Programme Area: Distributed Energy

Project: Micro DE

Title: Project Summary Report

Abstract:

Please note this report was produced in 2010/2011 and its contents may be out of date. This deliverable is number 7 of 7 in Work Package 3. The report is intended to act as a high level record of the activities carried out within the project and to summarise the key findings from the project. The key findings being:

- DE equipment, as installed, does not reach the full potential of its laboratory promise
- Buildings Energy Management Systems (BEMS) are required to maximise the efficiency of both existing heating systems & micro DE systems
- Energy storage is essential to maximise use of generated energy within the home and reduce use of supplemental energy

Extensive background to these key findings is provided within the report.

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 CO2 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.

3.7 Micro DE Project Summary Report

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UCL ENERGY INSTITUTE

Executive Summary

Energy consumption within buildings represents the largest single category of final energy use in the UK. The “Micro DE” FRP project (under the Distributed Energy Programme) is a scoping and feasibility study to determine the opportunity for technology development and demonstration for building control systems and micro-distributed generation and their combined impact on energy consumption and CO_2 reduction.

The underlying assumption of the work is a decarbonised grid from 2030 and beyond, in the context of the UKERC 2050 ‘Carbon Ambitions (CAM) scenario.

The project has:

- delivered a segmented model of the UK housing stock;
- collected energy, environmental, and occupant behaviour data from a field trial of 18 dwellings with micro DE generation, storage, control and monitoring systems;
- identified the CO_2 savings possible by combining building control systems with micro-DE sources.

Although a relatively small study, the project has endorsed many findings from much larger trials, such as those conducted by the Energy Savings Trust on heat pumps and the Carbon Trust on Micro CHP, in particular that ***the DE equipment as installed is not reaching the full potential of its laboratory promise.*** If this situation is allowed to develop as the market is stimulated by initiatives such as the Renewable Heat Incentive (RHI), the risk is that many of these installations will not achieve the required level of performance to be classified as ‘renewable’ meet policy objectives, e.g. heat pumps with a Coefficient of Performance < 2.875 cannot be classified as ‘renewable’.

Inevitably this situation would create a loss of confidence amongst purchasers and lead not just to market failure but also reduce the impact of new carbon reduction legislation. Many of the DE technologies studied, if networked and suitably controlled, also support the future introduction of innovative smart grids and heat networks. The UK has an opportunity to create leadership and export potential in this sector. Hence, it is imperative that the ETI’s next steps focus on establishing how to ***fix*** these critical issues.

Some of the key findings are basic and relatively straightforward to remedy. The UK needs a far bigger base of adequately trained installers e.g. Microgeneration Scheme (MCS) accreditation for all individuals, with additional modules and practical verification, particularly for Category 4[1] and above sustainable homes. Homes must be accurately assessed prior to decisions on the choice of DE technologies and infrastructure interventions made, such as improved thermal insulation, to reduce the demands on technologies such as heat pumps. A coordinated approach is needed to ensure that installation is for the whole home and not just the new equipment being installed, particularly in Social Housing where this can occur as a result of limited budgets. Occupants need to be educated on the use of the DE systems especially where houses change hands or new tenants move in.

Point DE solutions are common, where the equipment is purchased at different times, and fitted by different installers. Compromises have to be made to integrate the new with the old. Operational information is not shared between these complex and bespoke installs. . One of the key conclusions from the report relates to the potential complexity and underperformance that can arise from several DE technologies providing useful heat. There is a need for unifying control systems to integrate and enhance performance of mixed DE equipment for the whole house. Such solutions are approaching commercial readiness. SAP will need further refinement over time, backed up by good evidence and data, to accommodate these complex in-situ performance interactions.

Other findings are harder to fix or are more resilient to change, such as issues with inadequate space for equipment or thermal storage, high levels of CO_2 and humidity from inadequate building ventilation, under heating and uninformed occupant behaviour.

Heat represents 75-80% of all energy used in the home and energy for heating represents 45% of all carbon emissions in the UK. Hence, the integration and better utilisation of heat are by far the most challenging issues facing the introduction of distributed energy into the UK's 26 million existing homes to support decarbonisation policies. For these reasons, the consortium recommendation for a larger follow-on trial is to ***focus on heat***.

The proposal is to involve around 1,000 occupied homes from a potential 25,000 homes taking up the RHI premium payment incentive. The trial should focus on the local generation and efficient utilisation of heat within homes. Effort should be concentrated on demonstrating that the technologies are capable of meeting projected levels of performance paying particular attention to:

- insulation of the building;
- correct installation of the technology;
- electricity ***and*** heat metering;
- occupant behaviour and comfort.

The opportunity for thermal storage and trading should also be explored. There should be 500 active participants with a control group of 500. The opportunity should also be taken to leverage other Government backed trials and schemes as much as possible. It should also be possible to test emergent technologies for smart electricity and heat networks through boutique assessment.

Conclusions

Installed DE equipment is not delivering its full potential as a renewable technology because of:

- Poor energy surveys, system design, sizing and specification;
- Inadequate thermal insulation of properties resulting in the need for ancillary heating;
- Poor installation and commissioning;
- Complex, multi-component, point solutions requiring system integration;
- A lack of understanding by residents as to how the systems are intended to work.

Failure to address these issues will destroy the economic viability and inhibit the potential market for these technologies. In turn this will mean that we will have to look for other contributions to meet Carbon reduction targets and provide security of energy supply.

Recommendations

Hence, there is a need for:

- A DE equipment accreditation scheme and testing facilities;
- Adequately trained installers to appropriate qualification standards;
- Resident education and training;
- Unifying control systems, using shared operational data to integrate system components, manage energy storage and optimise integrated performance;
- Mass market solutions for in-situ seasonal performance monitoring and metering of DE systems;
- A systems development facility for addressing heat pump performance issues through rapid prototyping, component simulation and emulation;
- A larger follow-on, financially leveraged trial that focuses on fixing the integration of heat and involves at least 1,000 occupied homes, 500 of which would be active and the balance would act as a control group.
- Collaboration with other related projects to explore the potential role that DE has in facilitating demand management, supporting time of use tariffs and fuel switching.

1. Introduction

This document consolidates the learning from seven reports presenting the findings and recommendations from the ETI Micro Distributed Energy project, a scoping and feasibility study to determine the opportunity for technology development and demonstration for building control systems and micro-distributed generation and their combined impact on energy consumption and CO_2 reduction. 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.

The content of these reports are summarised into different categories according to whether they:

a) Create insight and learning for immediate dissemination to the ETI and its intended audience;
b) Provide reference material or instructions for expert practitioners involved in future activities such as modelling or data collection;
c) Are techno-economic studies that are dependent on validation of the UK Stock model predicting micro DE impact to 2030.

The focus of this report is on the first group (a). At the end of the body of this report there are the following Appendices:

- Appendix A – Project Organisation
- Appendix B – Report List
- Appendix C – Lessons Learned Log
- Appendix D , Annex 1-9 - Technology Fact Sheets

2. Overview

The consortium that has conducted the project is led by PassivSystems and consists of PassivSystems (field monitoring, project management and technical input), Building Research Establishment (BRE) (modelling and occupant interviews), EDF (R&D, EIFER and EdF Energy - technical evaluation) and the UCL Energy Institute (technical leadership, modelling and monitored data evaluation).All partners contributed technical input to the project and reports. The project commenced in February 2010 and was completed formally in March 2011. Some monitoring and occupant interviewing activities are continuing post project through the 2011/2012 heating season to gather further data following a series of interventions and in support of a potential follow on project.

The key strands of the project are the:

- Evaluation of the potential benefits of current and emerging micro-Distributed Energy (DE) technologies in existing domestic buildings (excluding flats and communal dwellings);
- Categorisation of:-
    - The stock of existing domestic UK buildings;
    - Building occupants into groups of similar energy use behaviours;
    - The main appliance types (energy use patterns, control strategies, etc);
- Evaluation of the platform technologies and standards likely to be used in developing buildings control systems;
- Analysis of the potential benefits of buildings energy service controls;

- Analysis of the potential benefits of the combination of micro DE technology, controls and storage with the UK housing stock;
- Modelling of existing UK domestic housing stock as the basis for predicting micro DE impact to 2030;
- Identification of development and demonstration opportunities;
- Forensic monitoring study of micro DE systems installed in 18 occupied homes;
- Recommendations for a future, larger scale follow-on project.

The term 'micro-distributed generation' in this project covers:

- Local generation of electricity: Micro-CHP, Solar Photovoltaics, Wind turbines, Hydro turbines, and Electricity Storage (though the latter is not strictly generation)
- Local generation of heat: Solar Thermal, Biomass, Heat Storage (again not strictly generation) and Heat Pumps (which require electricity, usually centrally generated).

The DE technologies analysed or field monitored (mainly renewable ones) in this project are the following:

- Biomass
- Micro-CHP system
- Air source and ground source heat pumps to water
- Solar PV
- Solar thermal
- Small Wind Turbine

Fact sheets have been created per technology with a general description, the current products available on the market, the technology maturity, CO_2, energy savings and existing or future subsidies. These are listed below and available as appendices to this document:

- Air Source Heat Pumps (ASHP)
- Ground Source Heat Pumps (GSHP)
- Solar Thermal Hot Water (STHW)
- Solar Photovoltaic (PV)
- Fossil fuelled Micro-CHP
- Biomass
- Small Wind Turbine
- Thermal storage
- Electrical storage

These technology fact sheets are supplemented by Deliverable 3.4.1 which provides insight into the roadmap for future developments for these technologies in the 2020 – 2050 timeframe

3. Key Insights from the Field Trial

This section outlines the results of field evaluation of 18 occupied homes in which a mix of 30 pre-installed distributed energy systems existed:

- Air Source Heat Pumps (ASHP)
- Ground Source Heat Pumps (GSHP)

- Solar Thermal Hot Water (STHW)
- Solar Photovoltaic (PV)
- Biomass

It should be noted that the 18 case studies covered a very diverse range of occupant and dwelling types. For example, there was a mixture of old and new, detached and terraced dwellings ranging in size from $42m^2$ to $520m^2$ total floor area with SAP ratings of 38 to78. Some of the occupants had purchased and overseen the installation of the technologies themselves whereas other occupants lived in social housing properties were the technologies were chosen and installed for them. Only one of the properties had been designed and built specifically to Sustainable Home standards and specifically to accommodate the micro DE technologies. All except two installations predated the Feed In Tariff (FITs), although many of the technologies had been installed in the last two years, with some installed over 5 years ago. Many of the households had a mix of two or three DE technologies adding to the complexity of the systems. Due to the small diverse sample and wide ranging results of these case studies they should not be used to arrive at general conclusions. ***However, the ETI trial has identified similar problems to those found in larger trials.*** These are highlighted in the following sections.

Occupant Feedback

Overall, the findings indicate that the ***key investment drivers*** for the early adopters of micro DE technologies were:

- Saving money on energy bills,
- Reducing their carbon footprint and impact on climate change,
- Reducing their reliance on oil and gas (concerns over rising prices and future supplies).

The key drivers for social housing landlords were replacing electrical storage heating with something that:

- Saved money for the potentially lower income tenants,
- Provided a stable comfort temperature for the tenants,
- Demonstrated the ‘green’ agenda.

The findings suggest that financial incentives such as Feed in Tariffs and the Green Deal are likely to be important future drivers. Financial incentives are likely to make PV panels in particular more attractive to consumers in the near future but questionable in the longer term.

Control

Occupants with STHW and PV systems tended not to interact with these technologies other than to look at any digital displays. Many noted that there was little or nothing to adjust on these systems and that they would like more detailed and user friendly feedback. Many had not adjusted anything on their controls since the systems were first installed and set up. Therefore the installation and initial set up of these systems will greatly affect how they will perform. Some noted that because interaction with the systems was so rare it was easy to forget how to use the controls. Thus occupant behaviour appears to have little effect on the performance of these technologies. However, for many occupants these technologies did influence their behaviour. Participants reported altering their behaviour, and the times at which they carry out certain tasks, to make maximum use of the electricity and hot water generated by the PV and STHW systems.

It was observed that in several households, occupants were trying to use their ASHPs, GSHPs and Biomass boilers as they had their previous conventional boilers. They tended to have their systems timed to come on at certain times and only to be on for relatively short periods of time. These households described the systems as being slow to bring the house up to the desired temperature and sometimes unable to reach set point temperatures. Conversely, participants who followed best practice, and ran their heat pumps either continuously or for larger proportions of the day described the systems as providing a stable temperature over time and being quick to react to temperature changes. Occupants with heat pumps tended only to interact with their central heating programmers and thermostats rather than to adjust anything on the heat pumps themselves.

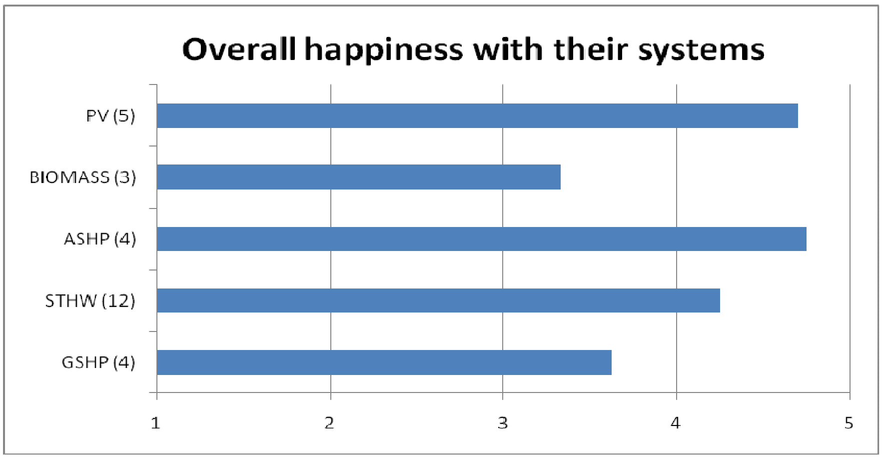


Figure 1 – Average 'happiness' ratings

Note: the number of respondents for each category is shown in brackets alongside the category.

Satisfaction

The findings showed that occupants with Biomass boilers and GSHPs were least happy overall with their systems and rated the performance of these systems lower than the other technologies looked at in this study. Biomass boilers were described as the least easy to control. Many of those with a Biomass boiler felt that they were still learning how to live with their system and use it most efficiently and effectively. This technology seemed to require the most trial and error and had the greatest learning curve. Several participants noted that these systems required a great deal of attention, cleaning, interaction and maintenance. Participants were required to interact manually with this system much more than the other systems, and the system's performance was reliant on this interaction (i.e. cleaning it out and refuelling).

The findings from site surveys and occupant interviews indicate that the key factors that influence the performance of these technologies are the:

- Quality of the installation;
- Information provided to the occupant at the point of installation;
- Occupants' level of understanding of how to use their system efficiently and effectively.

Performance

The way a micro DE technology is installed, for example its orientation and location, the length and position any pipe work, and how it is set up has a big influence on how the system will perform. Several occupants noted that their installers did not appear to be fully informed about the systems they were installing. The findings indicate that, apart from owners of biomass systems, occupants very rarely adjust anything on their micro DE controls (where they have them). This means that the systems are left to run exactly as they were set up when installed. It is therefore vital that the systems are installed and set up to work as efficiently as possible.

System Knowledge

The quality and quantity of the information and advice provided to householders with these systems varied a great deal in the field trial. A few of the participants did not receive any kind of manufacturer's manual with their systems, and others were given no information or advice from the installers. It is important that occupants are given good clear information about how the system works and how to use it efficiently. Without this information many people will struggle to understand how to use their technologies efficiently and get the most out of them. This information can be passed on by the installers of new systems, although the findings of this field trial suggest that in many cases this is not happening.

Occupants' levels of understanding of how the technologies worked and how to control them varied a great deal. However, it was noted (even by the participants themselves) that there is a big difference between understanding how to get the systems to do what the occupants want them to do and how to use these technologies efficiently and get the most out of them. Users also did not know what to do in the case of a fault. Without this deeper level of understanding many occupants were failing to use the technologies as they had been designed to be used. This can lead to underperforming systems, higher than expected fuel bills and dissatisfied occupants. In addition there is the issue of whether occupiers would be aware of a fault which compromises efficiency while still providing service – indicating the need for control systems with fault indicators.

Note:

- a single warranty visit to any underperforming site for any technology costs the installer approximately £1000. Given that 75% of heat pumps are underperforming with no remedial action in place, an install base of 1m units by 2020 – the cost to the industry is £1billion.
- The costs of supplementary electrical heating to a homeowner of a three bedroom semi-detached home for an underperforming heat pump is around £250 per annum

Maintenance

With the exception of Biomass boilers very few, if any, of the participants had had their technologies serviced or professionally maintained. Note that it is recommended that solar thermal systems have their circulatory fluid replaced every three years. Without such maintenance, any deficiencies in the set-up of the technologies are unlikely to be identified and rectified, meaning that a particular system can be underperforming for years and/or degrade over time without the occupant or anyone else knowing. Occupants are calling for more user-friendly information on how to get the most out of their DE technologies, when to service them, and to whom to go for servicing.

Learning from the Data Acquired by Remote Monitoring

Field trials that aim to assess several technologies that may interact with each other are much more difficult to undertake than single technology trials and require more planning and effort for monitoring and analysis. The data checking and analysis has helped identify a range of possible causes of poor quality data including:

- DE technologies installed at the bottom of the garden leading to poor wireless transmission of data from sensors;
- Snow covering transducers;
- Wiring faults;
- Poor thermal contact of transducers with hot water pipes;
- Mislabelling of transducers as a result of installation issues
- Issues with the GSM supplier.

A number of remote and server based data checking procedures have developed during the project to provide early warning of faults either with the measuring and monitoring equipment or with the installed technology in order to increase the level and quality of data collected.

System Underperformance
Analysis of the data suggests that many of the DE technologies are significantly underperforming. For example, heat pump Coefficients of Performance (COPs) are significantly below the manufacturer's expected values of 3.5 or better (and fall below the EU renewable COP classification threshold of 2.875) and the monitored efficiency of most solar thermal systems is significantly below expected efficiencies of 40%. The poor monitored performance is due to many potential factors including monitoring at a period where poor DE performance would be expected e.g. low solar radiation, cold weather and snow cover. In addition the complexity of some systems increases the chances of poor systems design, installation, integration, control and operation. Further research is required to understand in terms of both economics and carbon emissions the appropriate sizing for micro DE systems – for example, should they be sized to function in exceptional conditions or is it accepted that supplementary heating will be required?

Data Checking
An analysis tool has been developed, using an Access database, to bring together in a unified format monitored data from 30 distributed energy technologies located in the 18 "early adopter" homes. The purpose of the analysis was to develop processes and methods for the analysis of a future, much larger field trial, i.e. to demonstrate the functionality and key lessons rather than to arrive at detailed conclusions from the analysis of the collected data.

Heat Pumps:
The project monitored 4 air source and 4 ground source heat pumps. All of the systems where combined with a radiator space heating system. All except one of the systems also provided the domestic hot water.

The Seasonal Performance Factor calculated from the monitored data of all of the heat pumps field trial homes is **2.4-2.6 –** although it should be noted that this does not include the summer months. This compares with the EU target COP SPF 2.875 for classification as a renewable technology.

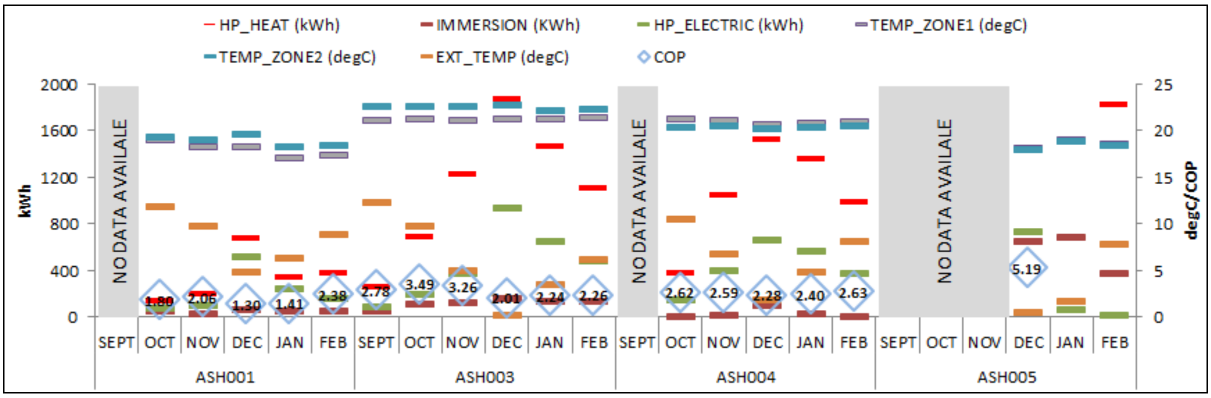


Figure 2 Mean internal temperature, external temperature, and coefficient of performance and heat output of the air source heat pump homes in the trial

Whilst the properties in this trial had double glazing, loft and cavity wall insulation, the systems were not performing as expected. In some cases this can be attributed to the way in which the heat pump is used, other issues include poor draft proofing of the home, inadequate insulation of pipes and hot water cylinders, poorly sited radiators and lack of control of temperature for different rooms of the house.

For Social housing it is evident that budget constraints and differing areas of responsibility for budgets means that not all necessary work can be done to ensure an optimal installation.

Solar Thermal

98% of the measured efficiency falls below manufacturer predictions e.g. 40-50% efficiency. The monitored poor performance is due to many potential factors including monitoring at a period where poor DE performance would be expected (e.g. low solar radiation, cold weather and snow cover). Also the complexity of the systems increases the chances of poor system design, installation, control and operation. Occupants have little control or opportunities for interaction with the system.

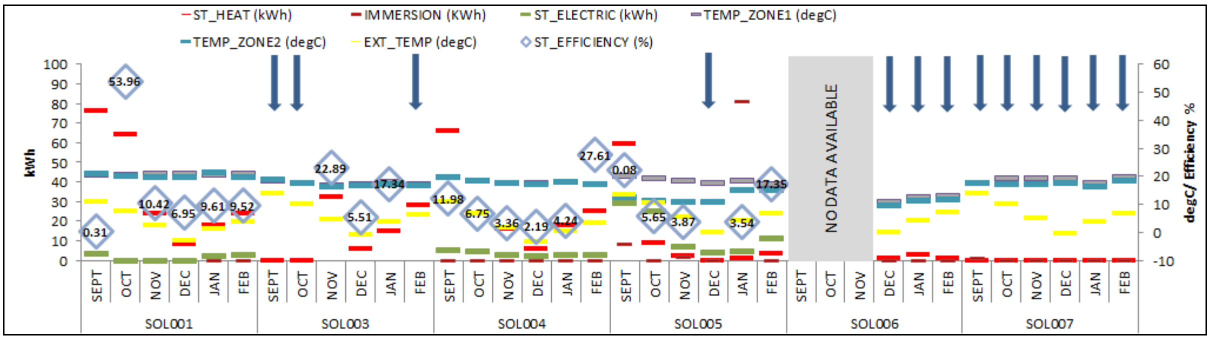


Figure 3: Mean internal and external temperatures, solar heat and electricity usage, immersion and efficiency of the solar thermal homes in the trial

Moreover the poor performance is often not directly attributable to the technology, but to its installation within a complex system of heat emitters, controls and storage; plus the building itself and the behaviours of the people within the home. From the field trial we have found that the performance of an existing solar thermal system is often 'ignored' when a second DE systems, such as Biomass, is installed leading to significant reductions in performance of the solar system. Other examples of causes for lower than expected performance (some of which were highlighted in the small field trial) include:

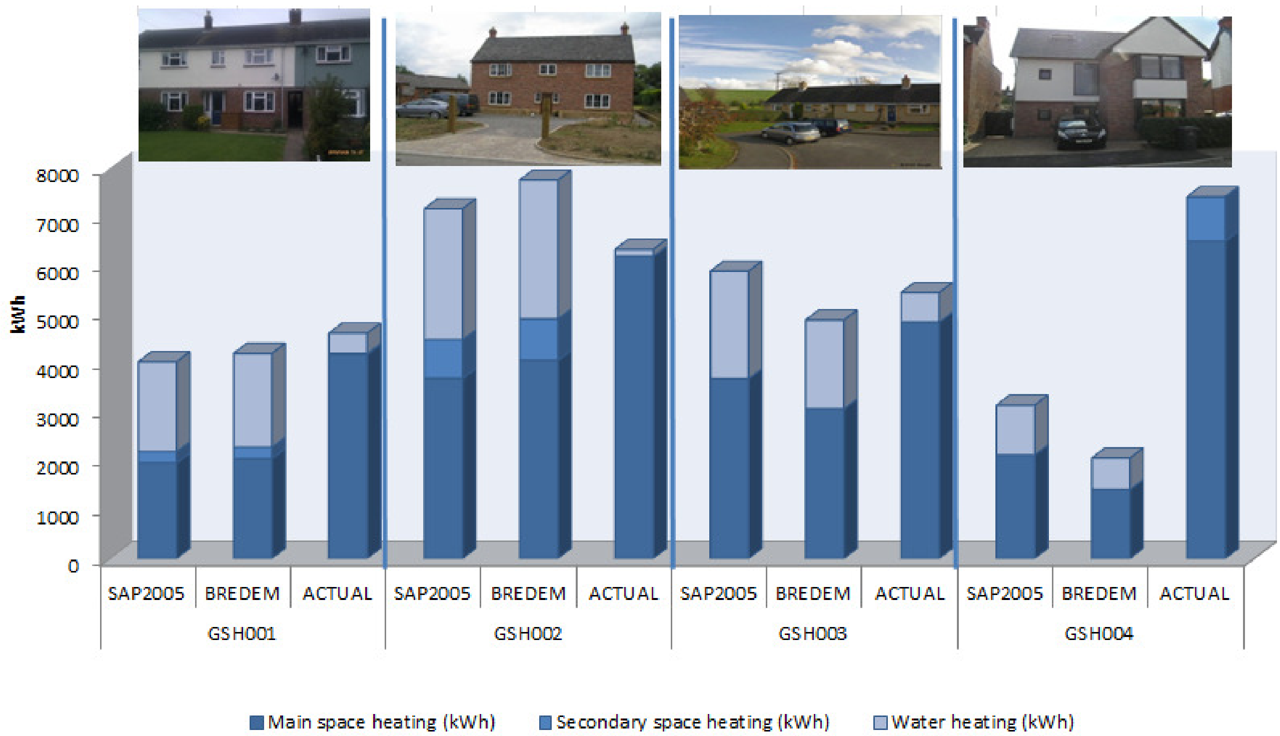
- **Poor system design**:
  - emitters not increased to cope with lower temperatures attained from DE technology;
  - inadequate sizing of plant due to poor assessment of heat loss;
  - selling to meet ‘budget’ rather than ‘requirements’ of the home;
  - sizing of storage and emitters for present and not future needs**.**
- **Poor installation**
  - lack of thermal insulation;
  - long pipe runs between generation and storage;
  - lack of proper integration with existing systems;
  - existing systems not cleaned out or re-balanced prior to installation of the new technology.

- **Commissioning**
  - Leaks;
  - low pressure;
  - delivery temperatures;
  - property left in a poor state.

- **Maintenance**
  - no clear advice on expected and achieved performance levels;
  - no clarification of what maintenance is required and when;
  - lack of willing maintenance organisations.

- **Operation**
  - occupants do not know what to do;
  - users treat DE inappropriately as conventional heating systems;
  - equipment displays are inconveniently positioned;
  - controls are not integrated.
  -
- **Change of occupants/Change of lifestyle**

The monitoring has not only been undertaken to evaluate the performance of individual DE technologies but also to assess the overall building and systems performance. This has been done by comparing SAP and BREDEM predictions of the whole system performance against monitored energy data. SAP is a constrained version of BREDEM which utilises standard occupant and climate data, whereas BREDEM can be modified to account for actual occupant behaviour and climate during the monitoring period. Examples of this are shown below.



Figures 4 & 5 SAP versus BREDEM versus Actual Building performance

4 Lessons Learned from the Field Trial

A 'lessons learnt' log has been maintained throughout the project. Some key findings are given below and the complete log is provided as Appendix C to this document.

Heat Pumps

As explained earlier there have been many reported issues with heat pump systems in this trial including:

- Lower than expected performance with difficulty in achieving required set point temperature and supplementary heating almost always being used;
- Ground Source displaying lower coefficients of performance than Air Source heat pumps;
- Issues with the pressure and leaks of ground source systems following installation;
- Radiators undersized for lower temperatures from the heat pump, no thermostatic controls and inconveniently placed so as to be blocked by furniture;
- Insufficient insulation of the pipes connecting the heat pump and the hot water cylinder.

Solar Thermal Systems

Whilst solar thermal systems are perceived as simple to in stall and use the following issues have been evident from the field trial:

- Thermostats for hot water production are set too high and pre-heated by other means to allow solar thermal to have any effect;
- Cost effectiveness of a small Solar PV panel for the pump and controls of the solar thermal system;
- Maintenance required, minimum 3 yearly, to change anti freeze in order to maintain performance;
- Issues with aged panels failing after extreme winter weather conditions;
- Electric showers still being used when solar generated hot water available.

Solar PV Systems

Solar PV systems are an expensive investment and purchasers would therefore expect optimum performance from their investment. However the following issues have been found:

- The percentage of energy exported over the autumn and winter period was above the expected average at between 32 and 93%;
- Issues with inverter performance when subject to the extremes of temperature in a loft space;
- Newer systems have a higher level of performance than older systems;
- Partial shading disproportionally affects performance;
- Inverter lifetime is less than that of the panels but a replacement inverter is not included in 'Return On Investment' calculations.

Biomass Systems

Again Biomass systems are expensive items to purchase and far exceed the costs of traditional gas or oil condensing boilers. The following issues have been found in the field trial:

- Bulk delivered pellets disintegrated when blasted into hopper;
- Recycled wood often contains pieces of metal ;
- Inconsistent methods of burn back protection between systems of similar size;
- Ventilation required when clearing ash as monitoring has shown CO spikes.

Mixed Systems
A mix or combination of systems within a home brings added complications such as:

- Lack of understanding of which technology to use;
- Systems individually controlled with no sharing of data therefore complex manual decision making required;
- Additional costs for purchase, installation and maintenance;
- Issues with the integration of disparate systems.

Monitoring and Data Analysis
General lessons learnt with regard to the monitoring and data analysis include:

- The importance of planning and logistics well in advance of the actual monitoring;
- Regular review of the integrity of data collected;
- Working closely together as a team when undertaking monitoring and data analysis;
- Issues with consistency of data in 'real' homes;
- The term 'monitoring' is confusing for occupants;
- Checking all devices are recording before leaving site;
- Telephone interference from sensor transmitter;
- Forensic monitoring costs are expensive;
- GSM costs add to expense;
- Input cold water temperature affects energy used;
- Energy usage not relative to number of occupants;
- Naming conventions for data to be agreed ahead of installation.

5 Advanced Control Systems

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 promoting good control of energy use within the home:

- demonstrating the benefit obtained from control systems is not easy without complex trials looking at before and after scenarios;
- government incentives take no account of the possible impact of advanced control systems because of this lack of information on the benefit obtained;
- greater account of the human factor is required;
- 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 will be 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 nationwide 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, 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 (within the Field trial exported electricity ranged from 34 – 98% of generation over the late autumn and winter periods). For wind and micro-CHP the proportion is even higher at 49% and 45%, respectively.

A building energy services management system (ESM) 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.

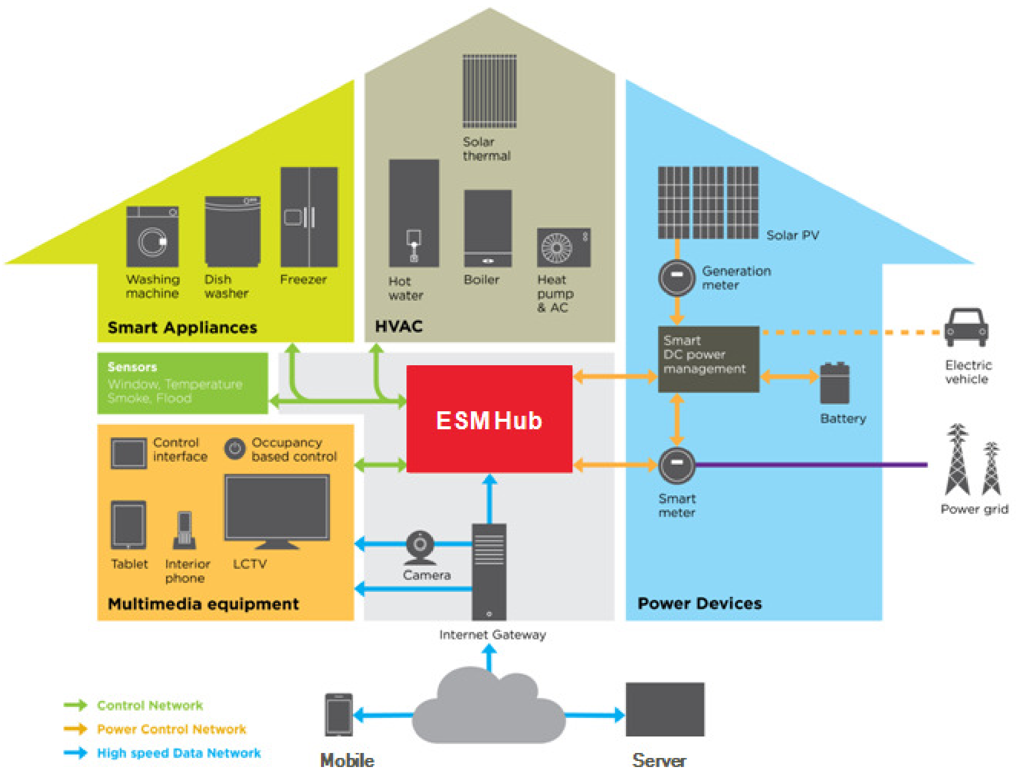


Figure 6: Illustration of key functions of a building Energy Services Management System

A roadmap for development of a building ESM system is suggested in Document 3.3. 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 potential benefits and main beneficiaries of key functions of a building ESM system have been identified in the form of a function-stakeholder matrix. See Table 1

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	£- 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)					

Table 1 Benefits and beneficiaries from a building ESM system

This project came to the following conclusions with regard to advanced control systems:

- Advanced controls systems can in theory improve system performance and hence narrow the current gap between DE technology laboratory and field performance. It can do this in one of two ways, either by providing better integrated system control algorithms utilising data from a range of sources, smart meters, internet weather predictions etc, or also alerting occupants to poor DE performance requiring action such as servicing or maintenance.
- 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.

- 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.
- 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.
- 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.
- 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 represents a potential means of management of the lulls and slews in power generation associated with sustainable sources.

6 Guidelines for Combining Technologies with Storage & Controls

In general, storage technologies have two objectives, to:

- make best use of energy generated from intermittent renewable sources by matching local supply and demand, enabling occupants to benefit from free and/or excess production;
- help match supply and demand nationally.

Occupants are not always available and at home to ensure that these objectives can be met. Automated control systems fully integrated both in to the home and all systems within the home that use or generate energy will significantly contribute to achieving these objectives.

Whatever the system or the application, an optimal control system for storage should be able to:

- Identify when energy is available for storage and, if necessary contribute to the global optimisation of a system including one or several sources such as solar thermal panels, heat pumps, geothermal, micro-CHP, etc.;
- Manage the balance between demand side and available stored energy, extending if necessary the management of several dwellings and different types of grids (electric, district heating);
- Integrate economical parameters: electricity or heat prices;
- Reach an optimal storage capacity by controlling for example: the water temperature gradient inside a tank;
- Communicate with other control system in the house to enhance comfort;
- Provide diagnostics to indicate any need for repair or maintenance;
- Display data on system performance, saved energy/electricity/money, and CO_2 emissions reduction.

7 Plan for a Larger Field Trial

Field trials are an invaluable method of evaluating how a system that has been tested in controlled laboratory conditions actually performs in real life, with real people, under normal day to day conditions while still having an element of control and the ability to withdraw or modify the technology under test. ***Heat is by far the most challenging issue*** facing the introduction of distributed energy into the UK's 26 million existing homes because of the massive complexity of integration with central heating systems and the thermal performance of the building. Most field trials have demonstrated a significant underperformance in heat generating DE technologies with a theoretical potential to greatly increase the performance in many cases. The potential rewards from a heat based field trial are therefore very high both for government (e.g. heat pumps need to achieve a seasonal coefficient of performance of 2.875 or greater to meet renewable targets) and to industry that can open up new markets for improved technologies, installation and controls. It is critical that these integration issues are understood and solved, to support the introduction of key decarbonisation building blocks such as the Renewable Heat Incentive. Besides the all-important systems design and specification and quality of installation, there is also the role of controls and thermal storage to consider in making renewable heat work effectively and efficiently in homes with attention to building performance, DE performance monitoring, heat and electricity metering, and exploring the opportunity for thermal storage and trading.

Recommendations for a future trial are a key output from this project. In the Climate Change Act, the Government has established a legally binding target to cut greenhouse gas emissions to at least 80% below 1990 levels by 2050 and to reduce emissions to at least 34% below 1990 emissions by 2018-22. One of the key ways it will achieve these carbon budgets is through a commitment in law to get 15% of all energy, for electricity, heat and transport, from renewable sources by 2020. The Government's Renewable Energy Strategy lead scenario suggests that by 2020 about 30% or more of our electricity - both centralised and small-scale generation - could come from renewable sources, compared with around 7% today. **Micro DE technologies can contribute to these targets provided a) there is better technological design, installation, control, integration and energy storage; and b) they are cost-effective with a carbon price of less than £30 per tonne.**

An underlying principle in examining the options for an ETI follow-on DE trial has been to consider the potential leverage from other public and private spending on field investigations. As much leverage as possible should be made of other work in this area by Government, NGOs and industry through interactions, collaboration, data sharing and co-funding provided that doing so does not put the overall objectives of the larger field trial at greater risk or prevents the field trial achieving its core aims.

The follow-on trial must be representative of the UK's domestic stock, involve circa ***1,000 occupied homes recruited from a potential 25,000 homes taking up the Renewable Heat Incentive (RHI) premium payment incentive.*** The trial should focus on the local generation and efficient utilisation of heat within homes, with attention to building performance, DE performance, heat and electricity metering, occupant behaviour and comfort and exploring the opportunity for thermal storage and trading.

There should be ***500 active participants*** in this 1,000 home sample, with a control group of 500. The active sample would be designed to answer questions about the efficiency of the technologies. Information would be collected on DE technologies performance and occupants' comfort before and after the introduction of the micro DE technology, under real UK climate and operating conditions. Groups of domestic buildings would be closely monitored through all phases of design, building integration, commissioning and operation. Other homes would have a degree of monitoring and improvement, while some would form a control group.

Multiple installer organisations will be required to meet the challenging scale of the programme. These must meet stringent pre-qualification standards in regard to health and safety. Automated data checking and analysis will be essential for a statistical trial of this magnitude. Data collection must be consistent across all dwellings.

The specific technology samples introduced into homes must be carefully designed so that the results can be extrapolated to other homes. Sufficient time should be allowed for recruitment of a representative sample of the UK population and house types. The contract should be flexible to allow investigation and resolution of issues arising from the field trial.

It is envisaged that the funding required for such a trial would be approximately ***£10m***. This would include £5m for the direct costs associated with the trial homes (surveys, monitoring equipment, data collection, forensic analysis, interventions, micro DE technology installation, insulation, problem resolution) with £5m for running the project (data analysis, modelling, recruitment of participants, learning back into the industry, programme management). As with the present scoping study, a larger field trial would need to complement the trial findings with modelling and field trial data from previous studies. In letting the contract, the ETI would need to ensure that partners have experience of conducting similar work and have learnt important lessons from previous work in order to plan and manage a large field trial operation efficiently.

In a sub sample, the trial could also assess the feasibility of distributed electricity demand management in the home as a facilitator of a future smart grid. This could include the optimisation of intermittent centrally generated renewable energy as well as that created locally by e.g. PV and address its local storage and prospective options to reduce network peaks and demand in general.

A demonstration of new and emergent technologies should also be included in order to investigate how they function in occupied homes, whether they may replace current systems/models and to provide guidance on installation and operating practice ahead of mass roll out.

We are concerned that the current set of ETI trials appears to have overlooked the possibilities of shared distributed energy resources for small communities. Hence, this consortium also recommends that the ETI look at sharing of assets amongst homeowners within a small community, such as flats, rows of houses or social housing communities, either as an adjunct or as a separate larger project. We consider that this is an essential social inclusion element, enabling sharing of assets and providing cost effective solutions.

8 Reference Material

Roadmaps for Micro DE Technologies – Deliverable 3.4.1

The roadmaps presented for each technology are based on the corresponding fact sheets from Work Package 1 and ranks potential micro DE candidates for installation now, in 2020 and 2030. According to the selection criteria proposed at the beginning of this study (greenhouse gas reductions and affordability) remarkably few micro DE technologies are sufficiently promising or sufficiently advanced to meet these requirements in 2011. The recommended technologies are essentially restricted to solar thermal systems and wood pellet boilers in the immediate future as these are considered mature technologies with air source heat pumps becoming interesting over the next 20 years as the anticipated decarbonisation of the electricity grid progresses.

For technologies that still have technical or design hurdles to overcome, desk and lab-based research and development may be required in order to bring these technologies to maturity.

Micro DE Technology Case Studies – Deliverable 3.4.3
This report describes the impact of DE systems placed in the context of established UK energy scenarios for the future. Three cases have been derived from the chosen scenarios, covering the key building types and energy applications, which have then been used to study micro DE choices and benefits.

Field Trial Data Analysis – Deliverable 3.1.2
This report describes the methods used to analyse the data collected from the 30 monitored technologies in the field trial of 18 homes. It provides details of the complexities of analysing data from a diverse range of homes with varying intervals of the recorded data with recommendations for data collection and analysis in a larger field trial. The results of the analysis of the small samples of different types of micro DE systems are included.

Findings from the Field Trial Occupant Interviews – Deliverable 3.2.1
As well as collecting physical data from the field trial homes a series of interviews are also have also been conducted with the occupants. Information is being collected on:

- Demographics and occupancy patterns;
- Occupant comfort and control;
- Perception of the environmental conditions;
- Typical energy use behaviours;
- Perception of the micro DE technologies installed;
- Feedback on participation in the field trial study and the recruitment process..

9. Output pending model

Modelling Micro De Human Factors, the cost effectiveness and hence potential uptake of technologies – Deliverable 3.5.1 & 3.5.2
This report utilises the Alpha (V2: Stock) version of the micro DE Model to obtain new insights into the current and future potential of technologies. The micro DE project is a pilot project and the original intention was to develop within the one year pilot a meta-model derived from existing models. Since the micro DE project started, a 2 year Optimising Thermal Efficiency of Existing Housing (TE) project was commissioned by the ETI and it was decided that together the projects should develop a unified core model, rather than different models for each project. This decision was taken after the micro DE project had started; as such the model development was delayed to the latter half of the micro DE project and it was agreed that only a constrained Alpha version of the model would be available for the conclusion of the micro DE project, the fully functioning and tested version only being available at the end of the TE project.

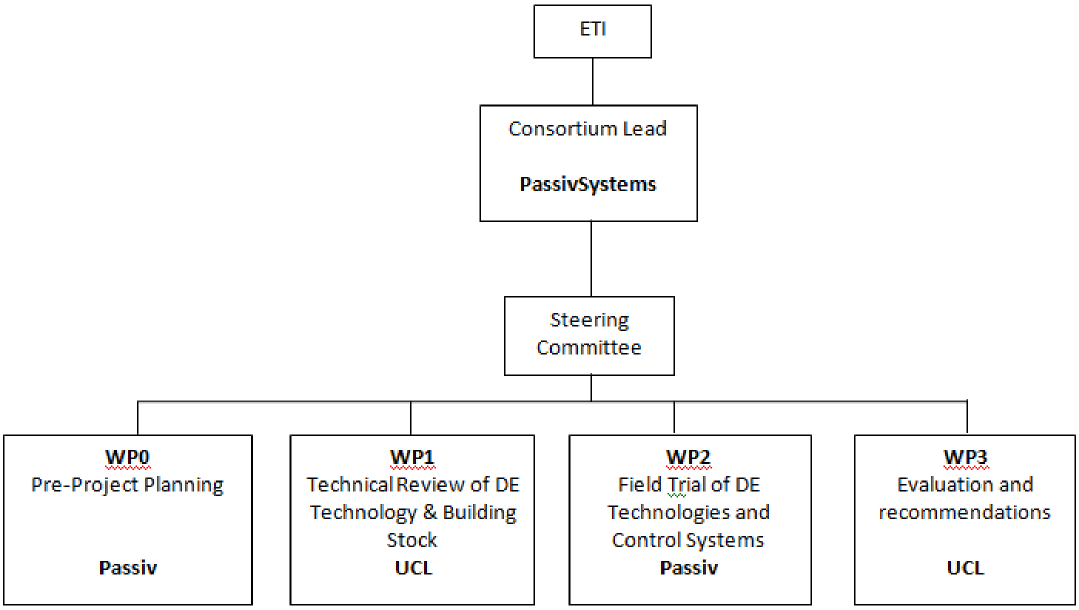
User Guide for the micro-DE energy model – Deliverable 3.1.5
Guidance for users is provided on the installation and operation of the micro DE energy model. This is a provisional model of the existing UK domestic housing stock, forming a basis for predicting the potential impact on energy use of penetration of micro DE in future years. It is an Alpha version program whose development has been integrated with the modelling requirements for another ETI project on Optimising Thermal Efficiency of Domestic Housing.

Micro DE Technology Comparisons – Deliverable 3.4.2
This report:

- Presents a methodology to rank the different results of combinations of DE technologies to refurbish an existing dwelling with either CO_2 emission, energy consumption or investment cost key rankings;
- Analyses the ranking results to know if they are relevant.
-

The conclusions of this study are highly dependent on the assumptions made regarding the performance of the DE technology, the CO2 intensities per unit energy, and energy prices

Appendix A- Project Organisation



WP0 – Pre-Project Planning

The objective of WP0 is to gather and catalogue statistically significant data on household energy loads and DE usage, based on ongoing or completed field trials. Analysis and interpretation of this data was used to drive the modelling and field trial design.

WP1 – Technical Review of DE Technology and Building Stock

Building on the work of WP0, Work Package 1 of this project 'Landscape Review and Planning' has assembled existing information and field trial research on micro DE, energy storage technologies, control systems, and appliance types. It has also reviewed the existing building stock and user behaviour, and how both of these aspects might usefully be segmented, together with future scenarios, particularly in relation to the development of a UK housing stock model (see Work Package 3). It also included planning for the Work Package 2 field trial.

WP2 – Field Trial of DE Technologies and Control Systems

Work Package 2, the 'Field Trial', proposed monitoring 20 dwellings; this was proposed by the project partners as an alternative to the originally proposed 200 dwellings, due to the practical difficulties inherent in undertaking a field trial within the limited timescale of the project. This view has been amply justified, after two withdrawals it resulted in an 18 dwelling field trial, which has provided many lessons relating to the resources and time required, and issues arising. Although this smaller field trial clearly cannot provide results which are representative for the UK, nevertheless it has provided many insights into the interactions described earlier, and the causes of underperformance of micro DE devices.

The field trial is broken down into 2 phases:

1) Acquisition of performance data from 18 properties previously equipped with various types of micro-generation equipment independent of the ETI project.
2) Interventions / modifications to each of the properties based on analysis of the data acquired from the properties, interviews carried out with the residents and observations made during the installation of the monitoring equipment.

WP3 – Modelling, evaluation, analysis and estimation of potential energy and CO2 reductions from technology development; recommendations for ETI project(s).

The work package draws together the outputs of the previous two work packages into a conclusion. This includes a coherent view of the technology opportunities, an analysis of the confidence levels that are possible from the evidence collected and an outline of what would be required to move to the next stage.

Each of these work packages is divided into a number of individual deliverables.

The outputs from this project are intended to be used to define the opportunity for large scale Distributed Energy within the UK and to project the benefits case to support a demonstration project in this area.

Appendix B Report List

3.1 Field Trial Data Analysis – Deliverable 3.1.2 **Reference**

Details of the analysis work carried out on data arising from the field trial carried out by the project.

3.2 Findings from the Field Trial Occupant Interviews – Deliverable 3.2.1 **Informing**

Details of and consequent insights from a series of interviews carried out with participants in the project field trial, carried out at various points of the project.

3.3 Analysis of the potential benefits of a range of buildings energy services control systems- – Deliverable 3.3 **Informing**

Description of the potential opportunities for advanced control technologies deployed with micro DE equipment

3.4 Analysis of the impact and viability of different types of micro-generation technologies. This deliverable is broken down into 3 sub-deliverables which look at the development timeline, opportunities and impacts of different types of micro DE equipment

- 3.4.1 Micro DE Technology Roadmaps **Informing**
- 3.4.2 Micro DE Technology Comparisons **Reference**
- 3.4.3 Micro DE Technology Case Studies **Reference**

3.5.1 Modelling the cost effectiveness and hence potential uptake of technologies – Deliverable 3.5.1 **Reference**

Details of the modelling and scenario analysis carried out within the project on the different types of micro DE equipment considered.

3.5.2 Guidelines for Combining Technologies with Storage & Controls – Deliverable 3.5.2 **Informing**

This report considers how control and storage systems can help optimise the output from the likely micro DE technologies of the future

3.5.3 Recommended future technologies **Informing**

Identification of which micro DE technologies are likely to deliver the optimum CO_2 reduction in the 2050 timeframe. Note this report is combined with 3.4.1.

3.6 Plan for a Larger Field Trial – Deliverable 3.6 **Informing**

Document to provide the outline scope, time, and cost of a project to develop and demonstrate micro-generation and control technologies robustly in a large scale field trial

3.7 Summary Report – This document Deliverable 3.7

Overall project conclusions and recommendations **Informing**

[1] Following the Stern review The Code for Sustainable Homes has been introduced to drive a step-change in sustainable home building practice. http://www.planningportal.gov.uk/uploads/code_for_sust_homes.pdf