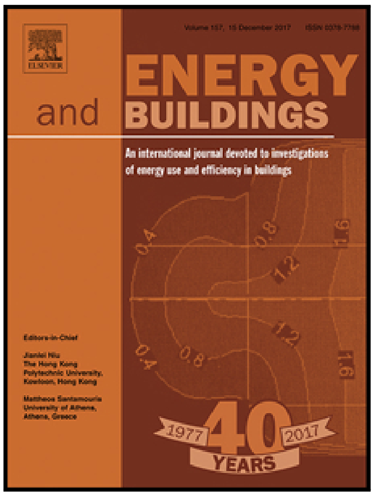
Accepted Manuscript



Implementing an integrated meter and sensor system (IMSS) in existing social housing stock

Ashish Shukla , Shuli Liu , Mark Gaterell , Georgina Wood , Rosie Day , Obiajulu Iweka , Atif Hussain , Dan Van der Horst , Panagiotis Petridis

PII: S0378-7788(17)33211-5
DOI: https://doi.org/10.1016/j.enbuild.2018.10.012
Reference: ENB 8841

To appear in: *Energy & Buildings*

Received date: 25 September 2017
Revised date: 22 August 2018
Accepted date: 15 October 2018

Please cite this article as: Ashish Shukla , Shuli Liu , Mark Gaterell , Georgina Wood , Rosie Day , Obiajulu Iweka , Atif Hussain , Dan Van der Horst , Panagiotis Petridis , Implementing an integrated meter and sensor system (IMSS) in existing social housing stock, *Energy & Buildings* (2018), doi: https://doi.org/10.1016/j.enbuild.2018.10.012

Implementing an integrated meter and sensor system (IMSS) in existing social housing stock

Ashish Shukla[a], Shuli Liu[a*], Mark Gaterell[b], Georgina Wood[c], Rosie Day[d], Obiajulu Iweka[a], Atif Hussain[a] , Dan Van der Horst[c], Panagiotis Petridis[e]

[a]Centre for Built and Natural Environment, Faculty of Engineering, Environment and Computing, Coventry University, Coventry CV1 2FB, UK
[b]Faculty of Technology, University of Portsmouth, Portland Street, Portsmouth, PO1 3AH, UK
[c]Geography and the Lived Environment, University of Edinburgh, Drummond Street, Edinburgh, EH8 9XP, UK
[d]School of Geography, Earth and Environmental Sciences, University of Birmingham, Edgbaston, Birmingham, B15 2TT, UK
[e]Operations and Information Management Group (OIM), Aston Business School, Aston University, Aston Express Way, Birmingham B4 7ET

Abstract:

The current rollout of smart meters for gas and electricity, both in the UK and internationally, will help suppliers to better forecast demand and supply accurate bills to consumers. However, even with an in-home display (IHD), the benefits of a smart meter to a domestic customer are limited by the so-called 'double invisibility' of energy [1] and the standardisation of IHD design for an imagined home 'micro-resource manager' [2]. Furthermore, low-income households may be limited in the benefits they can reap from such systems; already living within a tight budget, suggestions for further energy-related cost savings may be detrimental to their health and wellbeing. This makes it important that the impact of actions taken to save energy is communicated. This can be done using indoor environmental measures, including carbon dioxide, relative humidity and temperature, as part of an integrated meter and sensor system (IMSS) and an associated IHD or digital application. Such a system gives users the ability to make informed decisions about their energy use and indoor environmental health. This paper explores the potential barriers to implementing an

[*] Corresponding author: Email: Shuli.Liu@coventry.ac.uk
Tel: +44 (0) 24 7765 7822

IMSS in practice. It explains how an IMSS was designed, based on a review of meter and sensor systems; details the process is taken to trial the IMSS in 19 social housing properties in the English Midlands; and makes recommendations for a larger scale rollout of IMSSs. The paper also reviews current progress in cloud storage and security as relevant to IMSSs and smart metering.

Keywords: Integrated meter and sensor system; Energy; Social Housing.

1.0 Introduction

Managing energy consumption in domestic buildings has a key role to play in helping to meet a broad range of environmental and social policy priorities; in particular, limiting carbon emissions and potentially helping to combat fuel poverty. Clearly, the appropriate design and construction of such buildings is an essential element in managing demand, however, occupant behaviour also plays a significant part. Indeed, the household behaviour is a key factor that dictates energy consumption, efficiency and conservation [3]. Traditionally, householders received data on consumption through their bills, often several months in arrears, making it difficult to link specific elements of behaviour to the energy consumed. One way by which policy makers and other stakeholders have been trying to ensure occupants recognise their role in managing energy demand and address this issue is through the implementation of so-called smart meter programmes. Smart meters are devices that provide far greater levels of detailed consumption data and feedback than tradition meter systems, often in real time [4, 5, 6] and it is this increased level of feedback to households that are expected to deliver the anticipated reductions in energy consumption [6, 7]. It is important to recognise that the drive to implement programmes which deliver the wide uptake of such meters is global; encompassing both developed and developing countries [8].

While smart meters are considered to be 'essential tools for gaining access to information regarding energy consumption in an objective and transparent manner' [8]there are growing concerns that, as currently implemented, they do not actually deliver the anticipated benefits through reductions in energy consumption. For example, while smart meters collect and present real-time data on consumption, research suggests that such data do not enable consumers to recognise specific aspects of their energy usage that would allow them to make effective changes to their behaviour [5]. The suggested 'double invisibility', namely the fact that energy is not only invisible but it also cannot easily be linked to everyday behaviour, suggests that data generated from smart meters might not by themselves be sufficient to ensure behaviour change occurs [1]. Consequently, the nature of the data collected and the way in which they are presented, particularly the type of interface adopted, are likely to play a key role in the efficacy of smart meters as a tool to manage energy consumption [7, 9, 10].

Increased feedback also has the potential to cause unintended consequences, particularly amongst certain types of households. For example, for those in fuel poverty, there might be very limited opportunity to reduce energy consumption without raising health or wellbeing related risks [9]. Under such circumstances feedback that simply focuses on absolute energy consumption or the financial implications associated with energy-related behaviour might be counterproductive. For such households or those vulnerable to going into fuel poverty e.g. people living in social housing, the nature of the data used to help inform behaviour, as well as the interfaces adopted, might need to focus as much on helping users understand when their behaviour jeopardises health or wellbeing as on financial benefits. Reeves et. al highlighted that social housing in the UK exists to provide affordable housing, having equally shared responsibilities between local councils and housing associations [11]. Such an approach would require the impact of users' actions that affect energy consumption on the key determinants of comfort, such as operative temperature, humidity etc., to also be fed back through an appropriate interface.

This paper explores the potential barriers to implementing an integrated meter and sensor system (IMSS) designed to address this issue and deliver data that link energy consumption with a range of environmental indicators associated with comfort. It focuses on the application of such systems for lower-income households and on their implementation in existing dwellings. It also presents a review of the advantages and disadvantages of cloud computing for IMSSs.

2. Defining IMSSs

2.1 Use of IMSSs in different fields

IMSSs incorporate a number of different sensors that can be integrated into a single system to monitor a range of conditions. IMSS applications can be classified into two main categories: tracking and monitoring (see Figure 1). Tracking applications include tracking animals, humans, objects and vehicles while monitoring applications include indoor/outdoor environmental conditions, health, power, factory and process automation, seismic activity and structural performance [12].

IMSSs are also used to monitor energy consumption in the commercial and industrial sectors and results have shown great benefits in energy management. Consequently, IMSSs are now finding the way into the residential sector [13]. The deployment of IMSSs in the residential sector faces challenges such as a perceived invasion of privacy, difficulty in ensuring data security and issues related to the acceptability of different technologies. The development of wireless sensor networks systems (WSNs) has in part made the installation of IMSSs more acceptable and delivered benefits such as reducing installation time and providing the ability to monitor inaccessible locations e.g. at certain heights where wiring is not possible. [14].

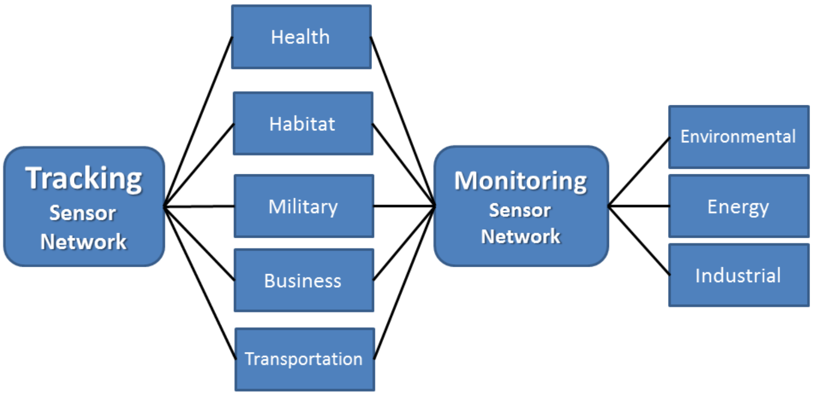


Figure 1. Sensor network applications

2.2 Displaying data collected from IMSSs

In many cases, an IMSS is in place for the purpose of collecting and transmitting data. However, it is beneficial to display and feedback the collected data, for reasons of transparency and user education. Indeed, the UK smart meter roll-out programme is providing an in-home display (IHD) with every installed meter.

A large body of literature exists reviewing trials of IHDs with energy monitoring systems in domestic and workplace settings. People have been found, in practice, to use IHDs for different purposes. For example, several studies report the use of the IHD to determine a benchmark or baseline; for instance, being used as a 'tracking device' to keep the household's energy consumption below a certain benchmark [2]. Hargreaves et al. [15] noted many participants speaking about being 'in the red/black' or in credit, and personal or household establishment of a baseline. This was also the case in the two small-scale studies reported by Pierce et al. [16], where participants used devices to determine what they considered to be 'normal' consumption and to monitor this. None of the study's users looked to reduce their consumption.

These kinds of studies have been used to provide recommendations for effective IHD design. No clear picture emerges on favoured types of visual display. A speedometer display was universally favoured in one focus group study [17], though the use of an

IHD designed around the concept of a car dashboard was found to be more popular with men in another study [15]. In a study in which six different types of water IHD display (including a virtual aquarium) were shown to users, the bar graph design was preferred by 67% of participants. However, there was little agreement *within* each household as to their preferred design, leading to the suggestion that multiple options should be available [18]. Displaying energy use in monetary terms is commonly argued to be popular and easily understood [17], and a key benefit of an IHD is the ability to provide near-real time information. Yet Wood and Newborough [19] warn that displaying energy use financially might not help encourage a reduction in usage, as day-to-day figures tend to be low. Displaying total expenditure over a month or a year may be more influential.

The effectiveness of gamified forms of feedback has been acknowledged. Goal setting [20] and comparisons with self and other households [21, 22] have been noted to be effective ways of providing feedback about energy consumption [23]. Already, aspects such as comparisons and setting goals have been integrated into energy feedback from UK suppliers (e.g. neighbourhood average; [24]; targets and budgets, [25]).

There is a dearth of studies reporting on systems that collect data on indoor environmental conditions and feed this back to the occupants of the property, although the usefulness of incorporating information on humidity, temperature and carbon dioxide has been noted for motivating behavioural changes [19] and monitoring the activities of elderly relatives living independently [26].

3.0 Challenges arising from implementation of IMSSs

Considerable research has already considered the development of IMSSs to monitor energy consumption in the residential sector (Table 1); and while this paper focuses on the potential barriers to the implementation of IMSSs in the residential sector identified in one of these projects, the Smarter Households project, it does so in the broader context of this other work. Smarter Households is a 5-year project funded under the UK Engineering and Physical Sciences Research Council (EPSRC) BuildTEDDI programme (Transforming Energy Demand in buildings through Digital Innovation). The project aims to explore how households can be engaged with their energy use data through the use of an interactive three dimensional 'Energy Dashboard' application. IMSSs were installed in 19 homes owned by the social housing provider Orbit Housing in the West Midlands, UK.

A key feature of the project is the 'Energy Dashboard' application which allows the household to view their data on the tablet provided. In order to design 'Energy Dashboard' application the proposed IMSS architecture is displayed in Figure 2. This have three main layers (i) data collection from end users/service provider (ii) storing data to Coventry University data base server and internet server and (iii) linking the data using appropriate user interface to be used on tablets by end user. This was designed in conjunction with the social housing provider via participatory design workshops, and extensively tested and evaluated before making it available to the trial households.

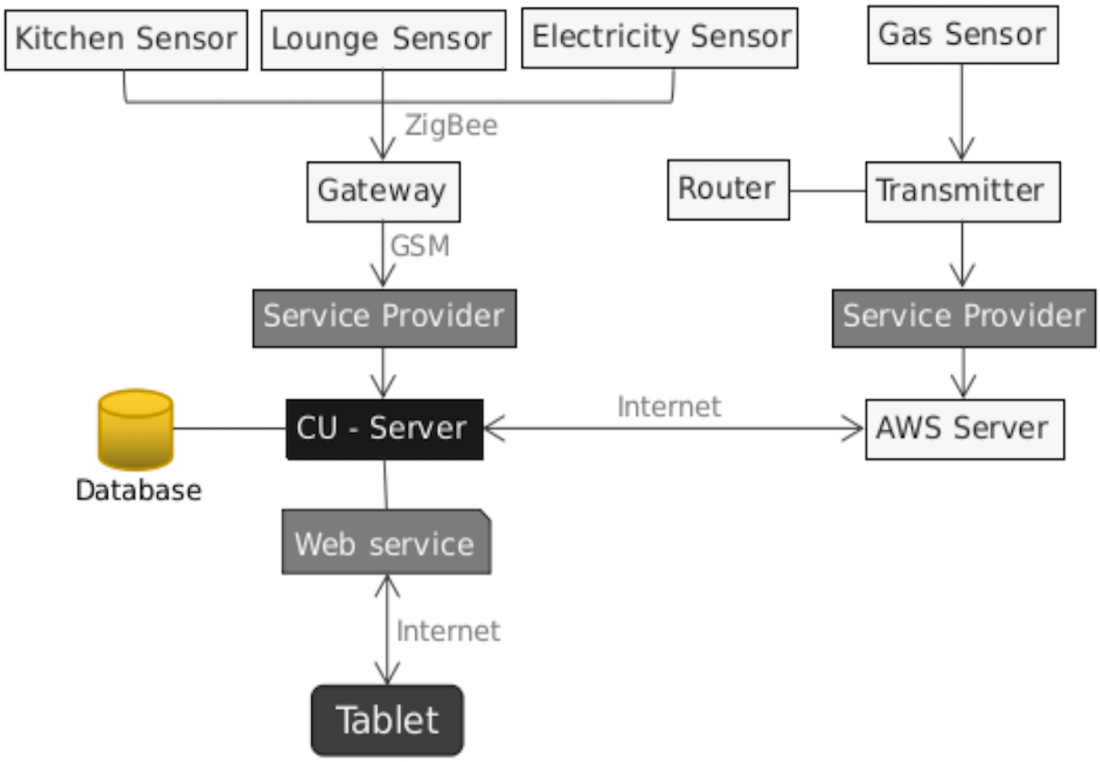


Figure 2 The proposed IMSS architecture.

Organisation Projects	**Internal data transfer Data transfer from sensor to logger /gateway**	**External data transfer Data transfer from logger to server**	**Software used in house or proprietary**	**Database format**	**Data storage *RNS= Remote Network Server (Cloud) *LNS local Network Server**	*Project data*
Waterford Institute, Ireland *(9 homes monitored) (2012)*	ZigBee	Wi-Fi (Internet)	Proprietary *company web based*	*Microsoft SQL*	LNS	A bespoke system was designed to monitor whole building energy use for one year pre- and post-retrofitting. The wireless system installed in nine social housing dwellings regularly (15 minutes) logged indoor temperature, humidity, external temperature wind speed and direction as well as volatile organic compounds, gas, segregated electricity are measured. ZigBee communication protocol was applied for internal data transfer to a gateway and internet Wi-Fi to transfer data from various gateway to a HUB (internet hub in a house) and then transfer the data via internet to the LNS server. In stage 1 three options were explored for the wireless communication within the houses: 1. Self-designed system using all bi-directional wireless transmitters and receivers on a permitted frequency; 2. ZigBee, an international free open standard; 3. Zwav-, similar to Zigbee, a proprietary system requiring a license to use

						from Sigma Designs. All Zwave devices work with each other. They work on a lower frequency than ZigBee so have better range for the same power but antennas are physically larger. The cost of both Zwave and self-designed systems were found to be too expensive to implement; therefore, a Zigbee system was used. Stage 2: The use of a General Packet Radio Services (GPRS) SIM card to transfer data was also investigated but due to potential reliability issues it was deem unattractive, therefore Internet was used [27].
Nottingham Trent University *Nottingham City Homes* (NCH) *(2012-2015)*	proprietary radio 868MHz	*GPRS*	Proprietary software	MySQL	(Cloud) company server	40 Social homes were monitored using sensors to have online real-time data. Homes were monitored based on their age of built and occupancy type, 10 points were monitored per home. The WSNs was used to measure; door and window openings, gas, electricity and water consumption, indoor, outdoor air temperature, radiator temperatures and front external wall temperature were measured. Thermal imaging and thermal real time video imaging were also used to obtain an insight in the relationship between energy consumption and occupancy behaviour patterns. The IMSS also investigated if various energy saving devices installed in homes would reduce energy consumption. The IMSS system employed proprietary RF to transfer data from the sensors to the gateway and then used GPRS to transfer data to the cloud storage [13]. The main challenges identified with the installation were related with sensor size and design. The gateways were

						installed in the loft of the homes to prevent the occupants turning of the gateway.
Loughborough University (LEEDR) Low Effort Energy Demand Reduction (2010-2014)	-Stand-alone -- ZigBee	*Internet*		-	*Cloud (RNS) and LNS(standalone sensors)*	The project employed a combination of energy monitoring, video ethnographies and workshop techniques to explore opportunities for energy demand reduction through digital innovation and assess the possible impact a changing energy landscape might have on family life. The system used both stand-alone sensors and wireless network to transfer data [28, 29].
University of Edinburgh (IDEAL) *Intelligent Domestic Energy Advice Loop (2013-2017)*	ZigBee	*Internet*	In house analytics	*MySQL*	LNS	The project is a sociotechnical study, concentrated on existing housing, with a strong social science component and an experimental design that looks at income levels and household composition as primary factors. The project aims to monitor up to 600 homes for data on, gas, electricity consumption, light level, temp, humidity, temp sensor on hot water pipes. Wireless sensing, machine learning, and natural language generation technologies were utilised. Using an IMSS the project aims to construct an

						intelligent advice loop that will provide information to householders on what activities they are engaging in which use energy, and how much energy is used for each one, together with suggestions for what they might do to reduce their energy expenditure. For stage 1 the temperature and humidity data related to behaviour are gathered using a small number of wireless sensors in the home (using mostly ZigBee technology), together with data on weather, building factors and household composition. For stage 2, this data is then transmitted over the internet to storage servers, where it is analysed using Bayesian machine-learning methods to extract household-specific behaviours in near-real time. Information on the cost, carbon content and amount of energy used for specific behaviours is reported back to the householders via a dedicated wireless tablet [30].
University of Nottingham *(Nottingham Green street) (2012-)*	proprietary radio 868MHz	*GPRS*	Proprietary software	MySQL	Cloud and company server	The IMSS has been used to monitor eight newly constructed houses that aim to achieve level 4 of the Code for Sustainable Homes (CSH) and Building for Life Gold standard. The homes were designed to maximise use of natural light and minimise energy consumption and are expected to have levels of insulation and air tightness which far exceed current UK building regulations. The homes also have whole-house ventilation systems and natural heat stacking to maximise warmth in winter and cooling in summer. The IMSS monitored the project deployed using proprietary RF to transfer data from the sensor to the gateway and

						used GRPS to transfer data to cloud storage.
Delft University of technology, Netherland *(3 homes test)*	ZigBee	*GPRS and 3G*	Proprietary *Web base software*	MySQL	Cloud (RNS)	The aim was to design a low cost HEM system. The main objectives of the IMSS system were to enable and inform the end user to make decisions concerning a) trade-offs for switching appliances on and off at a given time of day, b) scheduling the ventilation and screens of the house based on preferences/weather condition, c) enabling user to set temperature settings by different zones based on preferences/presence, d) informing the user expected and current amount of solar energy/net electricity, e) providing advice on energy storage, given planned electrical vehicle (EV) connected to a house. The IMSS system was tested in three research locations (Germany, UK and the Netherlands), where users could remotely control real-time electricity usage through web and other mobile devices such as smart phones or smart pads. The research tested both the use of Wi-Fi and ZigBee and found that ZigBee was more energy efficient than Wi-Fi, therefore ZigBee was chosen over Wi-Fi. The findings also suggested that the response time increases when using a smart phone to control a single light in a house as the command needs to travel back and forth to the central server over 3G. The findings concluded that response time is expected to be instantaneous inside a house, therefore a Wi-Fi access point would need to be presented to facilitate response times [31].

University Salford University (DEHEMS) Digital Environmental Home Energy Management System (2009-2011)	-Radio frequency 433MHz - ZigBee	*Internet*	-	XML format. Into SQL format	RNS	The Digital Environment Home Energy Management System (DEHEMS) project is a European Union funded project, looking at how technology can improve domestic energy efficiency. The project aimed to extend the current state of the art in intelligent meters, to look at the way in which energy is used. Bringing together sensor data in areas such as household heat loss and appliance performance as well as energy usage monitoring, it offered real time information on emissions and the energy performance of appliances and services. In turn the potential exists to make changes to appliances/services remotely from the mobile phone or PC. The system can also provide specific energy efficiency recommendations for the household. The home data is transferred using ZigBee and RF from the sensor to the gateway and internet to the store servers [32] [33].
University of Bath (ELITEN) Energy Literacy Through an Intelligent Home Energy Advisor	-ZigBee -Wi-Fi	Internet	*In house software using API method*	*MySQL*	Cloud (RNS) for electric & gas, other sensors data stored on LNS	The project monitored up to 80 homes with the aim to reduce carbon emissions from energy use within buildings by understanding, incentivising and influencing changes in the habitual behaviours of the buildings' occupants. The IMSS system used in the project included an in-house manufactured gateway using a Raspberry Pi, which allows the monitoring sensors to transfer data using ZigBee and Wi-Fi and then using internet transfers the data to storage server.

(2012-2016)						The project has deployed various monitoring sensors having different data protocol which has resulted in the storage of the data in both local and cloud storage. [34, 35, 36]
Nottingham Trent University (Estate Department) 2012-	proprietary radio 868MHz	*GPRS*	Proprietary software	MySQL	Cloud and Company server	Nottingham Trent University campus buildings are monitored
Coventry University-Smarter household	GPRS	GPRS and internet	*Proprietary (Design of software-dashboard and serious gamification)*	MySQL	Virtual server LNS	Monitoring of total 20 house measuring gas, electricity, indoor environment and ambient temperature.
Universitaet des Saarlandes, Germany	ZigBee	*Internet*	Proprietary company software	Postgre SQL	Cloud	The IMSS system consists of three technical components: information acquisition, information processing, and information presenting, The aim of the research project is to integrate a system using ZigBee sensor networks and an intelligent home gateway. The IMSS system is to continually sense and updates electricity data in order to provide real-time electricity consumption information to users. The main function of

						the IMSS system gives the users the option of remotely monitoring and control household appliances to save energy. The data is views via the internet and is stored on the cloud [14].
University of Exeter (DANCER) Digital Agent Network for Customer Energy Reduction (2012-2016)	-ZigBee -XBee	Internet	*In-house*	MySQL	LNS The Raspberry Pi is the Storage server.	The IMSS system used in the project has manufactured its own gateway using a Raspberry Pi, which allows the monitoring sensors to transfer data using ZigBee and XBee to the gateway. The project has successfully investigated the use of the gateway as a device that not only transmits data but also it can be used as a storage server with access to the data via internet connection. The aim of the project is to deploy an IMSS to develop a system that uses wireless sensors and embedded software to produce a system that both interactively and automatically manages users' energy consumption within indoor environments. The system employed novel sensing and communication mechanisms which monitored users' movements and the energy use of a range of appliances These data, together with the information either collected directly from end users via their smart phone application (e.g. indications to reduce energy use by 20%) or inferred indirectly from user habits, were fed into a decision making agent that decides when to switch on/off certain appliances and for how long.

Table 1 A review of past and current UK energy and indoor environmental monitoring projects

4. Technological barriers and issues

4.1. Investigation of existing meters and sensors in residential buildings

Selecting the correct equipment for a diverse range of housing stock, even for a small sample of 20 houses, has been challenging. For example, the type of gas or electricity meter installed plays a significant role in the ease with which key data can be collected. Some of the gas and electricity meters encountered are highlighted below (Figure 3).

Typical George Wilson make gas meter

Typical George Wilson (new) make gas meter

Typical schlumberger make gas meter

Typical Krome Schroeder gas meter

Typical Siemens electricity meter

Typical AMPY electricity smart meter

Typical Landis Electricity meter

Typical Sangamo Weston Ltd. Electricity

meter

Figure 3. Range of gas and electricity meters encountered.

While there is a significant diversity of gas meters, for the purpose of this analysis two types can be distinguished (i) digital (or smart meters) and (ii) dial meters. In order to read the digital/smart meters, they must be configured such that they can link directly to the cloud and the IMSS server. In some cases, in the Smarter Households project, this meant an existing meter would have to be replaced with a new metering system capable of transmitting data to the designated server. In contrast, it is possible to directly measure dial meters with optical devices e.g. using Loop Energy (www.loopenergysaver.com) (Figure 4). Meaning that the existing metering set up need not to be disturbed.

Loop Energy gas metering device

Gas metering in a typical house before Loop Energy device installation

Gas metering in a typical house after Loop Energy device installation

Figure 4. Installed Loop Energy gas metering

Similar issues relate to electricity meters, although in this case installation of a clamp has proved to be effective (Figure 5).

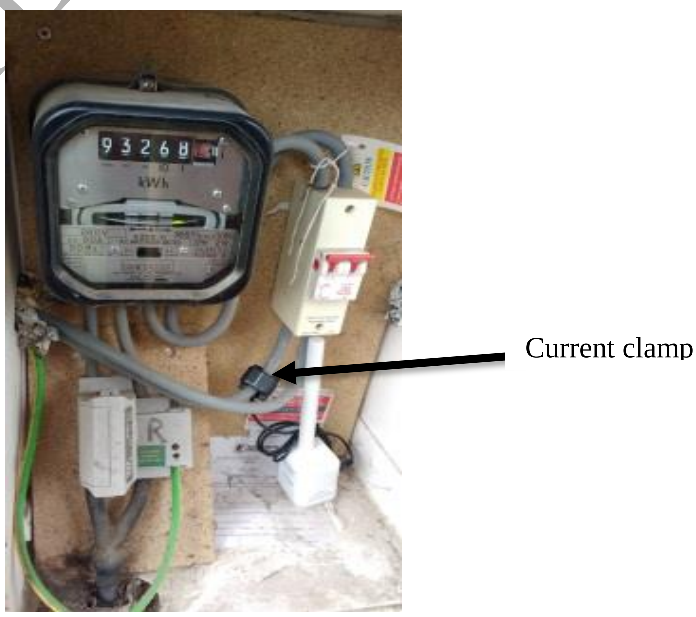


Figure 5. Clamp attached to electricity meter

In addition to monitoring of gas and electricity, each house was also installed with CO_2, temperature and humidity sensors located in the lounge and kitchen (Figure 6). Smarter Households decided to adopt a wireless sensor network approach for the following reasons:

1. To avoid dependency on wiring and associated risks in the households; and

2. Ease of data collection and assessment.

The key challenges faced during the implementation of this network were:

1. Finding a suitable place on the property to locate temperature and humidity sensors;

2. Compatibility of monitoring technology with metering e.g. the curved screen of some gas meters makes it almost impossible for them to be fitted with monitoring equipment;

3. Sensors falling off, or occasionally being removed/displaced/ powered off by the householders;

4. Households switching off internet routers or electrical sockets during holidays;

5. Range limit of network and sensors, and

6. Type of construction e.g. apartments with concrete flooring makes it impossible for sensors to communicate with the network if meters are located on the ground floor.

Bathrooms and bedrooms have not been considered as part of monitoring privacy because of reasons.

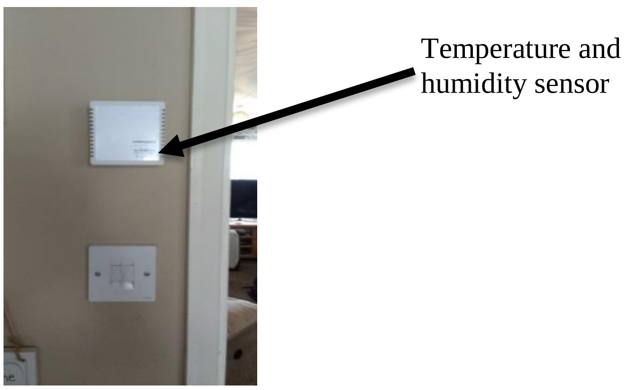


Figure 6. Installed temperature and humidity sensor in the lounge

4.2 Data collection, storage and security issues

(i) Data transfer

Current research suggests there is no single method used to transfer internal data from the sensors to the gateway; however the use of ZigBee is increasingly popular due to the low associated costs (Table 1). Indeed, the UK smart meter programme will also use ZigBee technology to transfer data from the smart meters to the gateway. Smarter Households has adopted radio frequency to send sensor data to the gateway because they are good with the range where sensors have been installed and it has been found that their installation has been very reliable in terms of communication between gateways and sensors.

The method of transferring data from the gateway to the required storage server depends on the complexity of the project. The most popular method used to send the data from the gateway to the required storage server is via the internet (Table 1).

For the Smarter Households project, General Packet Radio Services (GPRS) was used to send data from the gateway to a storage server. The reasons for this selection were:

1. No need of internet;
2. Accuracy and reliability of data is much better and
3. Possible data loss is minimal.

(ii) Data Storage

As the quantity of data increases, the need for data storage also increases. Traditionally, large quantities of data were stored in local servers (person and company-based servers), but the popularity of cloud computing has introduced a new type of storage server: “cloud storage”. Currently, the understanding of cloud computing is developing and changing constantly, and cloud computing still has no unanimous definition [37]. However, the most common understanding is that the cloud is the common term for the infrastructure that allows organisations to receive IT services via a network such as an internet. These services can be data storage, computing power, or even complete software applications and the platforms on which they. It can be said that cloud computing as a new business model has developed from distributed processing, parallel processing and grid computing. Larger organisations such as Amazon, Google, IBM, Microsoft, Sun and various other IT giants are all investing significant resources in developing cloud computing technologies and products [38].

Hosted services delivered through the cloud are divided into three categories: Infrastructure-as-a-Service (IasS), Platform-as-a-Service (PaaS) and Software-as-a-Service (SaaS). [37, 39].

The service delivery model allows the users to rent virtualised servers and associated services for running existing applications or developing and testing new applications. Cloud computing is usually classified based on either the service or deployment model, Figure 7 shows the standard cloud definition framework [40, 39].

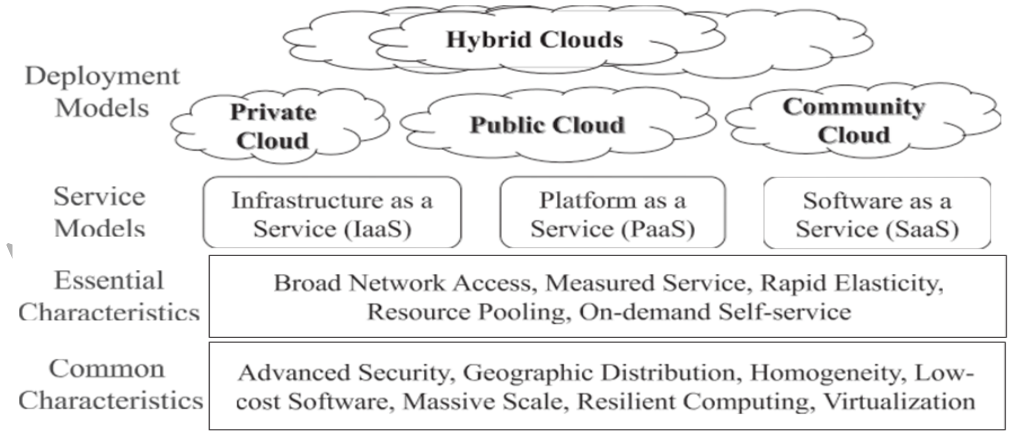


Figure. 7. The cloud definition framework [40]

Private cloud is proprietary network-owned or rented by an organisation, and the whole cloud resource is dedicated to that organisation for its private use. An example of this model is a cloud built by an enterprise to serve their business- critical applications [41].

Public cloud is where the cloud infrastructure is for open use by the general public: it may be owned, managed, and operated by a business, academic, or government organisation, or a combination of them [41]. It exists on the premises of the cloud provider; end-users can rent parts of the resources and can scale their resource consumption to their requirements. Examples of public cloud providers are Amazon, eBay, Google, and Microsoft.

A Community cloud is similar to a private cloud, but where the cloud resource is shared among members of a closed community with shared interests. A community cloud may be owned, managed, and operated by one or more of the organisations in the community, a third party, or some combination of them, and it may exist on or off premises [40]. An example of a community cloud is the media cloud set up by Siemens IT solutions and services for the media industry.

Hybrid cloud is the combination of two or more cloud infrastructures; these can be private, public, or community clouds. The main purpose of a hybrid cloud is usually to provide extra resources in cases of high demand, for instance enabling migration of some computation tasks from a private cloud to a public cloud [42].

(iii) Security and privacy

Communicating data over the public internet as an alternative to keeping it entirely within a private corporate network will increase data vulnerability [43]. Much of the concern around cloud security is related to third-party management [44], with the most critical security concern being about privacy and user data confidentiality. The end users' concern is that data in the cloud is owned by them but they have no information on where it is stored and which other organisation will have access to their private and confidential data. The organisation using cloud data storage needs to be assured that the critical information is not accessed and used illegally, even by the cloud providers. Data stored at the cloud service providers are affected by two major legal policy challenges, firstly data protection policy legislation by the cloud provider, and secondly by the legislation of the countries where the cloud providers reside. It is common for cloud service providers to have a standard contract with terms that are generally favorable to them and not to the user. When using the cloud services, the users will have to agree to the ‘‘terms of service’’ which could in fact grant the providers the right to disclose the private and confidential user information in compliance with laws and law enforcement requests. If deciding to use the cloud the users need to make sure that the contract has the organization's interest secured. Currently, the European Union (EU) has issued directive 95/46/EC, which aims to protect user privacy. The directive prohibits transfers of personal data to countries which do not ensure an adequate level of protection, however the law does have clauses where the transfer of personal data outside EU countries is legally possible if it is done with the owner's consent or if it is done to a country having a ‘‘safe harbour principle’’ and under some other special cases as mentioned in Article 26 of the directive. However, implementation and enforcement of this directive outside the European Union borders will be a major challenge to implement. Cloud computing has its advantages and disadvantages, which have been summarised in Table 2. While the technology can prove to be a great asset to the organisations using it, it could also cause harm if not understood and used properly. Cloud computing is the inevitable product with the development of the internet, and it has also introduced more rich applications to the internet. Cloud data storage technology is the central area in cloud computing and solves the data storage mode of the cloud environment. The popularity in the usage of cloud computing and cloud storage is increasing, and it is here to stay until it is replaced by other alternative technologies.

Table 3 summarises the cloud data user specific security requirement

Public cloud service providers, including Amazon, Microsoft, Rackspace, Google and others, have invested significant sums in ensuring the physical security of their data centre buildings. These companies employ teams of dedicated IT security staff, trained and concerned with ensuring that their systems are as secure as possible. New security standard that has been published on the 25th September 2013 such as ISO 27001 and 27002 describe the steps to be taken in maintaining physical and online security and also provides detail steps to be conducted in responding to breaches. [45].

Advantages of cloud computing	Disadvantages of cloud computing
Automatic software integration: In most of the cases cloud computing provides automatic software integration. Which implied that users do not need to put further efforts and can use applications are per their requirements. **Unlimited storage:** Data storage is key issues as we generate big amount of data every day. Cloud can provided large data storage capability. **Backup and recovery:** Most of the cloud computing service provider take regular backup, sot it is very secure and restively easier to backup data and get it when required. **Easy access and quick deployment:** Cloud based services can be accessed from anywhere while they do need internet connection to do so. Physical constraint of location is not valid anymore. Also, cloud computing services have benefit to be deployed relatively faster than having own	**Cloud limitation**: There are some limitations while using cloud computing e.g. some cloud computing provider can only support operating system compatible with their infrastructure. **Prone to attack and security issues:** It is always important to analyse the risk involved in storing sensitive information as many times cloud spaces are prone to attach and need special attention to avoid so. Security is further issue for risk of sensitive data. Paper will discuss some of security concerns in detail. **Technical issues:** As cloud based services require internet, service upgrade and technical issues. Access to cloud can interrupt and organisations should be aware of the fact that this technology is always prone to outages.

infrastructure. **Cost efficiency and environmental benefits:** Cloud computing bases services can share the expensive software's and reduce the cost of individual licenses. Also scaling up cloud bases services is rather easy and cost efficient. It is claimed that cloud computing is more likely to reduce the energy consumption and thus can reduce the carbon footprint and energy cost.	

Table 2 The Advantage and Disadvantages of Cloud computing [46, 47]

Level	Service level	Users	Security requirements	Threats
Application Level	Software as a Service (SaaS)	End client applies to a person or organisation who subscribes to a service offered by a cloud provider and is accountable for its use	• Access control • Communication protection • Data protection from exposure (remnants) • Privacy in multitenant environment • Service availability • Software security	• Data interruption (deletion) • Exposure in network • Impersonation • Interception • Modification of data at rest and in transit • Privacy breach • Session hijacking • Traffic flow analysis
Virtual Level	Platform as a Service (PaaS) and Infrastructure as a Service (IaaS)	Developer – moderator applies to a person or organization that deploys software on a cloud infrastructure	• Access control • Application security • Cloud management control • Communication security • Data security, (data in transit, data at rest, remnants) • Secure images • Virtual cloud protection	• Connection flooding • Defacement • Disrupting communications • Exposure in network • Impersonation • Programming flaws • Software modification • Software interruption

				(deletion) • Session hijacking • Traffic flow analysis
Physical Level	Physical data centre	Owner applies to a person or organisation that owns the infrastructure upon which clouds are deployed	• Legal not abusive use of cloud computing • Hardware reliability • Hardware security • Network protection • Network resources protection	• Connection flooding • Hardware reliability • Hardware interruption • Hardware theft • Hardware modification • Misuse of infrastructure • Natural disasters • Network attacks

Table 3 User specific security requirement [48]

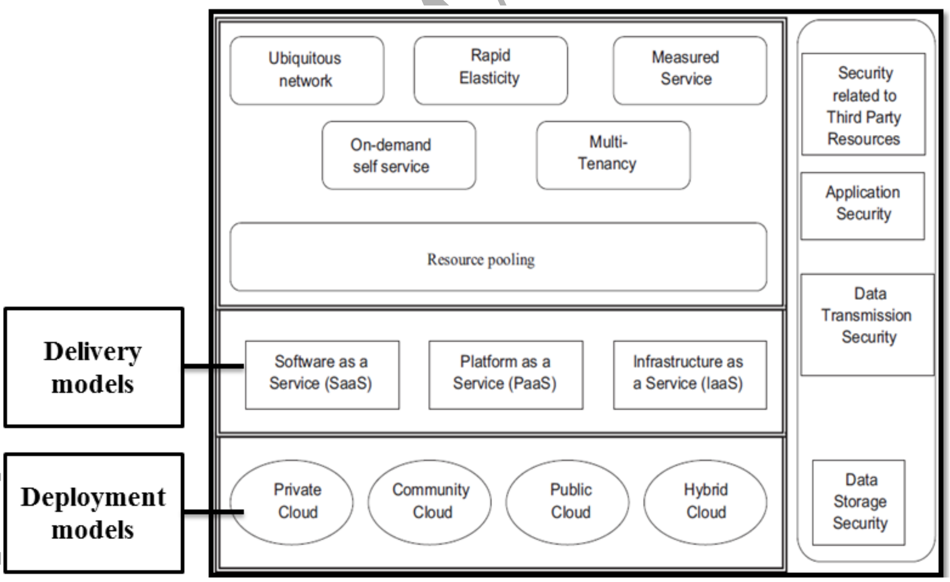


Figure 8 The complexity of the security in cloud environment [49]

Different deployment models and their delivery models for cloud are presented in Figure 8. Authors [48] reported that the various delivery models exhibit certain traits e.g. on-demand self-service, multi-tenancy etc. Resource pooling is when the service provider's computing resources are pooled together to serve multiple consumers using multiple-tenant model. On-demand self-services includes computer services such as email, applications, network or server service can be provided without requiring human interaction with each service provider. Cloud service providers which provide on demand self-services include Amazon web services (AWS), Microsoft, Google, IBM and Salesforce.com. Rapid elasticity cloud services are services that can be rapidly and elastically provided if required, the cloud services can be quickly scaled up or down depending on demand for the service. Ubiquitous network access cloud services are available over the network and accessed through standard mechanisms such as mobile phones, tablets, laptops and personal digital assistant (PDAs). Multi Tenacity in cloud computing refers to the need for policy-driven enforcement, segmentation, isolation and governance [50]. The above mentioned fundamental elements of cloud computing require security, which can vary depending on three features: 1) the deployment model that is used, 2) the method in which it is delivered and 3) the characteristics it exhibits. The main fundamental security challenges are data storage security, data transmission security, application security and security related to third-party resources.

(iv) Current security solutions

The security issues related to the use of cloud computing and storage are very complex and an issue of concern for organisations. Consequently, various groups and organisations have committed considerable effort to developing security solutions and standards for the cloud. The main contributors are Open Grid Forum (OGF), Cloud Computing Interoperability Forum (CCIF), Distributed Management Task Force (DMTF), Open Cloud Consortium (OCC), Cloud Security Alliance (CSA) and International Telecommunications Union (ITU). Table 4 shows both the main contributors and the participants working in the cloud security sector. A summary of recommendations for organisations that wish to use cloud computing and data storage is, that the data storage provider will need to provide security at the data storage, data processing and data transmission stages. The critical point for the data transmission is that the data in transit needs to be protected either at the application or the transmission level. The most common is the transmission level for protection and the secure sockets layer (SSL)/transport layer security (TLS) protocols. Data at rest must be protected by the application; the application must provide a mechanism to protect the data stored in the cloud. The most secure way to use a cloud storage service is to encrypt the files before they are stored on the cloud. If the encryption key is with the user, any un-authorised user will not be able to easily decrypt the files and therefore will not be able to read or use the data in the files. Whilst this is a good approach for a storage or archive service, it will not be possible to share these files with anyone without also sharing the encryption key which could be difficult to manage, and if the encryption key is lost or forgotten then it might not be possible to decrypt the files.

Organisation	Participants
Open Grid Forum (OGF)	Microsoft, Sun Microsystems, Oracle, Fujitsu, Hitachi, IBM, intel, HP, eBay.
Cloud Computing Interoperability Forum (CCIF)	Cisco, Intel, Thompson Reuters, Orange, IBM, RSA.
Distributed Management Task Force (DMTF)	Board Member: IMB, Microsoft, Novell, Oracle, Sun Microsystems, VMware, EMC.
Open Cloud Consortium (OCC)	Cisco, MIT Lincoln Labs, Yahoo, University of Illinois (Chicago), and various colleges.
Cloud security Alliance (CSA)	eBay, ING, Qualys, PGP, Zscaler.
International Telecommunications Union (ITU)	ITU-T member’s states / Sector / Associate.

Table 4 Cloud security contributors and participants.

5. End user concerns

In general, the Smarter Households trial found participating households to be motivated and accommodating when it came to having the IMSS installed in their homes. In most cases, participants were not fazed by the equipment being installed. Further to the technical challenges noted earlier in section 3, a difficulty was encountered in positioning 3-in-1 sensors where they would be collecting accurate readings but not be conspicuous. Some conditions were also made by the housing provider (e.g. preferring sensors to not be affixed to wallpaper, and screws/nails to not be used).

As expected with this type of user group, many households were already doing all that they could to keep their energy consumption low. In some cases, it was notable that they could have been encouraged to take further action which may have been detrimental to their health and wellbeing, and so showing indoor environmental data flagged up where the environment was in danger of becoming unhealthy. In other cases, this data caused householders to reflect upon the choices they could make in order to reduce the relative humidity in their home, including turning up the thermostat and opening windows whilst cooking, although barriers existed to them doing so (e.g. cats climbing through windows and eating food whilst it is being prepared). Some common misunderstandings emerged amongst householders which needed to be addressed: in particular a concern that their Energy Dashboard app was displaying high carbon monoxide readings (when in fact the IMSS was measuring carbon dioxide).

While almost all participants reported regularly using the app, very few properties had more than one person in the household using the app. This may be an advantage of a typical smart meter IHD which can be placed anywhere in the home to constantly display collected data; however similar outcomes have been found in other studies with traditional IHDs which are moved to home offices, or put away in drawers [15]. Having the IMSS data displayed on a tablet application enabled the Smarter

Households researchers to add more engaging features through colours and gamified elements, such as the ability to set personalised goals, and earn points through reading hints and tips.

6. Government Policy support

The UK smart meter roll-out programme aims to replace 53 million ‘dumb’ meters with smart meters by the end of 2020. As of 30 September 2016, 4.05 million smart meters were operating in UK homes (8% of all domestic meters) [51]. The gas and electricity meters will transmit energy consumption data to the IHD and communications hub via a home area network (HAN) using ZigBee [52]. Smart meters and IHDs alone will not save households money, and a clear opportunity exists for engaging people with their electricity and gas consumption data and increasing energy literacy through providing displays and systems which offer more detailed information than the standard IHDs offer.

7.0 Conclusions

As existing ‘dumb’ meters are getting old, most commercial electricity and gas providers are looking to replace these by smart meters because these can provide more accurate and regular information at lower cost. But rather than leaving this transition to individual companies, a government-coordinated transition to universal smart metering has the potential benefits of greater standardisation, data security, provision of data feedback to citizens and governance of energy data for wider societal benefits. But whilst government-sanctioned smart meters plus in-home displays provide households with information about energy use and costs in unprecedented detail. Improving the energy management in the home is impossible for people to pursue without also having reliable information about the benefits of energy use and the trade-offs of reduced energy consumption, including the risks of deterioration in indoor air quality if homes are insufficiently warm and ventilated. In other words, smart meters need to be accompanied by smart sensors in the home. Hence IMSS is essential for the successful adoption of smarter energy use by households. This paper reported some early experiences in the installation of IMSS in voluntarily participating households. We found that implementing IMSS on existing properties is quite difficult and this can only be achieved smoothly once householders have smart meters installed in their properties.

Acknowledgements

This work has been supported by EPSRC smarter household project (EPSRC, Grant No.: EP/K002716/1, An Intelligent Digital Household Network to Transform Low Carbon Lifestyles).

References

[1] J. Burgess and M. Nye, "Re Materialising energy use through transparent monitoring systems," *Energy Policy,* vol. 36, no. 12, pp. 4454-4459, 2008.

[2] Y. Strenger, "Designing eco-feedback systems for every day life," in *CHI 2011*, Vancouver, BC, Canada, 2011.

[3] X. Tong , R. Li, F. Li and C. Kang , "Cross-domain feature selection and coding for household energy behaviour," *Energy,* vol. 107, pp. 9-16, 2016.

[4] G. Pepermans, "Valuing smart meters," *Energy Economics,* vol. 45, pp. 280-294, 2014.

[5] J. Fletcher and W. Malalasekera, "Development of a user- friendly, low cost home energy monitoring," *Energy,* vol. 111, pp. 32-46, 2016.

[6] I. Laicane, D. Blumberga, A. Blumberga and M. Rosa, "Reducing household electricity consumption through demand side management: the role of home appliance scheduling and peak load reduction," *Energy Procedia,* vol. 72, pp. 222-229, 2015.

[7] S. Darby, "Smartmetering: what potential for householder engagement?," *Building Research and Information,* vol. 38, no. 5, pp. 442-457, 2010.

[8] J. Leiva, A. Palacios and J. A. Aguado, "Smart metering trends, implications and necessities: A policy review," *Renewable and sustainable energy reviews,* vol. 55, pp. 227-233, 2016.

[9] K. Buchanan, R. Russo and B. Anderson, "The question of energy reduction: the problem(s) with feedback," *Energy Policy,* vol. 77, pp. 89-96, 2015.

[10] T. Hargreaves, M. Nye and J. Burgess, "Keeping energy visible? Exploring how householders interact with feedback from smart energy monitors in the longer term," *Energy Policy,* vol. 52, pp. 126-134, 2013.

[11] A. Reeves, S. Taylor and P. Fleming, " Modelling the potential to achieve deep carbon emission cuts in existing UK social housing: the case of Peabody," *Energy Policy,* vol. 38, no. 8, pp. 4241 - 4251, 2010.

[12] J. Yick, B. Mukherjee and D. Ghosal, "Wireless sensor network survey," *Computer Networks,* vol.

52, pp. 2292-2330, 2008.

[13] A. Lotfi, L. I. Jalil and A. Al-Habaibeh, "Investigating occupant behaviour to improve energy efficiency in social housing case study," in *9th International Conference on Intelligent Environment(IE'13)*, Athens, Greece, 2013.

[14] W. H. Kim, S. Lee and J. Hwang, "Real-time energy monitoring and controlling system based on ZigBee Sensor Networks," *Procedia Computer Science,* vol. 5, pp. 794-797, 2011.

[15] T. Hargreaves, M. Nye and J. Burgess, "Making energy visible: A qualitative field study of how householders interact with feedback from enery monitors," *Energy Policy,* vol. 38, pp. 6111-6119, 2010.

[16] J. Pierce, C. Fan, D. Lomas, G. Marcu and E. Paulos, "Some consideration on the (in)effectiveness of residential energy feedback systems," in *DIS 2010*, Aarhus, Denmark, 2010.

[17] W. Anderson and V. White, "Exploring consumer preferences for home energy display functionality: Report to the energy saving trust," Centre for sustainable energy, Bristol, 2009.

[18] J. Froehlich, L. Findlater, M. Ostergren, S. Ramanathan, J. Peterson, I. Wragg, E. Larson , F. Fu, M. Bai, S. N. Patel and J. A. Landay, "The design and evaluation of prototype eco-feedback dispalys for fixture-level water usage data," in *CHI 2012*, Austin, Texas, 2012.

[19] G. Wood and M. Newborough, "Energy-use information transfer for intelligent homes: enabling energy conservation with central and local displays," *Energy and Buildings,* vol. 39, pp. 495-503, 2007.

[20] L. J. Becker, "Joint effect of feedback and goal setting on performance: a field study of residential energy conservation," *Journal of applied psychology,* vol. 63, no. 4, pp. 428-433, 1978.

[21] J. H. Van Houwelingen and F. W. Van Raaij, "The effect of goal-setting and daily electronic feedback on in-home energy use," *Journal of consumer research,* vol. 16, pp. 98-105, 1989.

[22] OPower, "Five Universal truths about energy consumers," OPower, London, 2013.

[23] W. Abrahamse, L. Steg, C. Vlek and T. Rothengatter, "A review of intervention studies aimed at household energy conservation," *Journal of Environmental Psychology,* vol. 25, no. 3, pp. 273-291, 2005.

[24] E.ON, "Saving Energy Toolkit," 2017. [Online]. Available: https://www.eonenergy.com/for-your-home/help-and-support/saving-energy-toolkit. [Accessed 22 January 2017].

[25] British Gas, "Electricity monitoring user instructions," 2017. [Online]. Available: https://www.britishgas.co.uk/content/dam/british-gas/documents/Electricity-monitor.pdf. [Accessed 22 February 2017].

[26] M. Fahim, I. Fatima, S. Lee and Y. k. Lee, "Daily life activity tracking application for smart homes using android smartphone," in *14th International conference on advanced communication technology,* PyeongChang, Korea, 2012.

[27] D. Sinnott and M. Dyer, "Energy monitoring programme for social housing in Irerland: Pre and Post retrofitting," in *Retrofit 2012 Conference*, Salford, 2012.

[28] P. C. Jorda, R. A. Buswell, L. H. Webb, L. Mackley, R. Morosanu and S. Pink, "Energy in the home everyday lige and the effect on time of use," in *13th Conference of the International Building performance simulation association* , Chambery, France, 2013.

[29] T. Coughlan, K. L. Mackley, M. Brown, S. Martindale, S. Schlogl, B. Mallaband, J. Arnott, J. Hoonhout, D. Szostak, R. Brewer, E. Poole, A. Pirhonen, V. Mitchell, S. Pink and N. Hine, "Current issues and future directions in methods for studying technology in the home," *PsychNology,* vol. 11, no. 2, pp. 159-184, 2013.

[30] N. Goddard, J. Moore, C. Sutton, J. Webb and H. Lovell, "Machine Learning and multinedia content generation for energy demand reduction," in *Workshop on sustainable internet and ICT sustainability (SustainIT)*, 2012.

[31] D. V. Keyson, A. Al Mahmuda, M. d. Hoogh and R. Luxen, "Designing a portable and low cost home energy," in *3rd International conference of sustainable energy information technology (SEIT 2013), Procedia computer science 19*, Delf University, 2013.

[32] N. Shah, C. F. Tsai and K. M. Chao, "Monitoring appliances sensor data in home environment: Issues and challenges," in *IEEE Conference on commerce and enterprise computing*, 2009.

[33] V. Sundramoorthy, Q. Liu, G. Cooper, N. Linge and J. Cooper, "DEHEMS: A user-driven domestic energy monitoring system Internet of Things(IOT)," 2010.

[34] T. Lovett, E. Gabe-Thomas, S. Natarajan, E. O'Neill and J. A. Padget, "'Just enough' sensing to ENLITEN: a preliminary demonstration of sensing strategy for the 'energy literacy through an intelligent home energy advisor'," ENLITEN Project, 2013.

[35] E. Gabe-Thomas, I. Walker and B. Verplanken, "Exploring mental representations of home energy practices and habitual energy consumption," in *Behaviour and energy efficiency conference BEHAVE 2014*, 2014.

[36] T. Lovett, E. Gabe-Thomas, S. Natarajan, M. Brown and J. Padget, "Designing sensor sets for capturing energy events in buildings," *e-Energy*, pp. 229-230, 2014.

[37] S. Zhang, H. Yan and X. Chen , "Research on key technologies of cloud computing," in *2012 International Conference on Medical Physics and Biomedical Engineering*, 2012.

[38] K. Liu and L. J. Dong, "Research on cloud data storage technology and its architecture implementation," *Procedia Enginnering*, vol. 29, pp. 133-137, 2012.

[39] C. Rong, S. T. Nguyen and M. G. Jaatun, "Beyond lightning: A survey on security challenges in cloud computing," *Computers and electrical engineering*, vol. 39, pp. 47-54, 2013.

[40] P. Mell and T. Grance, "Recommendations of the national institute of standards and technology, The NIST definition of cloud computing," NIST Special publication.

[41] G. Laatikainen, O. Mazhelis and P. Tyrvainen, "Role of acquisition intervals in private and public cloud storage costs," *Decision Support Systems*, vol. 57, pp. 320-330, 2014.

[42] Y. Lu, X. Xu and J. Xu, "Development of a hybrid manufacturing cloud," *Journal of manufacturing systems*, 2014.

[43] Ernst & Young, "Report on cloud computing issues and impacts, part of global technology industry discussion series," EYGM Limited, 2011.

[44] P. G. Dorey and A. Leite, "Commentry: Cloud computing- A security problem or solution?".

[45] N. Beagrie, A. Charlesworth and P. Miller, "Guidance on cloud storage and digital preservation," The national archives, 2014.

[46] A. Jula, E. Sundararajan and Z. Othman , "Review cloud computing service composition: a systematic literature review," *Expert systems with applications* , vol. 41, pp. 3809-3824, 2014.

[47] M. G. Avram, "Advantages and challenges of adopting cloud computing from an enterprise perspective," in *The 7th international conference interdisciplinary in engineering (INTER-ENG 2013)*, 2013.

[48] D. Zissis and D. Lekkas, "Addressing cloud computing security issues," *Future generation computer systems*, vol. 28, pp. 583-592, 2012.

[49] S. Subashini and V. Kavitha, "A survey on security issues in service delivery models of cloud computing," *Journal of Network and Computer applications*, vol. 34, pp. 1-11, 2011.

[50] K. Chadha and A. Bajpai, "Security aspects of cloud computing," *International journal of computer applications*, vol. 40, no. 8, 2012.

[51] BEIS, "Smart meter quarterly report to end september 2016," BEIS, London, 2016.

[52] DECC, "Smart meters, smart data, smart growth," 2017. [Online]. Available: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/591322/09022017_-_Smart_Meters__Data__Growth_DR_-_updated.pdf. [Accessed 22 February 2017].

[53] R. N. Katz, "The gathering cloud: is this the end of the middle?," in *The tower and the cloud: higher education in the age of cloud computing*, 2008.

[54] T. Andresen, "Report on the technical and economic," Chalmers University of Technology, Ratingen, Germany, 2009.

[55] UK Office of national statistics, "Household and Individuals," 2013. [Online]. Available: http://www.ons.gov.uk/ons/dcp171778_322713.pdf .