Programme Area: Distributed Energy

Project: Micro DE

Title: Project Analysis of the Benefits of Buildings Energy Services Control Systems

Abstract:

Please note this report was produced in 2010/2011 and its contents may be out of date. This deliverable is number 3 of 7 in Work Package 3. The report builds on earlier work from within the project to assess the role which Building Energy Management Systems can play in conjunction with micro DE technologies and energy storage to reduce energy consumption in the UK. The report draws a number of conclusions and makes recommendations regarding the development of intuitive controls / displays and standards.

Context:

The project was a scoping and feasibility study to identify opportunities for micro-generation storage and control technology development at an individual dwelling level in the UK. The study investigated the potential for reducing energy consumption and CO_2 emissions through Distributed Energy (DE) technologies. This was achieved through the development of a segmented model of the UK housing stock supplemented with detailed, real-time supply and demand energy-usage gathered from field trials of micro distributed generation and storage technology in conjunction with building control systems. The outputs of this project now feed into the Smart Systems and Heat programme.

WP3.3 Analysis of the Benefits of Buildings Energy Services Control Systems

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	Version: **1st April 2011**

Executive Summary

This report is one of seven reports presenting the findings and recommendations from the ETI Micro Distributed Energy project, a scoping and feasibility study to determine the opportunity for Distributed Energy (DE) technology development. The report deals specifically with the potential contribution of building Energy Services Management (ESM) systems in the residential setting.

Features of existing conventional and more advanced control systems were examined, through analysis of outputs from earlier phases of this project (factsheets, workshops, user feedback from field trials, etc.).

Four key themes were identified that highlight key failings of the current approach to control of energy use within the home:

- demonstrating benefit is not easy;
- government incentives take no account of the possible impact of advanced control systems;
- greater account of human factor is required;
- and future designs need to address integration of a host of appliances, devices and micro DE technology.

Drivers for change in existing approaches were examined to establish future needs. The supply and management of energy within the household is likely to become increasingly complex in the coming decades:

- schemes are being introduced to encourage building envelope refurbishment to improve insulation and reduce energy needs;
- building owners are installing technologies such as solar thermal, micro-CHP boiler replacements, heat pumps and solar PV panels;
- greater use is being made of energy storage, in the form of thermal mass (both hot and cold) and in batteries, either to exploit time-of-use energy pricing or to match supply and demand efficiently;
- a programme of installation of smart metering for gas, electricity and distributed heat is underway;
- new loads on the distribution system will appear as electric vehicles and air conditioning become more prevalent;
- appliances for lighting, entertainment, etc., continue to evolve.

This additional complexity adds problems to the user interface. For instance, with some control systems associated with micro DE technology, homeowners report difficulty in optimising performance or having to adapt behaviour to suit the technology. Typically[1], because of mismatch between output and demand profiles, around 43% of electricity generated from solar PV systems is fed back into the grid and not used within the home. For wind and micro-CHP the proportion is even higher at 49% and 45%, respectively.

[1] "Metering and Monitoring of Domestic Embedded Generation Part 2 – Data Analysis". BEAMA. November 2007

A building ESM system is therefore needed with an effective user-interface and adaptive control to integrate all the functions above and enable householders to meet their needs cost-effectively. Systems will need to optimise not just traditional space heating and hot water systems, but also integrate Micro DE systems, thermal storage and its release. Similarly decisions on optimum source from which to draw energy will need to be made: prioritising on-site generation, withdrawal from storage, or grid-supplied power at a given moment in time requires knowledge of and balancing a large number of factors. The likely features of such a system are explored and a table of required functionality is presented.

A roadmap for development of a building ESM system is suggested. Functionality needs are identified that will accommodate likely near-term drivers, such as widespread broadband access, growth in energy generation from sustainable sources and micro-CHP, and smart metering. Interaction with Smart appliances offer further demand-shifting possibilities, but its take-up will be dependent upon agreement of a standard communications protocol. Further into the future participation in regional/national demand-shifting schemes will need to be provided. In the longer-term, growth in electric vehicles will present a need for further demand-shifting, but provide opportunities for sizeable regional/national electricity storage and export in times of high demand.

The benefits and main beneficiaries of key functions of a building ESM system have been identified in the form of a function-stakeholder matrix.

Conclusions

1. The UK's policy on security of energy supply and climate change, translated into specific initiatives such as smart metering, Feed-in Tariffs, the Renewable Heat Incentive and the Green Deal for Housing, present a significant driver for development of more advanced building ESM systems. However there is no specific initiative or support mechanism for such advanced control systems themselves.
2. Establishment of widespread broadband services under the UK government's Universal Service Broadband Commitment will facilitate the establishment of "Smart" services and open up further possibilities for building ESM systems.
3. Integration of a building ESM system across a wide range of appliances and devices could result in a wide range of benefits, such as energy savings, reduced emissions and demand shifting, to the householder, grid operators and society.
4. Current Building Regulations deal with individual equipment and they do not consider the impact of device integration and the complex energy management duties of a building ESM system. Potential benefits are therefore unlikely to be recognised at the design stage.
5. In the longer-term, the growth of electric vehicles will place additional demands on grid operation and a building ESM can optimise timing of their re-charge. Conversely a large fleet of domestic electric vehicles represent a potential means of management of the lulls and slews in power generation associated with sustainable sources.

Recommendations

1. Development of improved controls and displays which are clear and intuitive are vital.
2. An agreed standard communication protocol for communication with and between Smart appliances is essential if growth in Smart appliances is to occur and the potential benefits realised.

3. A roadmap for development of building ESM systems is suggested, which aligns functionality requirements with likely technology developments and the anticipated impacts of specific government initiatives.

1. Introduction

This report is one of seven reports presenting the findings and recommendations from the ETI Micro Distributed Energy project, a scoping and feasibility study to determine the opportunity for DE technology development. The project combined desk top research and modelling with a small scale field trial to assist with the understanding of the supply and demand of energy services in residential dwellings.

This report deals specifically with the potential contribution of a Buildings Energy Services Management System in the residential setting. Section 2 provides an analysis of existing control systems (conventional and more advanced home energy management controls, controls associated with micro-DE and controls associated with home appliances) and highlights deficiencies in the way control is currently applied to Domestic Hot Water (DHW), Domestic Heating (DH) and micro DE. Section 3 examines the requirements for future control systems by examining a range of drivers for change in the approach generally taken by system suppliers. In Section 4 the concept of a Buildings ESM System is introduced and a product development roadmap is suggested. Finally, Section 5 sets out targets for change.

2. Review of Existing Systems

In this section an analysis of existing systems is presented. By existing systems, we mean principally:

a) conventional associated with conventional DH or DHW equipment and more advanced home energy management controls;
b) control systems associated with micro- DE equipment, such as thermal DE, electric DE or micro-CHP equipment; or
c) control systems associated with home appliances.

The emphasis is strictly on the control systems and not on the technology itself (be it solar thermal, solar PV, micro-CHP, etc.) as this document is concerned solely with the role that more sophisticated control systems might play in improving the benefits of such technologies.

Areas requiring improvement were identified by analysis of a variety of source material output from the earlier stages of this ETI project:

1. **Fact Sheets.** Work Package 1 produced a number of fact sheets, which provide basic information on the technology and key device features in the following key areas:

    a. Individual micro DE technologies
    b. Conventional domestic heating and hot water controls
    c. Advanced home energy management controls
    d. Thermal DE controls
    e. Electric DE and micro-generation controls
    f. Home appliances in a DE environment

Reviewing the factsheets allowed a number of deficiencies of existing systems to be identified, which can be subsequently grouped and classified.

2. **<u>The Occupant Interviews Report</u>.** Work package 3.2 delivered a report from a series of interviews with the occupants of 18 homes participating in a field trial of micro DE technologies.
3. **<u>The Lessons Learned Log</u>.** During the field trial mentioned above, a number of issues arose that were recorded in a "Lessons Learned Log". Whilst many of the issues relate solely to the operation of the field trial itself, some did have relevance to control systems and merit inclusion.
4. **<u>The Constraints Workshop</u>.** A workshop held on 17th November 2010 identified a number of issues for various micro-DE technologies. Although a large number of these issues were related to the technology itself, a number of deficiencies relating to control systems were identified.

The reader's attention is drawn to Table 1 in Appendix A, a **key summary** that lists all of the issues identified during this project, compiled for each area from the Factsheets and from the occupant interviews that can be associated with the control systems (rather than the micro-DE technology itself).

Also in Appendix A, Table 2 lists issues recorded during the Constraints Workshop that have relevance to control systems.

Tables 1 and 2 contain a large amount of detail and in order to provide clarity it was found helpful to group many of the individual points into a smaller number of key themes that are common to many technologies or control systems and these are summarised below.

Theme 1: Demonstrating benefits

Although advanced control systems and strategies could reduce energy usage it is difficult to quantify savings:

a) <u>At the design/assessment stage</u>. The lack of independently reviewed research based evidence, particularly for new types of controls, means SAP cannot offer a simple method to estimate potential benefits of individual control strategies. An assessor has to resort to calculations based on estimates and judgement from available information.
b) <u>During use.</u> Users typically have only a gross view of energy usage and, because the environment is continually changing (weather, home activities, etc.) it is difficult to assess how much change in energy use is attributable to the installation of DE equipment and controls. The lack of indication of current performance also impacts on the way householders interact with the system (see Theme 3).

The failure to quantify benefits adequately makes it difficult to justify investment in increased capital costs for DE systems.

Theme 2: Existing Government incentives

Government incentives in the form of the Feed-in Tariff (FIT) and the proposed Renewable Heat Incentive (RHI) are aimed principally at the installation of power generation or renewable heat technologies. There is currently nothing to incentivise the specific installation and use of advanced control systems, so retro-fit is not generally practiced. Control systems for advanced DE equipment are generally at the discretion of the manufacturer/supplier and advanced control systems tend not to be used. The level of (government) incentive is generally constant for each technology, so there is little to be gained by the manufacturer/supplier in fitting any form of advanced control systems.

Under the existing FIT and proposed RHI schemes, the sole purpose of metering is the quantification of renewable electricity or heat that is generated and hence the amount of incentive payment to be made. Smarter use of meter readings to infer, verify and ultimately optimise, performance is neither mandated nor directly[2] rewarded. So whilst, for example, the use of smart home appliances interacting with an advanced control system could contribute to a reduction in use of energy, the lack of a specific incentive inhibits both their design (by manufacturer) or use (by the homeowner) because of increased costs compared with conventional control mechanisms.

Theme 3: Human behaviour

Control systems for current DE technologies may require continual adjustment to optimise performance and users are averse to frequent intervention. On the other hand, a lack of visibility of a control interface discourages interaction and gives little feedback on performance, efficiency, energy saving (or even if the system is working). Ideally, a smart control system should continually adjust to optimise performance with little human intervention, yet provide a simple, clear indication of actual performance against an appropriate target, or use of the most appropriate tariff.

Some current DE systems trigger a change in household activities because of (unforeseen?) consequences of the technology. In some instances the change could be considered minor and not an unwanted outcome. For instance, some thermal DE users reported showering in the evening so as not to trigger unwanted heating of hot water by an immersion heater, some changed use of the washing machine to match hot water availability. Electric DE systems have also been reported to trigger change in activities requiring electricity to be used when it is being produced (e.g. Solar PV systems). Perversely, however, the combination of non-optimised performance and the green/sustainable image of the technology may even lead to increased energy use[3].

The control system display/interface can also be problematical. Common problems are with hard-to-interpret and non-intuitive displays, and deep menus requiring drill down to multiple sub-levels. Users tend to have most interaction with conventional controls, such as the thermostat and programmer/timer and have little interaction with the controls of the DE system itself. Some displays are rarely visited because they are located in inaccessible or inconvenient places such as the loft space (inverters) or outside (heat pumps). Users may also treat DE systems like conventional heating systems resulting in non-optimal performance. Often just one member of the household interacts with and understands a DE system.

Occupancy sensors are not entirely reliable and users are reluctant to use them.

Finally, users have reported concerns over smart home appliances, such as the safety of appliances when left (e.g. perceived increase in fire risk), increased risk of flooding, the need to change daily routines, and doubts about the maturity of the technology.

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[2] Although there is, of course, some indirect reward created by the differential between the export tariff and the buy-back price from the grid.
[3] See Section 2.4 of Report on WP3.2.1 "Findings from the field trial occupant interviews"

Theme 4: Design aspects

Control systems tend to be integral to DE technology and as a consequence there is little retro-fit of more advanced control systems to existing technologies and there is little incentive for common communication interfaces between various DE technologies, other in-home devices and advanced control systems.

There has been some initial concern over both the security of wireless communications, particularly if details of occupancy are broadcast. Reliability and cross interference of wireless signals could also be an issue. In refurbished houses where internal insulation containing aluminium foil has been employed, signal strength suffers.

High capital cost is a major issue, which requires users to take a more sophisticated view of whole life costs. This is not helped by difficulties in quantifying benefits and, for some components, unknown reliability and lifetimes.

Integration of micro DE equipment with conventional equipment (e.g. immersion heaters) and human activities needs to be considered more in the design of advanced control systems. Whilst more advanced control systems for DE are emerging, they are still limited to control of a single system and lack the wide-ranging functionality of a building ESM system.

3. Drivers for Change

In this section future advanced control systems are considered. Key drivers for change in the UK are identified, together with a number of technological developments likely to impact in this area.

Climate Change and Security of Energy Supply

Appendix B discusses in more detail the drivers that have led successive UK governments to address the challenges of climate change and security of energy supply.

Households play an important part in current energy use and carbon dioxide emissions (29% and 27% of the UK total, respectively) and if the UK's plans are to be realised a significant shift in energy use and emissions is clearly required. Heat is the dominant energy use; water heating (17%) and space heating (66%) in particular. Electricity adds a further 15% of total energy used in the home. Two-thirds of today's housing stock will still be in existence in 2050, much of which was built prior to the introduction of Building Regulations Part L (Conservation of Fuel and Power – see later in this section).

Three key initiatives have been therefore been launched or are about to be launched by the UK government to address the three aspects of electricity needs, heat needs and building energy performance:

- **The Feed-in Tariffs (FITs)** provide support for renewable electricity installations up to 5 MW. FITs were introduced in April 2010 and offer a financial incentive to install electricity generating technologies such as solar PV. Equipment and installation must be accredited, e.g. for systems below 50kW accreditation by the Microgeneration Certification Scheme (MCS) is required. This scheme ensures a minimum standard for equipment and installation, including controls.

- **The Renewable Heat Incentive** (RHI), launched in March 2011, is intended to similarly incentivise renewable heat generating technologies. Its introduction will be in two phases. The first phase will be targeted towards large emitters in the non-domestic sector, although £15 million has been ring-fenced for Renewable Heat Premium Payments to householders that install renewable heating systems. A second phase, which will include long-term tariff support in the domestic sector, will be introduced in 2012 to coincide with the introduction of the Green Deal for Homes.
- **The Green Deal for Homes** is a framework to enable private firms to offer consumers energy efficiency improvements to their homes at no upfront cost, in return for a charge in instalments on their energy bill. In the Government's proposals[4], Green Deal finance could extend to micro DE in the future, but initially it is expected that such measures be funded through alternative finance mechanisms such as FIT and RHI. It is uncertain what the scheme will require in terms of equipment and installation, and controls, but there are obvious benefits from their inclusion by scheme providers.

From these initiatives it is clear that security of energy supply and climate change considerations present a significant driver for increasing performance by use of more advanced building ESM systems.

Digital Britain

The Digital Britain Programme is a programme of actions identified in the UK government's Digital Britain White Paper, published on 16th June 2009. The White Paper based its actions around four key themes[5]:

- modernising the UK's communications infrastructure;
- developing a strong legal framework to enable the UK's creative industries to thrive in a digital world;
- enabling all to participate in a digital economy and society; and
- modernising government, improving its use and handling of digital information and promoting the progressive digital switchover of public service delivery

At the heart of the first theme lies the government's Universal Service Broadband Commitment of a 2MBps service for all by 2012 and the establishment of a "Final Third" project to deliver at least 90% coverage of Next Generation broadband for homes and businesses by 2017.

The establishment of such a broadband service across the country facilitates the establishment of "Smart" services and opens up possibilities for advanced micro DE control systems (see below).

Smart Grids, Smart Meters and Smart homes

A "smart grid" is an electricity network to which information and communications technologies (ICTs) are applied, enabling more dynamic 'real-time' flows of information on the network and more interaction between suppliers and consumers. These technologies can help deliver electricity more efficiently and reliably from a more complex network of generation sources.

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[4] The Green Deal. A summary of the Government's proposals. www.decc.gov.uk/assets/decc/legislation/energybill/1010-green-deal-summary-proposals.pdf

[5] Digital Britain: Factsheet. Department for Business Innovation and Skills, November 2009

With a progressively smarter grid, operators get more detailed information about supply and demand, improving their ability to manage the system and shift demand to off-peak times. Consumers are offered more information about, and control over, their electricity use, helping reduce overall demand and providing a tool for consumers to reduce cost and carbon emissions. A "smart" home is one in which householders produce their own electricity (through domestic micro-generation) and have smart appliances, which communicate with the electricity network through a smart meter.

Such a system offers a range of possible new services:

- **New appliances that do not need continuous power, such as fridges, freezers, washing machines or laptop computers with batteries, could be set automatically to stop drawing electricity (for varying lengths of time – perhaps only a minute or so) according to the demand and supply across the electricity system. The benefits of such demand management are not insignificant[1].**
- **Where a home produces its own electricity, for example from solar photovoltaic (PV) appliances might be programmed to run and take advantage of this on-site low carbon generation.**
- **When excess electricity is being produced it will be possible to export this and sell it to the network; smart meters will facilitate measurement of these exports of power.**
- **It could also be possible to integrate the recharging of electric vehicles to synchronise with a home's own micro-generation, or to ensure it occurs during low tariff (and low carbon) periods.**
- **Links between a smart home meter and mobile phones or the internet may potentially also offer even more convenience. For example, consumers may be able to remotely change the time their heating or cooling system comes on, overriding automatic timers if their plans change.**

DE System Controls

The "Advanced Home Energy Management Controls" factsheet highlights the emergence of advanced control products that incorporate existing control strategies commonly found on domestic micro DE systems, but additionally provide a range of further controls that improve operational performance.

Systems will also need to optimise not just traditional space heating and hot water systems, but also integrate Micro DE systems, thermal storage and its release. Similarly decisions on optimum source from which to draw energy will need to be made: prioritising on-site generation, withdrawal from storage, or grid-supplied power at a given moment in time requires knowledge of and balancing a large number of factors.

Not surprisingly, the Factsheet concludes that a radically different approach for human interaction with such systems will be needed as complexity increases.

A number of monitoring only products are readily available for displaying power consumption. They incorporate a simple clip-on sensor and display instantaneous power and totalised energy used. Increasingly these are being made available to the householder through energy suppliers.

A range of products are available for monitoring and control functions, but are more appropriate to small commercial installations owing to the need for specialist knowledge to install and set up.

A small number of new home energy controller products are beginning to emerge on the market with potential to develop into what might be considered to be a true building ESM for the domestic setting. Such products incorporate additional control inputs such as:

- knowledge of occupancy;
- learned human behaviour, such as when hot water is required/used, when power is required;
- learned thermal response of the building to internal and external temperatures.

Energy savings of the order of 10-20% are claimed for these advanced products. However, independent verification of robust research based evidence is required for these claims to be substantiated, and their benefits more widely accepted.

Thermal Storage Systems

The Factsheet "Thermal Storage Systems" produced from work package 1.1 of this project notes that current thermal storage systems based on sensible heat storage are the most mature and reliable technology and are commercially viable for residential applications.

Systems based on latent heat storage (using phase-change materials, PCMs) are not considered commercial except for certain niche applications. However, given their current availability[6] and rapidly growing market[7] for PCMs, and current demonstration trials in commercial applications[8] the latent heat storage for residential applications might be available post 2020.

Systems based on chemical storage are still at the R&D stage and cannot be considered commercially viable for the near future.

The Thermal Storage Systems Factsheet provides example energy savings when thermal storage is coupled with a sustainable, decarbonised energy source, such as a solar thermal heating system. When compared with a gas condensing boiler of 90% efficiency energy savings of 3.12 – 4.68 MWh/y and 7.32 – 10.98 MWh/y for a new and old semi-detached house respectively. The range of savings reflect the range in assumed coverage factor (the proportion of energy needs that can be stored and recovered, assumed to vary from 40%-60%).

Note that the savings above are slightly misleading in that, if demand and availability of energy were perfectly matched, then energy savings of 100% (7.8 and 18.3 MWh/y for the two houses) would be achieved without the need for significant thermal storage. The true impact of thermal storage relates to the proportion of heat that is produced but not needed, and the proportion of heat required but not available.

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[6] See, e.g., the range of salt hydrate PCMs offered under the brand name "savNRG" at www.rgees.com
[7] "Advanced Phase Change Material (PCM) Market: Global Forecast (2010 – 2015)". Report EP1250. July 2010 marketsandmarkets.com
[8] See, e.g. www.pcpaustralia.com.au.

Timing of heat production and heat requirement is therefore important and a building ESM system to manage the two can contribute to the overall savings.

Electricity Storage Systems

A report[9] evaluating micro DE electrical storage technologies concludes that a range of electrical storage technologies are available for use in domestic applications. Batteries were felt to be the preferred solution at the single-household level. Lead-acid batteries are the most mature of the technologies and met the anticipated cost criterion (as £/kWh). However cycle lifetime is felt to fall short of the 3,000 cycles thought to be required. Batteries based on Lithium cell chemistry are felt to offer step changes in energy density for the future and a number of drivers for technological developments in electrical storage were noted, such as energy policy and carbon mitigation objectives, "smart" grids and electrical and plug-in hybrid vehicles.

For electrical storage integrated with on-site PV generation a maximum annual benefit (relative to that without storage) of around £86 per household was estimated[10], assuming a storage capacity so as to avoid all export of electricity generated. Whilst economics might dictate a smaller capacity and a lower annual saving, energy prices are likely to rise and be more volatile, favouring energy price reductions for off-peak use in the future. Nonetheless, to make electrical storage systems commercially viable some hardware cost reduction or the ability to provide additional services (such as balancing services to the Distribution Network Operator, or DNO) would be required.

For electrical storage combined with an air-source heat pump, storage helps achieve the increased peak load caused by the heat pump by storing off-peak electricity.

Timing of electricity generation and demand is also important and a building ESM system to manage the two can contribute to the overall savings.

Electric Vehicles

A key consequence of the long term needs regarding climate change and sustainable energy is the decarbonisation of the transport sector, particularly so in the period 2020 - 2050. Electric vehicles are pivotal to delivering such a decarbonised sector and Mackay[11] describes an opportunity to balance out future electricity supply and demand using a fleet of electric vehicles in the UK.

Electricity generation from sustainable sources presents a key problem: most of the renewable sources cannot easily be turned on or off; wind and solar sources generate only when the wind blows or when the sun shines. Nuclear power stations are usually on all of the time and their power output can generally only be changed over a period of several hours. On an electricity network, consumption and generation must be equal at all times.

MacKay estimates a future need to store or avoid about 1200 GWh (around 20 kWh per person) in order to handle lulls in wind generated electricity production, and to cope with swings in supply of

[9] "Evaluation of Micro DE Electrical Storage Technologies". EA Technology Report No 6489. December 2010
[10] "Evaluation of Micro-DE Electrical Storage Technologies." EA Technology Consulting 2010. Net annual electricity spend £325 and £239 for No storage system and storage system sized to avoid all exports, respectively.
[11] D. J. C. McKay. "Sustainable Energy – without the hot air". UIT Cambridge Ltd 2009

up to 33 GWh (around 0.5 kWh per person). These requirements closely match[12] the energy and power requirements of electric vehicles and McKay envisages electric vehicles plugged into smart chargers that are aware of both the value of electricity and the car user's requirements (e.g. the car must be fully charged by 7am on Monday morning). The charger would be designed to meet the user's requirements in the optimum way – at cheapest electricity price, when sustainable sources are readily available (and not charging when it is not). Moreover it would provide a useful balancing service to the grid that could be rewarded financially. Operating the chargers in reverse (i.e. to put power from their batteries into the grid) would offer significant extra generating capacity. One-third of a fleet of 30 million vehicles, exporting 2 kWh of electricity (20% of storage capacity), represents a total energy capacity of 20 GWh.

Electric vehicles have the potential, therefore, to provide additional services to the Smart Grid, over and above the regulation of export of excess power generated by micro DE, and the regulation of demand through Smart domestic appliances (indeed, the electric vehicle could be seen as the ultimate, high capacity, domestic Smart appliance).

Societal factors

The changes which are envisaged in the future scenarios being considered in this project will have wide ranging effects in society, as discussed below.

Fuel poverty is a concept which has received much attention in recent decades, since the definition was first established by Dr Brenda Boardman in her 1988 book 'Fuel Poverty'[13]. The most widely accepted definition is that of a household which, in order to heat the home to an adequate standard, needs to spend more than 10% of its income on total fuel use for the house. As energy process rise more households fall into this group. Current schemes such as CERT, CESP, and Warm Front aim to give preferential treatment to the fuel poor. In these schemes benefits criteria are used as a proxy for fuel poverty, since the latter is difficult to assess, requiring information on household income and energy modelling of an adequately heated home. However use of benefits criteria has its drawbacks, as it does not correlate well with fuel poverty.

In the future it is likely that some of the rise in energy prices will be due to similar energy efficiency schemes with obligations on energy suppliers, and also investment to decarbonise the grid. As a result it is important that those who are in, or close to, fuel poverty, are provided with good access to the benefits of good heating systems with appropriate controls implemented by such schemes. A focus of effort in this area, particularly, for example, for solid (no cavity) wall dwellings which have high heat losses, and alternatives for off-gas grid dwellings, could do much to improve the conditions of the most vulnerable in society. Appropriate micro DE for such home may include heat pumps, solar water heating, PV, and bio-fuels, with appropriate controls.

In April 2010 PassivSystems commissioned research into the energy habits and preferences of 2,085 people across Great Britain. Almost half of those surveyed admitted that they didn't know how to programme their current heating system. Forgetfulness was the biggest behavioural influence, with

[12] An electric vehicle has a typical energy store of between 9 and 53 kWh, which fits well with the 20 kWh per person requirement. Simultaneously switching on 30 million battery chargers would create a change in demand of around 60 GW.

[13] B. Boardman. "Fuel poverty: from cold homes to affordable warmth". Belhaven Press, London 1991

52% of respondents saying that the main reason they wasted energy was because they simply forgot to take control.

Given the increasing proportion of elderly people in our society, attention in recent years is being given to relevant design of dwellings, in particular controls. For example smart controls which include a warning if the temperature becomes low thus risking hypothermia, or which generate an alert if no activity is detected. Controls which are automated where appropriate, but which can be adjusted manually effectively, with a user intuitive and clearly visible interface (or audible/tactile interface for those with disabilities), would be particularly important for the elderly.

A major change for householders who adopt micro DE and its controls will be the change from being entirely a consumer of energy, to participating in generating energy. For many people this is a 'feel good' factor, which can be enhanced and encouraged if controls and displays clearly indicate the energy generated. This may also encourage householders to make adjustments which optimise the operation of their equipment, though transparency of operation and user intuitive interfaces are vital for this.

In addition to adjusting the equipment, some people adjust their lifestyle, as has been found in the field trial. This alteration of behaviour will undoubtedly increase if time of day tariff metering develops, so that people can reduce their bills by, for example, changing the time they run their dishwashers.

The importance of controls and displays which are clear and intuitive is vital to ensure behaviour is modified without the need to constantly "remember".

The above considers individual householders, however there are some instances of communities meeting together and deciding to reduce their CO_2 emissions. This can be both through individual action, which of course may include micro DE and controls, or through community action such as the installation of a jointly owned wind turbine as has happened in Hockerton, Northamptonshire.

Legislation

Building Regulations Part L (Conservation of Fuel and Power) provides guidance on minimum standards for space and water heating, including relevant controls. The Regulations originally only applied to new dwellings and extensions, and change of use. However, since 1995 they have increasingly included requirements relating to relevant work in existing dwellings.

The current 2010 Building Regulations Part L refers to the second tier document 'Domestic Building Services Compliance Guide (2010 edition)' for standards relating to space and water heating.

For example, for gas or oil fired wet central heating systems, for new dwellings or when a fixed building service is extended or provided in an existing dwelling, the minimum standard for controls (which are similar to those required for new dwellings) includes the following:

- Boiler control interlock which turns off boiler and pump when there is no demand for heat
- Zoning with independent temperature control, and if over $150m^2$ also independent timing
- Time control of space and water heating
- Temperature control of space heating using room thermostats or thermostatic radiator values (TRVs)
- Temperature control of stored domestic hot water

In relation to micro DE equipment, the 'Building Services Compliance Guide (2010)' provides guidance for

- Solid fuel boilers (including wood logs, wood pellets, wood chips as fuel)
- Heat pump systems
- Solar water heating

For heat pumps (ground, water or air source to water), the minimum standards include the following:

- Control of water pump operation
- Control of water temperature for the distribution system
- Control of outdoor fan operation (air to water units)
- Defrost control of external airside heat exchanger for air to water systems
- Protection for various failure/temperature/pressure conditions
- Room thermostat interlocked with heat pump operation
- Timer to optimise operation of the heat pump

For solar water heating, the minimum standards include the following:

- Control which maximises gain from solar panels to storage
- Minimises accidental loss of stored energy by the solar DHW system
- Ensures back up heat source is not used when solar heated water is available
- Provides control consistent with the solar system being hydraulically secure against effects of excessive primary temperatures and pressures
- Where a separate DHW heating appliance is preheated by the solar system, control the appliance so that no extra heat is added if the target temperature is satisfied by the preheat.
- Inform the end user of the system's correct function and performance at all times.

Whilst Building Regulations deal with individual equipment, it could be argued that they fail to consider the impact of device integration and the complex energy management duties of a building ESM system.

Energy Performance Certificates (EPCs) have been in place since 2008, requiring them to be produced whenever a building is sold, rented out, constructed or refurbished. The certificate provides 'A' to 'G' ratings for the building. Accredited energy assessors produce EPCs with an associated report which suggests improvements to make the building more energy efficient. In the case of dwellings, the rating is calculated using SAP or RdSAP;

- SAP is used to calculate EPC ratings for new dwellings
- Either SAP or RdSAP may be used to calculate EPC ratings for existing dwellings.

SAP is the Government's Standard Assessment Procedure for assessing the energy performance of dwellings for two purposes

- It is specified in Buildings Regulations for new dwellings in terms of the DER
- It provides the calculation of ratings for an EPC

SAP gives indicators of energy performance in terms of:

- Energy consumption per unit floor area
- An energy cost rating (the SAP rating) expressed on a scale of 1 to 100, used on EPCs

- An Environmental Impact rating based on CO_2 emissions (the EI rating) expressed on a scale of 1 to 100, also used on EPCs
- A Dwelling CO_2 Emissions Rate (DER); this is a similar indicator to the EI rating, used for the purposes of compliance with Building Regulations, expressed in $kg/m^2/year$.

RdSAP (Reduced data SAP) was developed for use in existing dwellings based on a site survey, when the complete data set for a full SAP calculation is not available. The following are examples of a few of these inferences.

- Wall U-values are inferred according to the age of the dwelling and generic wall type, rather than being calculated in detail from construction components
- If there is no access to confirm the presence of a cylinderstat it is assumed there is none
- A boiler interlock is assumed to be present if there is a roomstat and cylinderstat

In relation to micro DE, it includes the following inferences.

- Solar thermal: if present a set of assumed typical parameters (size, orientation, pitch) are assumed.
- Solar PV: if present size is estimated visually and a set of assumed typical parameters (orientation, pitch) are assumed.

For conventional heating, SAP and RdSAP include the minimum standard of controls referred to above (i.e. cylinderstat, roomstat, programmer, TRVs). In addition they include a number of additional controls such as delayed start, weather and load compensation.

The recommended improvements given on an EPC list the recommended minimum controls, where they are absent in the dwelling.

For conventional heating systems in existing dwellings, the EPC, SAP, and RdSAP therefore have little impact in encouraging controls beyond the Building Regulations minimum standard. There may possibly be some cases where people are encouraged to install the additional controls such as delayed start, weather or load compensation because they are recognised in SAP, however many people will be unaware of this, and even if they are aware, these controls give little added benefit in terms of improving the EPC rating.

For the micro DE systems that Building Regulations refers to (listed above) again SAP and RdSAP include little beyond the minimum controls specified in the Regulations. The greater number of minimum controls specified in Building Regulations for micro DE compared with conventional systems, perhaps reflects the greater importance of proper control for micro DE systems to deliver heat effectively and efficiently.

CERT and CESP follow a similar policy, which is not surprising since much of the savings are based on BREDEM, which is a version of SAP without the fixed parameters (e.g. occupancy, demand temperature, location, demand temperature) appropriate to the purpose of SAP as a rating calculation tool. Thus while many of the minimum standard controls, such as TRVs, have been installed, there has been no incentive to install more advanced control under this scheme.

However, within CERT there is a ‘demonstration action’ which incentivises research into quantifying the saving from a measure which is reasonably expected to achieve a reduction in carbon emissions.

This is a potential route for funding some research into the effectiveness of controls in real world trials.

The main impact of legislation on heating system and microDE controls is therefore through the Building Regulations, which specify minimum standards - both for conventional heating systems and microDE. Legislation and incentive schemes for heating are to a large extent undergirded by SAP and/or RdSAP, and the lack of evidence from research into the effectiveness of controls in real life field trials prevents inclusion of advanced controls in this assessment procedure at present.

4. Product Development Recommendations

Context

Section 3 highlights the need for reduction in energy use in the home and how changes in legislation together with the introduction of government initiatives are likely to encourage use of sustainable low-carbon heat in the form of heat pumps, solar heat and biomass boilers, and on-site electricity generation through solar PV and domestic wind power. All of these sources tend to feature, to some degree, seasonal and diurnal variation in output (be it heat or electricity) and some form of energy storage is required to maximise use within the home.

Where on-site electricity generation is not practised, optimum use of grid supplies through electricity storage can provide benefit to the householder (by, e.g., exploiting time-of-use energy pricing) and benefit to the grid operator (by smoothing peaks in demand).

Smart appliances, by permitting local control can smooth out diurnal variations in the energy requirements of the household. If on-site electricity generation is practised this can minimise the need for (and optimise the price paid for) electricity delivered through the grid. More widespread control of smart appliances, regionally or nationally, can deliver significant benefit to grid operators e.g. by avoidance of installation of additional capacity, which in turn could provide income to participating householders.

Knowledge of occupancy (both intended, from knowledge of work patterns, holidays, etc, and actual, through appropriate sensing) together with a learned thermal response of the building, through appropriate sensing and interrogation of smart meters, would also permit energy needs to be anticipated and the optimum means of its delivery to be selected. Remote delivery of additional or changed occupant requirements (via smart phone or internet, for instance) will also become feasible.

In the longer term (2030-2050) the presence of a largely electric-powered vehicle fleet adds additional electricity demand in the home, but also provides additional storage capacity and could deliver significant generation capacity for delivery back into the grid to deliver benefit to the grid operator.

Functionality

Future home control systems operating over a Local Area Network will therefore need to incorporate communication and control across a wide range of appliances, storage devices, micro DE systems and electric/gas grid connections. Additional benefits can arise if widespread participation over a Wide Area Network in regional or national schemes (provided the needs of householders can still be met) can be enabled.

Deriving maximum benefit for the householder in terms of efficiency and use of sustainable and low carbon energy sources therefore requires development of a complete building Energy Services Management System to optimise the energy use within the home.

A useful analogy might be to compare a building ESM system with modern vehicle Engine Management Systems, which developed from discrete components that just worked due to their design, then as engine complexity was increased more software control was added, until you get to today with hybrid engines managed by very sophisticated software.

Systems are being developed along these lines and Figure 1 illustrates one manufacturers interpretation of some of the key concepts discussed above.

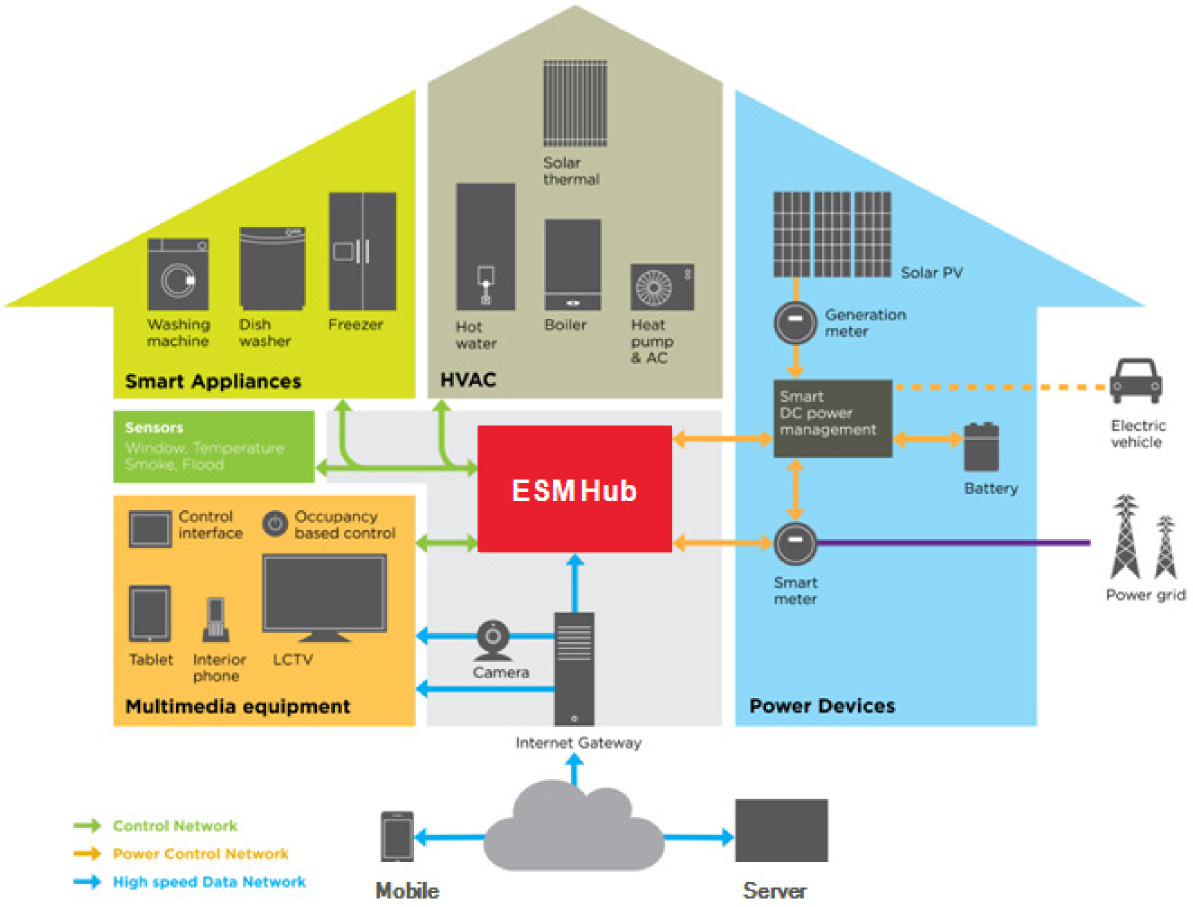

Figure 1: Illustration of key functions of a building Energy Services Management System

The table below lists features of a building Energy Services Management System.

<table>
<tr><th colspan="2">Possible functionality/features of a buildings Energy Services Management System</th></tr>
<tr><td>Human Factors</td><td>Interface needs:
Simplified interface to demonstrate optimum performance;
Simplified input of user preferences by e.g. use of profiles;
Different methods of interface to suit elderly or those with disabilities;
Remote programming/changes in user needs via, e.g. smart phone, internet;
Activity monitoring:
Planned occupancy, based on learned patterns of work, holidays, etc.
Actual occupancy information derived from sensors.
Advice to occupants on available energy/heat.

Primary Beneficiary: householder</td></tr>
<tr><td>Heating</td><td>Optimised selection of the heat source at any point in time:
on-site generated with heat pump, solar;
boiler fired with natural gas, LPG, oil or biomass;
micro-CHP fired with natural gas, LPG, oil or biomass;
heat released back from storage;
Control of buffer tanks
Excess heat
Optimised start versus continuous operation;
Antibacterial cycles

Primary Beneficiary: householder</td></tr>
<tr><td>Electricity</td><td>Optimised selection of electricity source at any point in time:
on-site generated with solar PV or wind;
micro-CHP fired with natural gas, LPG, oil or biomass;
electricity released back from storage;
supplied from grid using appropriate tariff.
Optimised use of electricity generated on-site at any point in time:
use within the home;
placed into storage;
export to grid.
Primary Beneficiary: householder</td></tr>
<tr><td>Appliances</td><td>Localised control to smooth out peaks in demand.
Monitoring lulls in on-site generation (e.g. wind, solar) and either switching off appliances or switching to grid supply, depending upon impact on functionality (e.g. ensuring fridge contents are not spoiled).

Primary Beneficiary: householder</td></tr>
<tr><td>External environment</td><td>External temperature, weather compensation & predictions, thermal response of building.</td></tr>
</table>

Possible functionality/features of a buildings Energy Services Management System	
	Primary Beneficiary: householder
Energy Tariffs	Interaction with Smart meter. Knowledge and optimum selection of tariff, depending on energy needs at a given time. Taking account of user preferences, such as biomethane from gas grid, renewable electricity. Primary Beneficiary: householder
Grid operation services	Managed participation in regional/national schemes to deal with lull and slews in demand: • by centralised control of heat pumps so as to smooth out electricity demand without prejudicing householder comfort; • by centralised control of smart appliances; • by centralised control of export of electricity generated on-site. Primary Beneficiary: Grid operator
Performance & Maintenance	Statistics • current & historical generation; • current & historical performance. Diagnostics to aid fault finding. Condition monitoring to ensure preventative maintenance. Primary Beneficiary: householder
Electric vehicles	Optimised selection of timing of charging and electricity source used. Electricity storage uses within the house. Primary Beneficiary: householder Centralised control of electric vehicle charging and release from battery. Primary Beneficiary: Grid operator

Participation in centralised control

Centralised control has been recognised as an imperative when significant sustainable electricity supplies are introduced. Delta[14] report three case studies of centralised control of heat pumps:

- In response to growing volatility in the German power market caused by a rapid increase in wind power, Vattenfall Europe has launched a "virtual power plant", comprising around 20 heat pumps and 10 CHP systems. Vattenfall owns each unit and sells heat to the customer. A central control centre dispatches schedules for each heat pump and CHP system, based on day-ahead power prices. If comfort levels are not being met the dispatch schedules can be overridden by customer. Communications and control functionality was retrofitted to each heat pump.

[14] "Smart Heat Pumps: Enablers of a Low Carbon Future". Delta Energy Environment Ltd 2011.

- Wind capacity in Denmark is set to grow from 3 GW to 6 GW by 2025, some 50% of Danish electricity demand. The Smart Heat Pumps Project will test the control of heat pumps as a mechanism for shaping demand to meet spiky wind generation. Some 300-400 homes will be included in the trial.
- In Switzerland, network operators have been controlling heat pumps to avoid grid congestion since the early 1990s. Around 80% of local network operators in Switzerland now offer a heat pump tariff with electricity savings of 20-40% in return for centralised control. It is estimated that over 100,000 heat pumps are operated by network operators under such tariffs. Installation of an additional 400,000 units is anticipated by 2020.

5. Targets for Change

Product development roadmap

A suggested product development roadmap, with some estimate of timescale is illustrated below. The roadmap is based on a (necessarily subjective) view on how some technologies may develop in the future and a judgement of the impact of external drivers. This view is based on interpretation of such sources as factsheets and reports from this project and elsewhere, and published government strategy. The final column (Building ESM system) suggests how functionality might need to evolve in response to key milestones in the future.

	Micro DE technologies	Storage	Smart appliances	Building ESM system
2010	Growth of Solar PV systems in response to FIT. Growth of heat pumps in response to RHI Growth of micro-CHP in response to FIT	Sensible heat storage readily available Latent heat storage systems available	Broadband in most homes Smart meters in every home.	Open-source communications protocol agreed for smart devices and micro DE control systems. Multi-platform micro DE system management with simplified user-interface. Localised control of appliances.
2020	Growth of advanced micro-CHP using fuel cells	Battery storage systems available	Access to smart meters for third parties granted. Growth in Smart appliances	Grid control communications established. Participation in regional/national demand

			Growth in electric vehicle usage	shifting
2030				Demand shifting by control of timing of electric vehicle charging Electric vehicles' batteries for grid peak shaving
2040				
2050				

2010 – 2020

Significant growth in renewable technologies is expected. Solar PV market has already seen significant growth in response to the FIT, although this has been at the larger scale at the expense of the domestic market and revision of FITs in response is anticipated. Significant growth is expected[15] in the domestic arena in, e.g., heat pumps (425,000 ASHP and GSHP units by 2020) and biomass boilers (299,000 units).

Nuclear power may be expected to attract further attention and potential delays in planning, following the recent problems at the Fukushima Daiichi nuclear power plant in Japan caused by the tsunami in March 2011. Pressure to increase decarbonisation of centralised electricity generation will lead to considerable growth in (largely offshore) wind generation and potential for intermittency in supply will underline the importance of demand-shifting measures.

Sensible heat storage is readily available and latent heat storage systems will become commercially viable towards the end of the decade. Electricity storage will become commercially available towards the end of the decade.

Broadband access to the majority of the households under the Universal Service Commitment of Digital Britain is planned for 2012. Smart meters in every home are expected by 2020 and access to them by third parties on behalf of the householder for energy optimisation and tariff purposes will be required.

An agreed standard communication protocol for communication with and between Smart appliances is therefore essential if growth in Smart appliances is to occur.

These developments will enable deployment of early versions of building ESM systems with multi-/cross- micro DE systems and Smart devices. Localised control of appliances for smoothing of peak demands in electricity and optimising heat storage, together with tariff optimisation are key functions of these early systems. In addition to performance optimisation, development of simple

[15] Central scenario "The UK Supply Curve for Renewable Heat" ERA/NERA for DECC. July 2009

user-interfaces, occupancy sensing and options for remote access is also important to encouraging user take-up of building ESM systems.

2020-2030
Commercially viable battery systems for electrical storage begin to appear on the market and building ESM systems add storage and release to the options available to the householder for optimising source at any one time. Adoption of electrical vehicles in significant numbers begins toward the end of this decade and localised functionality to optimise timing of their charging by the building ESM system is added.

2030-2040
Participation grows in regional/national demand shifting schemes in return for reduced energy tariff. Grid operator can communicate with on-site generators and loads to assist in coping with slews and lulls. Towards the end of the decade further growth in electric vehicles grow offer additional opportunities for regional/national demand shifting. The building ESM system handles the householder's participation through knowledge of user activities, needs and preferences.

6. Qualitative Assessment of Benefits

Benefits and beneficiaries from a building ESM system are set out in the following Table:

Primary and secondary beneficiaries of building ESM systems					
Application	**Householder**				
	Without on-site generation	**With on-site generation**	**Energy Supplier**	**DNO**	**UK**
Reduced energy use	£+ C+		£+	£+	C+
Demand-shifting	£+	£+	£+	£+	
Generation-shifting	£+	£+ C+			C+
Tariff options (e.g. biomethane)	£- C+	£- C+	£+(RHI)		C+
Smart Appliance control	£+	£+	£+	£+	
Regional/National demand shifting	£+	£+	£+	£+	
Electric vehicle charging control			£+	£+	
Key: £+, £+ primary, secondary beneficiary (financial) C+,C+ primary, secondary beneficiary (emissions)					

Appendix A: Analysis of Existing Systems

This Appendix details the analysis of existing systems discussed in Section 2 of the main report. Areas requiring improvement were identified by analysis of a variety of source material output from earlier stages of this ETI project.

In Table 1 all of the issues identified during this project are listed, compiled from Factsheets obtained in Work Package 1 of this ETI Project, and from the occupant interviews that can be associated with the control systems (rather than the micro-DE technology itself). For clarity, issues from the Factsheets are shown in black text, those from the occupant interviews are highlighted in red text, and those from the Lessons Learned Log in blue text.

Table 2 lists issues recorded during the Constraints Workshop that have relevance to control systems.

Table 1 : Deficiencies of existing systems identified by fact sheet (RED: additional deficiencies from "lessons learnt" log, BLUE: occupant interviews interim report)

Deficiency	Conventional DH and DHW controls	Advanced HE management controls	Thermal DE controls	Electric DE and micro-gen controls	Home appliances: washing machines, dishwashers, driers	Home appliances: Fridges and freezers	Home appliances: battery operated appliances	Home appliances: standby power and high efficiency appliances
Sensors		power requirements battery performance in extreme cold		lack of TRVs results in poor control of temperature of individual rooms'				
Actuators	TRV sticking RC TRV power requirements RC TRV price	power requirements						
Wiring	unsightly, expensive wireless expensive	Earth bonding on gas pipe not sufficient						
Benefits	demonstration of savings difficult	demonstration of savings difficult	demonstration of savings difficult lack of feedback on current performance (what is being actually achieved, is the system working optimally)	demonstration of savings difficult lack of simple method in SAP	users sceptical of environmental benefits	need for higher degree of control not justified		
Government incentives	lack of incentive specific to control system	lack of incentive specific to control system	lack of incentive specific to control system	lack of incentive specific to control system	no incentive to purchase smart appliances	no incentive to purchase smart appliances, no incentive to replace older appliances	FIT doesn't measure/determine power used on premises	
Appliance design			inability to control delta-T	manufacturers not incentivised to exploit	load measurement not practiced			

Table 1 : Deficiencies of existing systems identified by fact sheet (RED: additional deficiencies from "lessons learnt" log, BLUE: occupant interviews interim report)

Deficiency	Conventional DH and DHW controls	Advanced HE management controls	Thermal DE controls	Electric DE and micro-gen controls	Home appliances: washing machines, dishwashers, driers	Home appliances: Fridges and freezers	Home appliances: battery operated appliances	Home appliances: standby power and high efficiency appliances
			biomass boilers require steep learning curve excessive interaction of user required for biomass boilers (cleaning out ash, refuelling) pump didn't turn off when biomass ran out of fuel (had to be retro-fitted)	micro DE savings high integrity power supply needs (e.g. oxygen generators, dialysis machines) integration of ASHP with immersion heater operation and human activities (e.g. shower in morning triggers immersion to heat water that isn't required) long time to set up system optimally infrequent adjustment leads to unfamiliarity with controls when required	limited development of advanced design			
Human behaviour		owners averse to continued adjustment or optimisation reluctance to use home occupancy buttons re-education needs following change of tenancy	lack of visibility of control (fit and forget) ease of use HW overheating when on holiday homeowner didn't understand how system works and how to optimise timing of activities to suit system (e.g.	training needs of installers, maintainers and other tradespeople. homeowner use heat pumps on timed basis similar to a conventional boiler system (i.e. on when they think they'll need heat) timing of activities	automation concerns: safety (fire), flooding, change of daily routines doubts about maturity of technology			careful planning of activities required

Table 1 : Deficiencies of existing systems identified by fact sheet (RED: additional deficiencies from "lessons learnt" log, BLUE: occupant interviews interim report)

Deficiency	Conventional DH and DHW controls	Advanced HE management controls	Thermal DE controls	Electric DE and micro-gen controls	Home appliances: washing machines, dishwashers, driers	Home appliances: Fridges and freezers	Home appliances: battery operated appliances	Home appliances: standby power and high efficiency appliances
			shower in evening so as not to trigger immersion heater) timing of use of washing machine to when hot water is available	requiring electricity to when PV is producing it Usually just one member of householder interacts with and understands the system display unit hard to interpret, non-intuitive (tended to just listen to pump) most interaction is with conventional controls(programmer, thermostat) and not those of the (GSHP, ASHP) itself little interaction with controls drill-down deep into sub-menus is disliked green/sustainable image may drive behaviour that leads to increased energy use tendancy to try and use HP and biomass boilers like conventional systems (i.e. switch on for				

Table 1 : Deficiencies of existing systems identified by fact sheet (RED: additional deficiencies from "lessons learnt" log, BLUE: occupant interviews interim report)

Deficiency	Conventional DH and DHW controls	Advanced HE management controls	Thermal DE controls	Electric DE and micro-gen controls	Home appliances: washing machines, dishwashers, driers	Home appliances: Fridges and freezers	Home appliances: battery operated appliances	Home appliances: standby power and high efficiency appliances
				short period of time only when heat required)				
Communications		concern over communications security concern over reliability cross-interference cross-interference between CO2 transmitter and telephone high data management demands of smart metering missing data if homeowner is away on holiday and there are (e.g.) GSM connectivity issues access to broadband routers (may not have password) GSM signal varied/intermittant strength risk of cross – interference with	Wi Fi signals suffer where homes are refurbished and internal insulation containing aluminium foil		lack of common communications interface			

Table 1 : Deficiencies of existing systems identified by fact sheet (RED: additional deficiencies from "lessons learnt" log, BLUE: occupant interviews interim report)

Deficiency	Conventional DH and DHW controls	Advanced HE management controls	Thermal DE controls	Electric DE and micro-gen controls	Home appliances: washing machines, dishwashers, driers	Home appliances: Fridges and freezers	Home appliances: battery operated appliances	Home appliances: standby power and high efficiency appliances
		critical medical equipment (e.g. pacemakers)?						
Life costs	battery lifetimes	high capital costs unknown running costs unknown product lifetimes		high capital costs	high capital costs			
Retro-fit/ standalone		linked to new appliance often there is poor access to pipes for monitoring gas consumption	linked to new appliance controllers integral to appliance	built into appliance controllers integral to appliance	replacement market is small unless radical design emerges (e.g. Dyson)			
Control strategy				complex control needed to optimise heat/power demand and optimise price tariffs				robust room occupation sensing matching time availability of power FIT encourages home utilisation
Flexibility of appliance operation					lack of knowledge of impact of delayed, suspended operation on function	lack of information on tolerance on food quality		lack of knowledge of impact of delayed, suspended operation on function
Standards					communications interface standards			lack of home automation standards
Low voltage power				controls positioned close to generator				

Table 1 : Deficiencies of existing systems identified by fact sheet (RED: additional deficiencies from "lessons learnt" log, BLUE: occupant interviews interim report)

Deficiency	Conventional DH and DHW controls	Advanced HE management controls	Thermal DE controls	Electric DE and micro-gen controls	Home appliances: washing machines, dishwashers, driers	Home appliances: Fridges and freezers	Home appliances: battery operated appliances	Home appliances: standby power and high efficiency appliances
				necessitates weatherproofing				
Grid – consumer needs							balancing needs of grid and consumer when charging electric vehicles	

Table 2 : Control-related deficiencies of micro Distributed Energy technologies

Deficiency	Solar thermal	Solar PV	Mixed systems	Heat pumps	micro-CHP	Biomass
Operation, indication	Lack of status indication (OK/fault) no indication of production (heat meters not mandated by standard) No indication of when system degrading or requires maintenance		Complex control	need for simplified equipment controls		Combustion control required to ensure efficient combustion
Human behaviour	Mismatch between production and demand (low proportion of heat is effectively used) too much heat collected in summer months	Users don't know how to use system effectively	More for the user to understand installer should explain how they work and how to operate them	Users have difficulty understanding operation &use of heat pumps & how to use it most effectively change of mind set required: continuous vs intermittent operation human perceptions of comfort temperature vs heat		deployment of community schemes (people prefer retaining control)
Design	efficiency figures can be misleading SAP seen as a barrier	lack of standardisation	modelling of performance is difficult (SAP appendix Q)	Sap savings calculations (wrong CoPs) high electric current needs at start-up	Historic data currently used for evaluation is out of date Difficult to capture environmental value	
Costs	competing technology (electric shower) is cheaper to install	high installation costs availability of capital				
Grid connections		balancing home utilisation and export grid not designed for micro-generation	grid not designed for micro-generation		Grid integration issues	
Accessibility	Controls close to mechanics of system and not easily visible on a regular basis	Controls close to mechanics of system and not easily visible on a regular basis	Controls close to mechanics of system and not easily visible on a regular basis	Controls close to mechanics of system and not easily visible on a regular basis	Controls close to mechanics of system and not easily visible on a regular basis	Controls close to mechanics of system and not easily visible on a regular basis

Appendix B: Climate Change and Security of Energy Supply

The UK is facing two major challenges with regard to its energy consumption:

- Climate change. The Stern Review on the Economics of Climate Change, published in 2006, concluded that *"climate change is a serious global threat, and it demands an urgent global response"* and that *"the benefits of strong and early action far outweigh the economic costs of not acting".*
- Security of energy supply. In a recent consultation on renewable energy strategy, the UK government emphasised the need to *"ensure we are not dependent on any one supplier, country or technology"*.

In its response to these challenges and aims, the UK has set out a number of stated objectives and public commitments:

- The Climate Change Act. The Climate Act commits the UK to reduce its greenhouse gas emissions by 34% by 2020 and 80% by 2050, although the UK government is now working towards a figure of a 42% reduction by 2020. Both targets are against a 1990 baseline.
- The UK Renewable Energy Target. The EU's Renewable Energy Target commitment is that 20% of its energy consumption must come from renewable sources by 2020. The UK has agreed that its contribution should be that 15% of UK energy will be derived from renewable sources by 2020 with a target of 20% of this to come from domestic energy consumption.

The scale of these commitments is large.

The UK plans envisaged certain technologies playing key roles in meeting its renewable energy target:

In the Heat sector (12% from renewables by 2020) biomass, heat pumps and domestic micro-generation are seen to be important and these technologies are core to DE. Solar heat was initially seen by the government as a major contributor in its 2008 consultation paper, but in its 2009 strategy paper downgraded its contribution[16].

In the Electricity sector (30% from renewables by 2020) offshore and onshore wind dominates, with small scale generation contributing around 2% of renewable electricity.

In the transport sector a relatively modest contribution is assumed (10% from renewables by 2020), largely through the use of liquid bio-fuels. However significant decarbonisation of the transportation sector is envisaged between 2020 and 2050, with significant additional contributions from electricity and hydrogen.

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[16] Although DECC acknowledges that the forthcoming Renewable Heat Incentive may result in a greater contribution from solar panels.