology. An initial prototype system has been introduced as well as the lessons learnt from this first phase along with a subsequent data collection phase detailing the testing and analysis of a bigger data set. Following this, the considerations for the future direction of the work has been outlined. In summary, the benefit of energy-aware systems has shown to be a positive influence of the well-being of an older person by reducing their anxiety concerning interacting with technology and reducing costs associated with fuel poverty.

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