Programme Area: Distributed Energy

Project: Micro DE

Title: Plan for Larger Field Trials

Abstract:

Please note this report was produced in 2010/2011 and its contents may be out of date. This deliverable is number 6 of 7 in Work Package 3. The report provides a proposal for the design and execution of a large scale field trial of micro DE technologies based on learning's from the execution of the Micro DE Flexible Research Project. It should be noted that field trial proposed at the start of the FRP has now been integrated into the ETI Smart Systems project and as such the plan proposed here is unlikely to be executed in its current guise.

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.

WP3.6 Plan for a Larger Field Trial

Author:	**Contributors:**
Hazel Preston-Barnes Mike Patterson	Tadj Oreszczyn Catalina Spataru Andrew Smith Andrew Gemmell
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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 desktop 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.

1. Executive Summary

This report, based on a pilot Micro DE project, recommends a field trial focused around demonstrating that Micro DE heat generating technologies (heat pumps and solar thermal) with Building Energy Management systems and thermal storage can be made to work successfully in the UK domestic market. Such a field trial would demonstrate the key factors in Micro DE component and system design, installation, control, operation and maintenance. Without such a field trial it is likely that Micro DE technologies, which are essential in delivering significant government carbon targets (80% reduction in CO_2 emissions), will not meet these targets and potentially destroy consumer confidence in the Micro DE market. Additional benefits of such a field trial would be to provide robust data to ground better policy and Micro DE technology models and also answer key questions about the potential demand and supply profiles of Micro DE technologies including active cooling by heat pumps.

Project partners share the view that the ETI's follow-on trial should focus on heat with the hypothesis:

Micro-DE technologies can be cost-effectively installed to contribute significantly, within the domestic dwelling sector, to UK government targets, provided there is better technological design, installation, control and storage.

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. 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 quality of installation, there is also the role of energy management systems and thermal storage to consider in making both conventional and renewable heat work effectively and efficiently in homes with attention to building performance, Micro DE performance monitoring, heat and electricity metering, and exploring the opportunity for thermal storage and trading.

The field trial of 3600 occupied homes would be designed to answer questions about improvements to the efficiency of these technologies. Information would be collected on DE technologies performance and occupants' comfort, 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.

It is envisaged that the funding required for such a trial would require approximately £30m (to be reviewed when more detail is available). This would include £20m for the direct costs associated with the trial homes (surveys, monitoring equipment, recruitment of participants, data collection, forensic analysis, interventions, micro DE technology installation, insulation, problem resolution) with £10m for running the project (data analysis, modelling, 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.

A demonstration of new and emergent technologies should be included in the trial in order to investigate how they function in occupied homes and to provide guidance on installation and operating practice for mass roll out.

Recommendations

1. A follow-on representative trial of the UK's domestic stock 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 energy management systems, thermal storage and trading.
2. A central office situated in the vicinity of the trial should be considered to manage and support the installation process for such a large number of homes.
3. With a single location for the trial a single installer organisation with a large potential workforce will be required to meet the challenging scale of the programme. These must meet stringent pre-qualification standards in regard to health and safety.
4. Automated data checking and analysis will be essential for a statistical trial of this magnitude.
5. Data collection must be consistent across all dwellings.
6. The specific technology samples introduced into homes must be carefully designed so that the results can be extrapolated to other homes.
7. Sufficient time should be allowed for recruitment of a representative sample of the UK population and house types.
8. The contract should be flexible to allow investigation and resolution of unexpected issues from the field trial.
9. Aspects of cooling may also be investigated particularly in relation to its effects on peak energy utilisation.
10. 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 from PV for example and address its local storage and prospective options to reduce network peaks and demand in general

2 Background

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 existing 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 integrated energy management systems. 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 energy management systems and thermal storage to consider in reducing the demands of existing heating technologies and making renewable heat work effectively and efficiently in homes with attention to building performance, Micro 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.

An underlying principle in examining the options for an ETI follow-on Micro 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 prevent the field trial achieving its core aims. **However, it is recognised that ETI ownership of key programme elements is essential to ensure control of objectives, quality, strategic direction, scale, prospective integration across projects and consistent timeframes. Hence, the ETI is advised to budget at least £30m for such an integrated programme suite, parts of which may be attained through leveraging the spending of other organisations.**

3 Trial Hypothesis and Design

There have been many field trials of different DE technologies with the key aim of 'how does the technology really work in the field as opposed to the laboratory?' Such field trials have uniformly demonstrated a significant underperformance of the technology. We believe it is now time to construct a field trial which has a different objective i.e. not 'how does it work', but 'what do we need to develop to make DE technologies work as efficiently as possible?' This trial will involve development of DE technologies, improvements in the installation but more importantly also focus on energy and CO_2 reduction and optimisation by the introduction sophisticated energy management systems and additional thermal storage.

Therefore proposed trial hypothesis is:

Micro-DE technologies can be cost-effectively installed to contribute significantly, within the domestic dwelling sector, to UK government targets, provided there is better technological design, installation, control and storage.

Specific questions to be addressed by the trial include:

- *What are the real impacts of Building Energy Management Systems/Controls and how do we improve them for greater effectiveness, to provide load shifting/smart grid, better occupant acceptance and comfort?*
- *How do we close the gap between actual and theoretical performance of DE Technologies?*
- *What are the actual constraints for practical installation of DE technologies (including storage) and occupant acceptance?*
- *How can the impact of DE interventions be verified accurately through low cost metering in conjunction with modelling (e.g. SAP) effectively in practice to assess the installed technology and provide a true 'whole house' energy rating**?***

There will certainly be further questions posed during the course of the trial that may or may not be feasible to answer.

From the various reviews on the large trials that are either planned or underway in the UK, Europe and farther afield, it appears that the only trials that cover Building Energy Management Systems with Heat Pumps, Solar Thermal and storage are in the USA and have the main emphasis as Demand Management or Smart Grid rather than the reduction of emissions within the home through the optimisation of heat.

In order to keep the trial to a manageable size and ease the difficulties of finding participant homes it is recommended that this is a linear (longitudinal) trial, with a period of data capture from the homes as they are installed and currently set up and operated, for use as a baseline before any changes are made. The trial would be expected to span at least two winters with the first being a data collection and evaluation period, followed by a period of correction, intervention and necessary improvement works followed by a complete season of monitoring to asses the impact of the interventions.
Homes with heat pumps or gas boilers as the prime means of heat generation will be approached for participation in the trial. The sample of trial homes would be broken down into the following core groups:

- *Gas boilers with Building Energy Management Systems*
- *Gas boilers with Building Energy Management Systems & storage*
- *Gas boilers with Solar Thermal Hot Water, Building Energy Management System & storage*
- *Heat pumps with Building Energy Management Systems*
- *Heat pumps with Building Energy Management Systems & storage*
- *Heat pumps with Solar Thermal Hot Water, Building Energy Management Systems & storage*

Why should Condensing Gas Boilers be included? Aspects of modelling from the Micro DE Project and from the ETI's own ESME model show that there is a strong possibility that up to 50% of UK homes will still be using gas boilers as their main form of heating in 2030. There are a number of reasons why this might occur including the life expectancy of boilers currently available on the market, the comparative costs of changing to another source of heat such as a heat pump (the investment and the price of gas versus electricity) , and the lack of consumer confidence in new low carbon technologies.

It is recognised that gas boilers are a mature product with little or no development expected in the near term. This trial is not expected to replicate any of the multitudes of boiler trials that have already taken place but has two main objectives for inclusion in the proposed trial:

1. If it is the case that gas condensing boilers are still commonplace in 2030, work is required to ensure that they function as efficiently as possible for the demand within the home thereby reducing gas consumption to a minimum to both conserve resources and contribute to carbon reduction targets. This would also provide an opportunity for investigation into zoning of the home using remotely controlled Thermostatic Radiator Valves (TRVS).

   Currently TRVs do not perform well as the temperature sensor is incorporated into the TRV and therefore the radiator output is modulated using a temperature that does not necessarily reflect the temperature of the room but is affected by radiated heat. Trials of remotely controlled TRVs (where the temperature sensor is situated 4ft from the floor, out of draughts and direct sunlight has proved a better way of controlling temperature through radiator output but has not been successful as the battery life of the TRV has been unacceptably short. Over the last two years research is being undertaken into methods of harvesting thermal, solar, radio frequency (RF) and vibrational energy to power these devices and other wireless sensors in a sustainable manner. In June 2009 the Zigbee alliance announced '*development of the ZigBee Green Power feature set to establish a global, standard technology for self-powered devices operating through energy harvesting techniques*'**.** These devices (and other sensors using harvesting technology) are forecast to be readily available by 2014. It is expected that these devices would be ready for mass trials during 2012/3 and it would therefore be appropriate and relevant to include a sample in the future trial.

2. Homes with condensing gas boilers will provide a benchmark for comparison with heat pumps on a number of levels:
   - Reduction in carbon emissions
   - Annual running costs
   - Building Energy Management Systems – reduction in consumption and control of solar generated hot water
   - Occupant comfort and behaviour with and without a building energy management system

- The opportunities for storage of heat
- Effects of fuel switching – from gas to electricity for water heating
- Combining with Solar Thermal for generating hot water
- Effects of temperature reduction for demand side management of gas when supplies are low.

Why are Building Energy Management Systems important? The term building energy management systems (BEMS) means the use of digital computer technology for monitoring the status of buildings and their services systems, and then implementing the appropriate control action based on the measured data.

The features of a Building Energy Management system that might be tested in this trial include:

1. Flexibility to integrate and optimise heat from different sources (Gas or Heat Pump with Immersion heater or Solar Thermal, or District Heating with Immersion heater) giving potential lower cost and lower carbon means of heat
2. Ability to control different zones within a house so that heat can be directed to where it is required and not wasted by heating unoccupied areas for instance (applicable to gas/HP/DH) - lower costs & less CO_2 through less wasted heat.
3. Advanced heating controls PLUS Occupancy Control (applicable to gas/HP/DH) lower costs & less CO_2 through less heat wasted
4. Flexible heating of water from optimum energy source – when either renewable or low cost energy is available (as 1 above) giving potential lower cost and lower carbon means of heat
5. Sufficient water heated just in time to meet demand rather than a whole tank with wasted heat ‘escaping’ from unused hot water (applicable to gas/HP/DH) or heating a whole tank unnecessarily thus preventing storage of solar generated energy (applicable to gas/HP/DH with Solar PV) - lower costs & less CO_2 through less heat wasted
6. Optimise storage of heat and subsequent release from thermal stores (gas/ electricity /HP /DH) - lower costs & less CO_2 through less heat wasted
7. Allow occupants to see when free energy is available for use or when tariffs are high (applicable to gas/HP/DH) giving potential lower cost and lower carbon means of heat
8. Diagnostic analysis of performance (applicable to gas/heat pumps) – lower costs & less CO_2 through less energy wasted by underperforming system
9. Ability to provide a distributed energy network, allowing aggregated demand response, trading of heat. Reduction to cost to grid network of accommodating many renewables sources.
10. Control of RHI payments by limiting ‘wasted heat’

A PassivSystems trial of PassivEnergy product (points 2, 3, & 5 above for Gas & Oil boilers) in 50 occupied homes showed an average 25% savings in consumption over previous bills (using degree day analysis). Potential savings of 1500kg of CO_2 per annum per dwelling on a normal 3 bedroom house with three occupants. At current gas prices this would provide a Return On Investment (ROI) in under 2 years.

A table of available trial results (Domestic and Commercial) with benefits and case studies shows that there is potential to save energy and reduce carbon emissions by the use of building energy management systems as given below:

Domestic or Commercial	Title	Case Study or Trial	Findings/ savings	Link
Commercial	Ford Daventry – Intelligent Building Controls	Case Study	43% costs savings 30% reduction in CO_2 emissions	http://www.energ.co.uk/resources/files/236_BEMS%20Two-Page%20-%20Feb%202010.pdf
Commercial (US)	US Energy Group, Special Applied Intelligence and Sprint Collaborate to Make Buildings More Energy Efficient	Trial	Reduces fuel use by 15-35%, with payback in less than two years. In this recent five-building trial, fuel use decreased by 22%.	http://www.abc12.com/story/15151197/us-energy-group-special-applied-intelligence-and-sprint-collaborate-to-make-buildings-more-energy-efficient?clienttype=printable
Commercial (UK)	Web enabled Wireless Control Energy Management Systems	Case Study	15.4% energy savings (Boots) 19.4% energy savings (Fitness First) 17.4% energy savings (HMV)	http://www.adam-int.com/case_studies_boots.html http://www.adam-int.com/case_studies_fitfirst.html http://www.adam-int.com/case_studies_hmv.html
Commercial (UK)	M2G – reducing Gas consumption	Case Studies	11 – 14 % gas usage reduction	http://www.sabien-tech.co.uk/case_studies/m2g_reducing_gas_consumption/serco http://www.sabien-tech.co.uk/case_studies/m2g_reducing_gas_consumption/sabien_s_m2g_delivers_14_energy_savings_for_ish http://www.sabien-tech.co.uk/case_studies/m2g_reducing_gas_consumption/defra_reduces_energy_consumption_and_CO_2 emissions_by_11
Commercial (Public sector)	Analysis of Fuelstretcher Boiler Control Unit	Case Study / Trial	21% saving in gas cons.	http://www.fuelstretcher.co.uk/SwanseaReport.pdf
Commercial (Public sector)	**Controls & Automatic Meter Reading Workshop**: Controls Pilot Study ; Controls Case Study 1 & 2	Case Study	Primary school – savings pa £200,795.00, 1510 tonnes CO_2 (9.9%), Office building- savings pa 58,000 kWh (30%)	http://carbontrust.quadrant.uk.com/presentations/20110203-SWales.pdf

Although PassivSystems and others have conducted studies, with the largest reported trial in the UK to be 100 homes, there is no large scale statistical evidence that this new generation of intelligent energy management systems can achieve the savings revealed in the small scale studies in the wider population. A larger trial would not only prove the implications of domestic building energy management systems in a broader range of house and population types but provide awareness of the implications of heat pump and other renewable technologies to the local distribution network and an insight into future development opportunities and requirements for a Smart Grid network.

How does Integrated Storage fit into this trial? Thermal energy storage is an enabling technology that bridges the interval between the generation of heat and the requirement to use that heat. This is particularly advantageous when there is a plentiful supply of renewables (from solar) or low cost energy from the grid (from renewables and Nuclear, off peak tariffs).

The EST report 2008 states 'mean consumption household 122 litres/day' – typical cylinder size 100 litres' which implies that many homes heat water more than once a day according to requirement and therefore most likely to be at peak times.

The trend in many homes in the UK has been to reduce the availability of hot water storage by the introduction of combi boilers in order to reduce building size and increase the available living space, making it problematical to retrospectively install and optimise the use of renewables. This trend has also led to a fragmented approach to research and development of storage possibilities and limited trials in this area. The European funded PREHEAT project highlighted this fact in 2006 with a small number of trials and studies being carried out since that time. The results of which are presented below:

Domestic/ Commercial /Academic	Title	Case Study or Trial	Findings/ savings	Link
Commercial	Warwick University – CHP & Storage	Case Study/ Trial	Aim to cut CO_2 emissions by 800 tonnes pa, gas consumption by around 4,240,000kWh pa saving about £170,000 pa from the gas bill	http://www2.warwick.ac.uk/services/estates/projects/thermalstorage/
Academic	Development of Heat Storage System Using Metal Hydride: Experiment of Performance by the Actual Loading Condition	Trial	As the experimental result, heat storage finishes in a limited time, and heat quantity for cooling was 13.5MJ, sufficient for the heat capacity to cool the 10m^2 room for 3 hours. In addition, the coefficient of performance of 2.44 was achieved.	http://scitation.aip.org/getabs/servlet/GetabsServlet?prog=normal&id=ASMECP002004037475000185000001&idtype=cvips&gifs=yes&ref=no
Domestic	Korea – Economic Feasibility analysis of replacing Night Storage heating by Heat Pump & storage	Trial	Reduction in Energy use of 73.3%	http://www.aesieap0910.org/upload/File/PDF/5-Poster%20Sessions/PP/PP0101/PP0101003/PP0101003_FP.pdf

Renewable energy, energy savings and efficiency are widely promoted in the UK and energy storage should both benefit from these initiatives and contribute to the savings, energy and emissions reductions. However, energy storage is seldom directly mentioned (except in regard to the amount of insulation recommended for the cylinder) and its development remains linked to that of a few specific applications (e.g. solar thermal systems).

The benefits from Thermal Storage are seen as:

1. Ability to store heat when free or low cost energy is available (renewable, low tariff grid generation or the excess from technology that does not modulate such as MCHP, Biomass or older gas boilers) for use at a later time when energy is costly - potential lower cost and lower carbon means of heat (a function of a BEMS to match availability, storage and demand).
2. Use of a Buffer tank to speed up heat delivered by a heat pump (or other slow to heat technology), which could reduce or delay demand for electricity during peak times - potential lower cost and lower carbon means of heat. Buffer tanks can also reduce the 'cycling' of heat generation technology therefore prolonging the life of the initial technology investment.
3. Reduces waste of renewable heat from Solar Thermal systems. During peak summer conditions current storage may not be sized to allow all heat generated to be stored for later use with heat being 'lost' through some escape mechanism such as a radiator (or potential damage to the solar system from over heating the glycol).

***Note** that this increasing storage capacity in homes does not necessarily mean replacement of existing Domestic Hot Water cylinders with a single larger unit but could mean additional smaller cylinders in or around the home or other types of heat storage (such as Phase change, latent heat, hydrogen as available) that are suitable and appropriate for domestic use within the home.*

The recent report from The Energy Research Partnership Technology Board, entitled 'The future role for energy storage in the UK' states:

- Energy storage has the potential to contribute to meeting the challenges of a low carbon energy system, but has tended to be overlooked in favour of generation technologies.
- *Further analysis of the potential role of storage in the UK's energy system should be funded. Whole system and subsystem modelling, incorporating the full range of energy storage options across time and energy scales, is needed.*

Why focus on Heat pumps? Heat pumps are seen to have huge potential for reducing carbon emissions in the near future for properties that are not on the gas-grid and currently use oil or electricity for space heating. For homes with a regular natural gas supply properly performing heat pumps could provide a low carbon alternative boiler replacement by 2020/2030 particularly if the electricity supply is decarbonised. However this market will not take off unless there is a compelling consumer proposition. Short term incentives are inadequate unless equipment is reliable, cost effective, efficient and provides the right level of comfort for the occupants. The EST heat pump trial report advises that **'it is essential to conduct further trials to establish best practice and perfect this technology for buildings throughout the UK'.**

This trial would look at:

- Installation to a high standard of heat pumps following correct design, sizing, and preparation in a small number of homes
- Correcting existing issues with heat pumps already installed in the trial homes
- Introduction of an energy management and control system to optimise the use of energy generated from heat pumps, reduce wasted and investigate means of time shifting demands from the grid by the use of storage
- Provide diagnostics on the performance of the heat pump back to the occupants on a medium that is easily accessible and in an easy to understand format.

Why is Solar Thermal included? On average every home spends 20-25% of its combined energy bills on water heating. In the UK a well designed and installed solar heating system can provide almost all the hot water during the summer months and around 50-60% of the annual consumption. This provides a very low carbon source and reduces the heavy load required by other heating devices thus extending the lifetime of heat pumps and conventional boilers. However, in 2009 the Office of Fair Trading received over 1000 complaints related to solar thermal installation (out of an installed base of 100,000). From trials it has been determined that many of these systems are under achieving because the domestic hot water has already been heated by another means with only human intervention changing these patterns or using hot water when it is plentiful. It is essential that the problems underlying these issues are resolved by improved system insulation, effective energy management systems, and end user education.

4 The Right Size for the Field Trial

Sample Size. To ensure the field trial is representative of the UK's domestic stock, the sample will be made up of a mix of owner occupied and social housing homes within each of the six proposed technology groups. These groups would then be further broken down by energy consumption – with a group for high energy consumption versus average and lower energy consumption.

This would give 24 trial cells. It is recommended that each cell should have at least 100 trial homes and 50 control homes. This sample will allow the delivery team to examine the relative energy savings by type of heating technology, type of intervention, occupant tenure and typical baseline energy use. The control group will ensure that many differences in energy use from the first heating season to the second not attributable to the interventions (e.g. the effect of weather conditions, or the cost of energy) can be controlled for.

Homes would be taken from a single geographical location (possibly a large town) in the UK in order to be able to test the effects of the use of heat pumps and storage of energy on the supply and local grid network.

What effects the sample size required for a field trial / experiment? In general the larger the sample size the more accurate your sample statistics will be. Putting to one side cost, time and practicality, there are a number of factors that will determine the size of samples that are required in a field trial in order to correctly observe statistical differences between them. Briefly these factors are:

- The number of variables in your design and the groups you need to compare – the more variables there are, the larger the sample size will need to be.
- The size of the difference between the groups on key factors that you wish to observe (effect size) – as effect size decreases, sample size increases.
- The power required to identify these differences – as power increases, sample sizes also increases. A power of at least 0.8 is recommended increasing to 0.9 if feasible.
- The significance level of a test (commonly denoted alpha), is the likelihood of rejecting the null hypothesis when it is true – as alpha increases, sample size increases. An alpha of 5% (rendering a one in 20 twenty chance of making an incorrect conclusion) is commonly used across all areas of statistics.

How was the minimum sample size calculated for the current design? The 6x2x2 repeated measures design requires some sort of multivariate analysis to be conducted. In addition to this the repeated measures aspect of the data also needs to be considered.
There are various types of multivariate analysis however, taking the aforementioned elements into account it was determined that a repeated measures analysis design utilising a multivariate (MANOVA) type approach would be most appropriate. This allows examination between-subject differences and within-subject difference and interactions, whilst accounting for the repeated measures nature of the data. Further to that, utilising a multivariate approach to the analysis negates the need for meeting the sphericity assumption (where the variances of the differences between all combinations of related groups are equal) usually required with such analyses.
Calculations were based on a multivariate A x B design with 12 measurement points, 6 groups, with 2 factors of interest where each of the factors has 2 levels. In all cases the calculations were made with a power of 0.9, and an alpha of 0.05.

Based on the above design, if simply looking at the effect of an intervention (e.g. installing improved control mechanisms in an already monitored home) on energy use in each house (within subject effects) then a sample size of 2000 would allow us to pick up very small differences within a group. However, if we want to compare the size of the effect between different groups the required sample to pick up these small differences increases markedly.

If just looking at main effects and assuming medium to large effect sizes, then a total sample size 2000 should be sufficient. However, the more variables (and levels within them) to compare the larger the sample size will need to be.

Following some work on the calculations for conducting tests of main effects it was decided that there would be little to be gained from examining interactions given the increase in sample size it would require.

Impact of a single location. Conducting the field trial in a single location can reduce the commonality of the findings and how confidently the findings can be applied to other parts of the UK. There will be factors that differentiate the chosen location from other locations in the UK that therefore mean the findings cannot necessarily be applied to other locations. It will be import to select a location that is not dramatically different from the rest of UK on any factors that could affect key variables such as the energy production / consumption. For example if a location on the South Coast was selected that received significantly less overcast days and a higher average temperature than the rest of the UK, the findings regarding the performance of STHW systems and Heat Pumps may not be applicable to other parts of the UK. Similarly, the relative affluence of the area may also influence occupant behaviour, people's perception of energy costs and their energy use.

Size of the Control group. The control group is required so that any extraneous variables can be accounted for. Any factors that might influence the variables we are looking to measure (our dependent variables) need to be measured or controlled. In this case variables such as the energy used in the home, the performance of the Micro DE technologies and heating systems etc will be measured (these are our dependent variables). We will be looking to see what influence specific interventions have on these variables as well as what impact occupant behaviour and other factors have (these will be our independent variables). However, there may well be other factors that could influence energy used in the home and the performance of the Micro DE technologies such as external temperature, dramatic changes in the price of energy over the period of the trial, campaigns to encourage households to use less energy etc. In order to ensure that we don't falsely attribute the effects of these extraneous variables to our independent variable we need to be able to measure the effects in a controlled manner.

The proposed phased approach for the trial ensures that each house acts as its own control group for many factors assuming the same occupants remain in the homes and their typical occupancy patterns do not change during the trial. However, as described above, there are other extraneous variables that could affect the dependent variables that would not be accounted for without a separate control group who are not subject to any type of intervention.

Having the sample in one location could reduce the size of the control group needed as factors such as the external temperature and weather conditions are likely to be similar across the sample. It is proposed that for this design the control group homes should be in the same general location and that should monitored in the same way as the experimental group homes but without any interventions. This will allow the researchers to factor out the influence of the extraneous variables and confidently attribute any changes or differences to the experimental independent variables.

With the current trial design there is little requirement for a matched control house for each experimental house; However, it is recommended that there are matched control homes for at least 10% of the experimental homes.

Homes may be recruited from the potential 25,000 homes taking up the Renewable Heat Incentive (RHI) premium payment incentive, homes already participating in Low Carbon Network Funded schemes or other large scale programmes provided neither set of objectives are comprised by the dual activity. Recruitment of homes that are already part of another trial would relieve the ETI of the financial burden and responsibility of installing large amounts of equipment in a large proportion of the homes but does have the disadvantage of possible constraints on what interventions can be made to the home.

Data Monitoring Points. All homes would have a physical survey to characterise the properties. The detailed energy performance of the home and its heating technologies would be monitored in the active properties allowing accurate calculation of Seasonal Performance Factors (SCF) both for hot water and space heating. In addition to energy data flow meters for hot water and space heating will be installed to determine hot water and space heating demand. Room temperatures in each room and CO_2 measurements from the bedroom and living area will be made at frequent intervals plus external weather conditions including solar radiation levels. The internal temperature and CO_2 data will be used to assess the heat load and comfort of the building with the CO_2 data contributing to the understanding of the occupancy status and ventilation rate of the dwelling. Overall water consumption might also be monitored in order to gain an appreciation of the overall carbon consumption from a given home. Data is expected to be collected automatically at sub one minute levels during times when the values are changing but at a higher frequency when no changes are detected.

Summertime temperatures and Seasonal Performance Factors would also be monitored in a sub set of heat pump properties installed with units that can provide both heating and cooling. A control group of homes with heating only heat pumps would also be monitored in the summer to compare temperatures.

For the control group a range of energy consumption data will be collected – possibly using Smart Metering* technology if in conjunction with an energy supplier, as well as an occupant survey to understand who lives in the homes and their typical occupancy and energy use patterns.

***Note** Limitations on the installation of Smart Metering from the beginning of 2012 mean that the supplier has a mandated obligation to install a display and provide the occupants with training and energy savings advice.

5 Field Trial Improvements & Interventions

A set of underperforming homes in each active group will be investigated by team of experts including building physicists, engineers, expert installers and manufactures etc. The experts will visit the properties to decide what may be the cause of above or below average performance, and, if necessary, will install additional monitoring equipment in these properties in order to compare them with their better-performing counterparts. Based on the data and the visit the panel of experts will decide what interventions to undertake in order to improve performance in these properties.

A programme of work will be undertaken to improve the performance of these homes including:

- Upgrades to installed equipment include heat production technologies and emitter systems
- Further insulation
- Changes to Control strategies
- Additional storage
- Education of Occupants

The specific technology samples introduced into homes must be carefully designed so that the results can either be replicated or extrapolated to other homes. The contract should be flexible to allow investigation and resolution of issues arising from the field trial.

A demonstration of new and emergent TRL 5 and 6 technologies, such as Fuel cell Micro CHP as an alternative to gas boilers, should also be included as possible replacement technologies in order to investigate how they would function in occupied homes, whether they may replace current systems/models and to provide guidance on installation and operating practice ahead of commercialisation and mass roll out. It would be expected that new and emergent systems would be donated by manufacturers for inclusion in this prestigious trial.

For continuity of Health and Safety, the single location for the trial makes its practical to use a single installer organisation to deliver this challenging scale of the programme. The chosen organisation must meet stringent pre-qualification standards in regard to competency of health and safety and appropriately accredited and experience staff.

Automated data checking and analysis will be essential for a statistical trial of this magnitude. Data collection must be consistent across all dwellings.

6 Occupant Monitoring

Occupant behaviour will inevitably have an impact on energy consumption/generation in the field trial houses and a robust but not intrusive method of evaluating this is necessary. But what data should be collected, when should the data collection take place and how should the data be collected?

Frequency. As a minimum it is recommended that data is collected at three points over the field trial. It is proposed that the first round of data collection should take place within one month of the installation of any monitoring equipment. Data collected from occupants at this stage will establish:

- Typical occupancy patterns and the lifestyle of the occupants (inc frequency of visitors)
- Typical occupant behaviour and energy usage patterns
- Perceived environmental conditions in the house and occupant comfort
- How the occupants currently use and interact with their micro DE technologies and other key systems (e.g. heating and hot water systems)
- Establish level of understanding over how to use the systems effectively and efficiently
- Perceived performance of the systems and occupants suggestions for improvements to the performance and ease of use.

The second set of interviews should take place between one and three months after any intervention to establish:

- The perceived impact of the intervention
- Impact of the interventions on how the systems are used and how occupants interact with them
- Any changes in behaviour as a direct or indirect result of the intervention
- Perceived performance of the systems since the intervention
- Changes in level of understanding over how to use their systems effectively and efficiently
- Any perceived changes in the environmental conditions and occupant comfort
- Any changes to who occupies the house and their typical occupancy patterns.

The final round of data collection should take place in the final two months of the trial to examine:

- Longer term impacts of the interventions on occupant behaviour and how they interact with and use the systems
- Longer term changes in occupants level of understanding over how to use their systems effectively and efficiently
- Any evidence of rebound effects
- Any long term perceived changes in the environmental conditions and occupant comfort.

As with the pilot project there should also be the opportunities for ad hoc telephone interviews throughout the monitoring period if there are any unexplained substantial deviations from ‘typical’ energy use patterns.

How should the data be collected? The list below outlines the pros and cons of the possible options for collecting occupant behavioural information in a future trial:

- Face to face interviews at the properties. Conducting the interviews in the houses would allow the occupants to physically demonstrate how they interact with the properties and the technologies installed and allow the interviewer to gain a fuller understanding. However with such a large trial this could prove expensive and time consuming. Some participants may find it inconvenient and intrusive to have people coming to the house.

- Telephone interviews are less costly and easier to set up than face to face which ensures a larger proportion of properties can be contacted. There is still a direct dialogue with the occupants which allows both qualitative and quantitative data to be collected. However this is more expensive and time consuming than sending paper/electronic questionnaires and may result in slightly less in-depth information than the face to face interviews.

- Questionnaires (electronic or paper) are often the most convenient method for the participant as they can complete the questionnaire whenever they have time and is possibly the cheapest and least time consuming method for the researcher. However, it is extremely hard to ensure data is collected from every field trial property (as people may not send back the completed questionnaire). With no direct dialogue with the occupants some questions may be misinterpreted and the responses may be limited.

- Diary data / video diaries provide detailed in-depth data and information. Data can be collect at the time of the experience (or very soon after) so the collected findings can be more and representative of the true behaviour or experience and not based on a memory. However, it may be very difficult and time consuming to analyse and interpret the resultant findings and time consuming for the participant. It is often difficult to obtain consistent data over a long study as participants get fed up of doing them or don't always have time.

From experience of the pilot field trial where both face to face and telephone interviews were used, it is recommended that the majority of interviews are via the telephone with a number of face to face interviews with selected participants or those that require comprehensive intervention work.

7 Field Trial Benefits

The field trials should be undertaken with occupants who are representative of the UK energy consumers (not all early adopters/Greens) and are predominately driven by normal market mechanisms - there will be a number of drivers and barriers to occupants taking up Micro DE technologies, e.g. initial cost, anticipated running cost, confidence in reliability and effectiveness, attractiveness and convenience of product. The field trial will therefore deliver to ETI the following clear set of benefits which previous trials have not been aimed to achieve:

1. Quantifying the importance of integrated energy management systems and storage in meeting UK carbon reduction targets in representative samples of the housing stock with different heat technologies.
2. The technological improvements required for specific DE technologies that will make them work most efficiently in UK dwellings.
3. The barriers to take up of the Micro DE and energy management systems technology and how these might be addressed from the performance, cost and consumer confidence perspectives.
4. Ascertain the physical constraints of installing DE technology systems into existing properties with simplified remote rules that can be applied to the selection of these properties thereby identifying areas of the country which may be particularly attractive to the installation of Micro DE technologies.
5. An insight into the relationships between laboratory test efficiency and system efficiency when located in different dwellings with different occupants. This in turn will lead to the development of better models to estimate the impact that DE technologies are likely to have on the running cost of a particular UK dwelling.
6. Determine the key design criteria for a particular Micro DE technology in a particular dwelling. Including the development of a clear set of protocols for appropriately sizing Micro DE heating systems in UK dwellings.
7. The key factors affecting the quality of installation for each of the chosen Micro DE technologies.
8. Quantifying the impact of occupant behaviour on the performance and associated energy use of the Micro DE systems looked at.

8 Other Field Trial Options

In a further group, 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.

The model results show that potentially 15% of all dwellings in 2030 would be part of some sort of district heating scheme. It is believed that these will be addressed by the ETI under a separate project however some of the learning from Building Energy Management Controls in this project may be relevant.

Air to air heat pump units are built to provide both heating and cooling with the cooling features being disabled in most of the heat pumps marketed in the UK. These might be enabled to provide night time bedroom (sleep) cooling to provide the first comprehensive field trial to assess potential cooling energy demand and performance. Depending on the energy used and the occurrence of peak power the additional benefit of cooling could be a key motivator for heat pump installation without significant detriment to a decarbonised supply system. Such a field trial would be essential in determining whether cooling with heat pumps is a potential threat to a decarbonised society or an opportunity to encourage the installation of heat pumps while improving summer health and comfort with minimal impact on the energy system. The reality is that some heat pumps will be used for cooling and we need to understand how this will operate with minimal impact on a decarbonised supply system and maximum utility for the occupants.

The growth in central and distributed power generation coupled with new legislation around energy services, will encourage new market models potentially with innovative tariffs, reflecting the carbon content of delivered energy. Infrastructure constraints will also create new commercial opportunities for aggregators. The home will become part of this smarter energy supply model and a follow on ETI programme cannot ignore this significant prospect.

Poor installation is a major market failure and hence in parallel to the field activities, a heat pump support programme should be considered. This would simulate, emulate, create, test and understand some of the major heat pump sub-systems such that technical constraints or potential field failures may be identified and rectified remotely under controlled conditions, thus making sure that these different systems interwork and deliver the maximum return to the customer, and achieve their potential for de-carbonising. Integrated heat pump systems could be made to work as intended **well before** they reach customers' homes. A system for accreditation would also support the mass introduction of heat pumps into complex retrofit home environments. The assessment criteria required for a 'DE Mark of Conformity' and associated testing requirements could be identified from the above programme.

The latter four options have not been included in the costs of the programme at this stage.

9 The Future Programme

Whilst the field trial is a key element to the future project experience tells us that this is only one piece in a much larger programme of work that includes not only the field trial activities of planning, rollout of equipment and capture of data but a range of other activities to both support and enhance the work.

Further Development of the Micro DE Model

There are a series of models used in UK for calculation of the energy performance of dwellings as shown below. The models vary from simplified energy balance models to detailed simulation models, and from individual building energy models to models of the entire stock.

Energy Performance of Dwellings Models used in UK	
Name of Model	**Ownership**
BRE Domestic Energy Model (BREDEM)	BRE
Standard Assessment Procedure (SAP) SAP2005, SAP2009 & RdSAP	BRE
BRE Housing Model for Energy Studies (BREHOMES) (Stock model)	BRE
Energy Questionnaire (EnQuire) (Stock model)	BRE
IES VE Virtual Environment-Pro (VE-Pro)	Integrated Environmental Solutions Limited, UK
Tas building Designer	Developed by Cranfield Institute and owned by Environmental Design Solutions (EDSL) Ltd
Ecotect Analysis	Developed by Cardiff University and owned by Autodesk Inc
ESP-r	Developed by Energy Systems Research Unit at the University of Strathclyde

For the purpose of this trial it is recommended that BREDEM/SAP 2009 (or later) is be used for energy assessment of the buildings. For stock modelling the model developed jointly for the Micro DE Pilot project and the Optimising Thermal Efficiency of English Housing project should be used and updated where necessary.

Additional DE model development and use is required for two reasons:

1. **To help interpret monitored data.** Monitoring is only valuable if you can use the monitored data to help you understand what is actually happening. This requires some form, of model to help you interpret a complex set of data. This model can in some cases be simple but in the case of Micro DE technologies located in occupied buildings is often complex. Since it is impossible to measure every parameter or control for different parameters in a field trial it is normally only possible to understand the results by utilising a model of some sort. These models help you to control for variations in occupant behaviour, building type, climate, etc. The interaction of data collection, interpretation and model development is a circular process, i.e. you collect more data, compare model and data predictions and then refine the model.

2. **In order to represent the main features of the whole energy system** with reasonable realism and accuracy, a dynamic model is needed so that the largest flows and interactions of the national system are captured, allowing identification of the best solutions to be implemented across UK based on the available energy sources. The empirical relationships in current energy models will need to be improved in order to more accurately predict energy demand at a household level. Therefore, a well develop model which can take account of different dwelling types, regional climatic factors, alternative dwelling occupancy patterns and which can simulate the uptake of microgeneration, at both small and large scale, will give the industry confidence to invest and grow, as well as to reach the Government targets to achieve a zero carbon emissions by 2050 and contribute to our target of sourcing 20% of all EU energy from renewables by 2020.
3. **To provide a better model** to help evaluate and implement policy and help develop better technologies and install better systems. Micro DE models are playing an increasingly important role in the investment and deployment of £billions of technology. Policy makers use Micro DE models to assess future scenarios and the policies to support them, as well as an instrument to regulate and financially support the technologies. Building owners and installers use models to determine the likely payback on investment that these technologies will have whilst industry uses models to help develop their technologies and decide on the appropriate systems that DE technologies should be installed in. The pilot Micro DE project has demonstrated the potential usefulness of these models but also exposed several key weaknesses. We therefore believe three core model developments need to be undertaken:
   a. **Refine the standard assessment procedure** (SAP) for assessing the performance of individual and combined DE technologies. SAP has evolved over many decades from a tool predominately designed to assess the impact of changes to the fabric and heating system on the demand for space heating energy to compare one dwelling with another independent of occupant use. It was not designed with the aim of appropriately assessing DE technologies yet it is the model most commonly used for policy, regulation and assessment.
   b. **Develop a standard technology rich energy system model** to help industry develop appropriate products and installers know the impact on performance of installing the technologies in different systems. Such models can then be used to develop installation standards.
   c. **Refine the stock modelling** to better incorporate the technology performance (based on the results of the main field trials) and better assess the uptake of technologies. Stock models are currently limited by the data to populate them, as data from the field trial and from other trials such as RHI becomes available it will be possible to develop much more sophisticated stock models utilising distributions of behaviour.

Consumer Research – Investment in Micro DE technologies

As well as understanding the real world energy and C02 savings that can be achieved using Micro DE heating technologies, it is also vital to understand what the key drivers and barriers to investment and installation are likely to be for householders. It may be that research finds it is possible to save 80% of domestic energy use by installing these technologies, but if everyone refuses to have one in their home the targets can't be met. It will also be important to understand consumer awareness and which Micro DE technologies are perceived as 'desirable'. It may be that research suggests that the mass installation of heat pumps would result in the greatest reduction in C02 but heat pumps are perceived as very undesirable by consumers.

Building on the consumer segmentation modelling work conducted as part of the ETI Optimising Thermal Efficiency of English Housing project, it is proposed a national survey should be conducted to explore the potential drivers and barriers to the investment in Micro DE Technologies. The survey would explore; what factors discourage different segments of consumers from installing Micro DE technologies, how best to communicate with potential consumers and what changes need to be made to the products themselves, incentives, funding streams etc to make Micro DE systems more appealing. This data would further inform the refinement and development of the segmentation model.

From this work the ETI will not only have a clear picture of how these Micro DE technologies can perform in the field but also to whom these products currently appeal and what barriers should be overcome to encourage different groups of consumers to invest in them.

This piece of research could be done at anytime in the research programme as it is a separate independent study from the main field trial focussing on a different target population (the whole UK housing market rather than the population of a particular location) and different sampling strategy based on the segmentation model.

The options for the timing of this work are:

1. Conducted at the start of the project to ensure the ETI have the findings ASAP and overlaps with the Optimising Thermal Efficiency of English Housing project survey can be exploited
2. Timed so it is distributed after the launch of an initiative (e.g. Green Deal) so the impact of such initiative on perception could be measured
3. A survey at the start and one at the end of the project to explore changes over time or to measure the impact of a initiative/campaign

Programme Costs

The proposed work breakdown structure and associated costs of the programme are provided below.

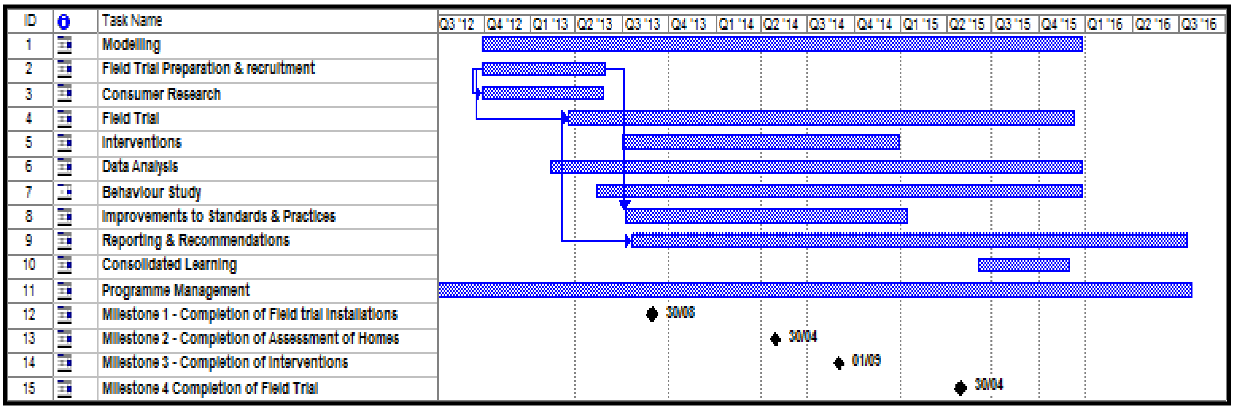
No.	Work Package Title	Description	Resource costs	Other Costs*
1	Programme Management	The general management of the programme including: • Project mobilisation, kick off meeting • Day to day management, Milestone, work package & Steering group management & reviews. • Project planning - Gantt chart, Raid logs, Lessons Learned, Comms Plan. • Legal & collaboration agreements. • Finance/budgeting, Reporting, • Knowledge management system. • H&S management. • Liaison with consortium partners. • Procedures, standards & templates • Resourcing • Change Management • Project Closure	£2m	N/a
2	Modelling	Conversion of current Micro DE model of UK Energy Use to provide options to compare alternative existing heating & Micro DE technology on a home by home basis, include District Heating Options etc. • Verification/Validation of the model • Model Documentation & assumptions. • Predictions from the model with various scenarios using field trial data. • Applicability to UK housing stock. • Feedback of data from monitoring, occupant interviews and Consumer panel studies to refine model.	£1.5m	N/a
3	Field trial preparation & recruitment	Trial design & detailed specification planning of trial cells, including housing stock, demographic, geographic & technology representations. • Definition & agreement of data capture system requirements. • Discussion with 3rd parties - availability of homes already being metered. • Selection & Recruitment of test home & trial homes, Site Surveys. Householder agreements. • Recruitment & training of installers including H&S competency assessment.	£1.5m	£8m

		• Installation arrangements • Procurement & Installation of data capture systems. • RDSAP surveys		
4	Field Trial Operation	Ongoing running of the field trial including: • Management of contractors • Data collection. • Automated data checking. • Problem Resolution • Support of field trial homes. • H&S management. • Removal of equipment at end of trial	£1m	£5m
5	Interventions	Assessment of candidate homes for interventions. • Detailed investigation of worst performing homes in each trial cell. • Procurement of equipment • Management of contractors • Installation of Control systems/ upgrades to systems. • Installation/upgrade of Thermal Storage. • Upgrade to Thermal Insulation. • Corrective action to existing heating systems. • Installation of new heating systems according to new practices. • Selective assessment of Technology Readiness Level 3 to 6 components.	£1m	£4.5m
6	Data Analysis	Data Cleansing. Development of analysis tool & data sharing mechanisms. Development of performance indices for automated checking and remote reporting of issues. Analysis & reporting of data collected from field trial homes. Data feed into model. Correlation with Model outputs.	£2m	
7	Behaviour study	Occupant questionnaires relating to energy use, barriers/drivers to potential uptake of Micro DE technologies and decisions taken on energy products etc at start & various stages during the project. Surveys on issues with current installed systems. Exit studies.	£1m	
8	Consumer research	Building on the consumer segmentation modelling work conducted in the ETI Thermal Efficiency project, a national survey to explore the drivers and barriers to the investment in Micro DE. The survey would explore the factors that currently	£50k	£50k

		discourage different segments of consumers from installing these technologies, how best to communicate with potential consumers and what changes need to be made to the products themselves, funding streams etc to make Micro DE more appealing. From this data the segmentation model would be further refined and developed		
9	Improvements to Standards & Practice in the Installation chain	Analysis of bad practices in traditional heating, energy management systems, Micro DE & storage installation/supply chain from previous trials & experience, surveys etc. • Recommendations. • Stakeholder workshops. • Training of small group of installers. • Analysis of results from improved planning/ installation.	£0.5m	£0.5m
10	Consolidated Learning	Review of individual work package and deliverable reports. Creation of summary document and presentational material for ETI Programme Management Board.	£0.5m	
11	Reporting & Recommendations	Reporting trial & modelling results & conclusions. Policy recommendations to Government. Recommendations on changes to appraisal of energy requirements for the building stock. Recommendations to Industry. Recommendations to supply/install chain.	£1m	

** Includes all non-consortium resource costs (installation, 3rd party involvement in consumer groups, expert forums), costs for equipment (BEMS, Storage, Micro DE, Insulation) and any other costs such as facilities.*

10 High Level Project plan



11 Risks to the proposed programme

Risk	Likelihood (L/M/H)	Impact (L/M/H)	Mitigation
Consortium partners slip on their project deliverables	H	H	Ensure a project manager (with the relevant skills) is appointed as the main point of contact for each partner. Ensure clear definition of roles and responsibilities is agreed at project initiation. Ensure deliverables table is signed-off with each partner and subject to change control. Ensure weekly project team meetings are attended by each project manager.
Timescales slip to start of programme	M	H	Use learning from previous contract negotiations Closely manage progress at key stages
Timescales slip during project affecting project end	M	H	Ensure Project Management resource allocated in all partner organisations. Provide detailed project plan with contingency for potential risk areas. Ensure project governance is in place from project initiation phase and that good practice is adhered to from the start of the project. Closely manage progress at key stages.
Government policy changes affect scope, objectives or the outcome of the programme	M	H	Monitor policy and ensure programme remains aligned. Ensure flexibility in approach to allow change for any significant external influences. Ensure a number of key experts are lined up to advise the consortium should the project scope change.

Risk	Likelihood (L/M/H)	Impact (L/M/H)	Mitigation
Time pressures (possibly caused by unexpected issue) leading to short cuts	H	H	Ensure sufficient time planned for work (End Of Day updates to co-ordinators). Allow 'free' days in schedule. Allocate additional installers. Rearrange schedule if necessary.
Gap is identified in plan that results in resource shortage	M	H	Conduct regular reviews of progress against plan with impact assessments of interactions and dependencies Maintain close engagement with ETI on changes to resource needs and costs
Project costs rise as more work is required to take home to a suitable standard for Micro DE equipment	M	H	Ensure budget is built on representative samples of homes with contingency. Canvass other funding options such as Green Deal. Seek donations from suppliers. Ensure regular budgetary and financial reporting in place to give early warning of issues against the financial plan.
Communications issues both at WAN and HAN levels	M	H	Utilise previous experience of field communications. Use GSM communications where broadband not installed or unreliable Ensure daily automated checks of data. Remote checking of system robustness. Systems engineer to hand. Site visits as necessary.
The installation programme for a large number of homes takes longer than expected	M	M	Ensure a signed-off programme plan is in place for the installations. Ensure the installer has a dedicated project manager in place. Build in contingency in case of slippage to installs (the plan will require flexibility). Ensure the planning for a large number of installs is not underestimated.

Risk	**Likelihood (L/M/H)**	**Impact (L/M/H)**	**Mitigation**
Data overload	M	M	Automate processes as much as possible & anticipate statistical resource needs.
Installation & supply organisations reject recommendations	M	M	Include representative organisation in the consortium, include other influential organisations in the programme as focus groups, installers etc
Due to numbers of persons required - installers use insufficiently skilled personnel	M	M	Use contract terms and conditions to reduce possibility. Check skills of all staff. Use training and induction processes to ensure skill levels are appropriate. Central office to be able to refuse access to site.
Existing safety issue in home	M	M	Existing safety issue in home.
The installations are not completed to a satisfactory quality	M	M	Ensure a reputable qualified installation company is used. Ensure Service Level Agreements are built into the contract. Automate processes as much as possible & anticipate statistical resource needs.
Householder withdraws from trial	M	L	Replace homes as required from the contingency reserve
Safety incident in home	L	H	Compliance to HSE policy and procedures. Site supervisors H&S trained. H&S assessment of installers prior to engagement. Regular Audits & spot checks. Ensure equipment safety checked. Ensure adequate liability insurance cover.
Householders interfere with equipment	L	H	Briefing processes and instruction hand outs. Adopt GSM approach and avoid using customers' comms equipment where potential issues envisaged. Organise local rapid response teams to respond urgently to any issues.

Risk	Likelihood (L/M/H)	Impact (L/M/H)	Mitigation
Consortium partner does not perform as expected	L	H	Ensure work package and task delivery responsibility is allocated clearly to partners Conduct stage gate and regular interim performance reviews
Suitable organisations cannot be found to form a credible consortium	L	H	Use both lead partner and ETI contacts to approach competent organisations
Consortium partner withdraws	L	H	Use consortium and ETI contacts to identify replacement organisation
Existing modelling tools cannot be adapted to the needs of this programme	L	H	Review and document requirements at earliest possible stage to allow additional work to be undertaken before the
Suitable locations/homes cannot be found for the field trial	L	H	Attempt to use some homes that are part of existing trials. Use local campaigns for desired geographic areas. As contingency, design trial with more homes than required.

12 Consortium Partners

It is essential that the organisations which deliver this programme of work are sufficient in size, competence and experience. It seems likely that a consortium of partners will be required to achieve this. Organisations that should be considered to form a consortium to deliver this programme of work might include:

- Micro DE, Storage and Building Energy Management System Technology manufacturers
- A Local Authority or Housing Association
- A utility supplier
- A Micro DE distribution channel and installer
- Academic organisations
- A buildings or micro DE consultancy
- A house building group
- A new market entrant e.g. major retailer or consultancy led innovator

13 The Value of Future Work to the ETI & its Members

The overall benefits from the field trial to the UK, to consumers and to technology organisations are provided in Section 7. The ETI and its members will also share in these benefits however there are some specific areas of value from the overall programme that are applicable to:

The ETI

1. A programme to demonstrate how energy can be used more efficiency in the UK housing stock with the possibilities for trading of heat
2. A programme to demonstrate GHG reduction in the UK housing stock by innovative ways of using energy management systems and storage (using both existing and new heating technologies)
3. Confirmation or otherwise of consumer confidence in a low carbon economy
4. A programme to assist with the reduction of carbon from domestic heating requirements and the consumer acceptance of a different way of storing and using energy
5. A programme to assist with accelerating the deployment of heat pumps – with advice to the industry on how to achieve optimum performance from UK homes and improving the ROI for consumers
6. A programme that starts to understand the effects of energy management systems and storage within the home on the demands of the grid that could be rolled into a larger Smart systems trial

The ETI Members

1. Utilities – Confirming a means of reduction in energy usage thereby reducing the need for future investment in infrastructure (both generation and distribution network) and assisting with security of supply
2. Utilities – Assessment of means of shifting consumption away from peak times by energy storage to times when supply plentiful (from off shore wind or nuclear for example)
3. An appreciation of the views of consumers (current and potential) and barriers to take up of Micro DE, Energy Management systems and storage technology.
4. Oil companies – how effective alternative means of heating can facilitate a move from fossil fuel use in the home thus preserving supplies for other larger uses
5. UK Government – effectiveness of RHI. Reduction in payments by limiting of 'wasted heat'

14 Costs of not undertaking this Programme

The UK government has agreed a legally binding target to cut greenhouse gas emissions to at least 80% below 1990 levels by 2050 and also has a target to obtain 15% of all energy, for electricity, heat and transport, from renewable sources by 2020.

These goals rely heavily on government incentives for both reductions in the use of energy within the home and by householders investing in renewable technologies. Whilst Micro DE technologies continue to fail to meet the intended levels of performance due to issues with installation and integration into existing heating systems, consumers will be reluctant to make the move to this type of technology.

Without this buy in from consumers more extreme reductions in emissions will be required in other areas as well as large investment in the energy infrastructure to meet continued demand, especially at peak times.

Some simple figures showing the effects of not addressing these issues are given below:

There is a projected install base for heat pumps of between 600,000 and 2m units by 2020 according to DECC AEA Scenarios for renewable growth **From EST & ETI Field trial – 75% of units are underperforming by around 25%**	
Costs to industry	
One day visit by MCS qualified team to correct issues circa	**£1000**
One visit to each underperforming site (75% of those installed by 2020)	**£450 - £1500m**
Costs to homeowner	
Additional cost for supplementary heating - for a 3 bed home at 2011 energy prices	**£250 per annum**
Costs to UK CO_2 Targets Heat pumps save 750kg CO_2 per annum over a Gas condensing boiler (EST web site)	
With underperformance 25% – 2020 loss of CO_2 savings if replaced by higher CO_2 form of heat	**85,000 - 280,000 tonnes per annum**

15 Field Trial Roll Out & Management

Introduction

There are a number of processes to be carried out in the high level planning that should be considered in advance. These are described in the following sections.

Health & Safety Management

Health and Safety is a key area in any field trial and covers the partner and contractual staff, occupants of the trial homes and the general public with the aim of preventing accidents and injury.

Adherence to Health and Safety legislation is mandatory and therefore adherence to the policy, processes and procedures of the project should also be mandatory.

Due to the number of homes in the trial and the consequential length of time for the installation works to be completed, the Field Trial is most likely to come under CDM (Construction, Design & Management) regulations and the rules and regulations for managing that type of project will also apply.

As the field trial homes are recommended to be in a single location it is recommended that a site office is set up for the duration of the installation works. This will serve as:

- a headquarters for the planning and scheduling of the work and the installation teams
- a base for the site managers
- a location for regular briefing and update s for the installation teams
- a training facility for new recruits into the installation team
- a depot for spares
- a crisis management office

The central office should be staffed at all times during the working day by both administrative staff, (scheduling appointments, arranging deliveries, front line support desk) and qualified technical staff who are on hand to assist in problem resolution, checking installers qualifications, additional installer training, plan and assist with emergency issues, perform ad hoc health & safety inspections, brief staff etc.

Health and Safety should be managed according to an agreed Health and Safety plan specifying the processes and procedures that will be undertaken for the duration of the project including:

- Roles & responsibilities
- Health and Safety Site Responsibility
- Site Working Practices
- Training and Induction
- Risk Assessment & Method Statements
- Audits & Inspections
- Accident and Emergency Procedures
- Incident Reporting and Investigation Protocol
- Escalation procedure

All staff working on the field trial should be provided with Health and Safety training and with a copy of the plan, processes and procedures.

It is recommended that a trained Health and Safety advisor is allocated to the project, with the authority to carry out audits and other checks on the processes and works being undertaken.

Management of Contractors

It is recommended that the installation teams are taken from a single organisation so that there is a standard method of working across all teams and a single set of processes and procedures to be followed. Prior to letting the installation contract the organisation must satisfactorily complete the criteria specified in the Competency assessment document. This document should be reviewed by a Health and Safety professional.

The Statement of Work that accompanies the contract should clearly outline the work required and define the responsibilities of all of the parties involved.

Multiple Installer Teams

Multiple sets of installers (at least 12) will be required in order to install the equipment into homes in the shortest elapsed time. There are a number of large organisations that operate across the UK and already have MCS qualified staff that could be encouraged to be a part of this project in order to assure quality installation standards.

Taking teams from a single installer would ensure that Health and Safety standards were common to all installers and thereby reduce risk of an incident through use of procedures and methods of working known to the installers rather than imposing an unfamiliar set of procedures.

Installer Training

All installers should be fully competent and accredited for the works to be undertaken. They should be trained in the installation of all new equipment, including the monitoring systems, before the start of, and as necessary during, the installation process.

Whilst this document does not necessarily recommend a permit to work system it is imperative that correctly qualified installers are allocated to each installation and that each installers experience and qualifications are checked prior to working on the project.

Support Desk

It is clear from our experience with the current field trial that the existence of a formal support desk is an essential part of the management of the field trial. The support desk should be available at all times during office hours (run from the site office) with a telephone service for emergencies outside of normal hours.

Duties of the support desk include:

- Daily review of the Automated Data Checking Log, investigation of issues
- First point of contact for queries and problems experienced by the trial participants
- Arrangements for the appropriate party to rectify any issues
- Maintaining a log of support calls and other issues, regular status reports, escalation of issues as necessary
- Any back office tasks required at installation time

- A status log of homes with full records of the monitoring system for all homes

Contractual Agreements

Contractual or other formal agreements will be required for:

- Project Partners with the ETI (or sponsor organisation)
- Collaboration between partners
- Data protection for parties that share or use the data (see section 4.10)
- Suppliers - particularly installers and those outside of the project partners that are supplying new technology to the trial
- Householders/Triallists

It should be recognised that this is a research rather than consultancy project with all organisations working together as a partnership .This requires a flexible contract rather than heavy contractual arrangements to allow the exploration of any findings, reaction to changed external influences etc, as necessary during the life of the project.

Householder Agreements

The Householder agreement is the formal agreement for taking part in the trial between the householder and the project stating respective responsibilities of both parties including:

- Information about the project, the partners and the equipment to be installed in the home
- Requirements on the householders time – such as time for surveys, installation, interviews
- Arrangements for visiting the home
- Feedback or Incentives
- Rights to withdraw from the trial
- Equipment ownership
- Insurance cover

Programme Management

The lead contractor should have a strong programme management team in place from project initiation that can organise all resources to ensure a satisfactory and timely delivery of all elements of the project. Ideally the Programme Management team should use a recognised methodology such as Prince 2, to control the project and to ensure all stages are adequately planned, designed and executed.

The central Programme Management team should be backed up by a project manager in each of the partner organisations who is able to take responsibility for that organisation's planning, deliverables, sub-projects, progress reporting etc.

Programme Management responsibilities include:

- Writing and gaining agreement for the Project Initiation Document outlining roles and responsibilities of the parties involved in the project including sponsors and partners
- Creation of a Work Breakdown Structure for the project tasks and deliverables
- Developing and maintaining project management tools including Gantt charts, communication plans, installation schedules, deliverables charts, RAID (Risks, Assumptions, Issues and Dependencies) log, resourcing

- The project budget
- Milestone & Status reporting
- Maintenance of the project document repository
- Project process, procedures, standards and templates
- Arrangement of stage gate reviews, technical workshops and update meetings
- Issue escalation & resolution
- Change Management
- Quality Management
- Project Closure

Project Documentation Repository

A central Document Repository and knowledge base is essential in a large project to manage the documents and other content produced or used, to prevent circulation of large emails and to ensure that all project resources have access to the latest versions of documents at all times. It may also be used as a discussion forum for project ideas. The Document Repository should be available to all project partners and members of the sponsor organisations, although differing levels of access rights may prevent people from reading or changing some documents.

The most important aspect of a document repository is that it is flexible to cope with all types of documents and easily accessible without requiring specialist software or multiple levels of menus to access documents. The structure of the system, access privileges and rules should be set up at the start of the project and all project participants are made aware of its existence and guidance for use It is essential that sufficient resources are available to create and maintain the document repository.

Another key feature is an automated function that generates emails to inform the relevant set of users when documents are added to or amended on the system.

Data Protection

The Data Protection Act of 1998 states that ‘if we handle personal information about individuals we have a legal obligation to protect that information’. The purpose of the legislation is to ensure that personal data is processed with care, according to the eight principles of the act and is not processed without the knowledge and, except in certain cases, the consent of the data subject, to ensure that personal data which is processed is accurate, and to enforce a set of standards for the processing of such information.

Some data collected within the field trial will be personal data and will be easily recognised as falling under the Data Protection Act. Other data in itself may not be personal data but with other knowledge held by the team may be categorised as personal data by implication.

The Data Protection Act includes two levels of responsibility for data collected. The **data owner** is the organisation that has a direct relationship with the trialist and has ultimate responsibility for the data in terms of registration with the Information Commission, security, privacy, controlling who sees the data and responding to access requests.

Any party who collects, uses, or processes the data is known as a **data processor** and has the same responsibilities with regard to care of the data as the data owner but must pass all access requests to the data owner and must seek permission from the data owner to pass the data to a third party.

It is recommended that a formal Data Protection Agreement is put in place between all parties as soon as the data owner is determined.

In addition to agreements between parties viewing or handling the data collected it must be clearly explained to the trial participants how the data collected, stored and used. Full informed consent must be obtained from all participants and they must be free to pull out of the trial at any time.

All data circulated should used codes to identify properties and any data published will be aggregated and any specific details will remain anonymous.

16 Data Analysis & Management

Data repository & controlled but easy access

Data preparation, sample selection and documentation are critical steps in research projects. The requirements of the study will be defined at an early stage within a fixed timeframe. Important steps are the development of a specification for the monitoring required and to ensure that the monitoring system is working correctly.

The key parameters that need to be measured and analysed must be defined well in advance and their future interpretation planned for. Before monitoring officially starts, a small amount of sample data should be analysed to ensure that the results produced are consistent in the format specified.

A common format for data delivery will be considered from the early stage since not having this can create problems in data analysis. The recorded data interval should be five minutes. The data should be provided to the data analysts by the internet, where they can be downloaded in a format suitable for all databases. It is important that the quantitative data is maintained on a regular basis. It is preferable to have clean data for data preparation and analysis.

Ownership, security & privacy

All data should be stored securely and held in such a way as to ensure first level anonymity, particularly for dwelling occupants but also for members of staff working for the organisations involved.

An agreement should be written prior to the monitored system installation between the parties, where it should be specified that the published results will be made in an anonymous form.

Automated data checking

The quality of data and monitoring design is a very important aspect in a field trial. A series of checking rules should be decided by all parties before the monitoring process starts. Excessive data gathering can prove problematic in terms of time management and there is always a long 'wish list' of data to be collected. However, there are certain parameters that would have proven very helpful in the process of analysis if measured. Therefore a list of these measurements parameters should be decided for each technology between partners, i.e. the one monitoring and the one analysing the data. Checking for inconsistent responses should be done at an early stage, so that problems encountered can be resolved at an early stage, and to ensure clean data for analysis. All data checking and analysis software must be developed before monitoring starts. It is essential that the error checking happens as soon as any data is collected otherwise data will be lost.

Data analyses, reporting & feedback

Data analysis is time consuming. Data can be read by a wide variety of software tools: Excel, Matlab, Axum, Delphi and Visual Basic. Automated checking and generating standard graphs will help to analyse data efficiently and spot problems in monitoring from an early stage. One way to do this is to use the tool already developed by for the pilot study, but updated for the groups of variants for this field trial before data collection begins. Requirements for measurement accuracy and frequency will be established at an early stage. The tool is capable of retrieving information about environmental parameters, energy consumption and occupancy (if this is measured). It consists of a series of event procedures which perform an action or a series of actions about energy consumption, internal and external environmental conditions. The method is easily set up and feasible to any users and enables the researchers to analyse data for any dwellings without having any knowledge of coding programming. The tool can be updated by integrating an automated statistical analysis.

The tool will provide breakdowns of domestic energy consumption, CO_2 emissions for any specific period: e.g. day/month/year and statistical analysis of the performance of the technologies and occupants.

This approach is invaluable in ensuring that solutions and problems encountered are quickly shared across the whole project. The analysis will consider both overall performance and specific behaviour.

The key goal of the monitoring process is to establish the performance of different DE technologies under real operating conditions. For example, to determine whether the systems are operating in line with predictions, whether similar performance is observed when looking at identical systems installed on separate sites, to explore the reasons for any discrepancies observed between expected and observed performance, and to determine the performance of individual system elements.

17 Learning from the Current ETI Micro DE Trial

Introduction

The Lessons Learned and Insights Log is an invaluable tool for recording issues that arise with the trial homes, the trial roll-out, comments from the trialists about their experiences with the DE equipment etc.

It may also be used to record thoughts about future stages of the trial, learning points from partner participation, things to look for in the future and snippets from other sources (internet, conferences, suppliers and manufacturers) that should be shared with the project partners. The log should be readily available and all partners should be encouraged to add items and to look at new items on a regular basis.

This section looks at the Lessons Learned from the current ETI Micro DE field trial of 18 homes. It does not reflect on Lessons Learned about the various technologies, their installation and maintenance or control systems as this is covered in Documents 3, 4 and 5 or the experience of the occupants of the trial homes which is found in Document 3.2.1 of the set of final reports from this project.

This document focuses on Lessons Learned from recruitment of trialists, installation and support of the monitoring systems, data presentation, resolution and collection methods and issues found when working in occupied homes.

Recruitment of Trialists

A good field trial should recruit the population specified to meet the trial objectives. However this very rarely happens which means that it is very difficult to meet the objectives of the original trial design. The main reason for this is that the time allocated for recruitment of the required population is always underestimated. Therefore recruitment often defaults to obtaining any properties available even if they are likely to be atypical of the whole population as that will always be better than none. The lesson learned in this case is, that to avoid compromise it is necessary to protect time for recruitment and to be aware of the impact that delays in starting the project or changes to the initial specification may have on this important phase.

The current field trial used a consultancy organisation, Encraft, to assist with the recruitment of homes into the trial. Encraft have a database of people they have advised on DE technologies as well as a list of installers they have worked with in the past.

The Installer route proved most difficult as, while willing to take part they were so busy installing that found difficulty assisting with providing information, time for surveys or the installation. Their preference would have been to install the monitoring equipment themselves – but again availability was an issue.

Some trialists were recruited through a heat pump manufacturer with links to a number of housing associations. The manufacturer was interested in how their heat pumps were performing in homes and agreed to investigate any performance issues.

Most people approached were willing to take part as they wanted more information on how their equipment was performing. Once the details of the monitoring system were explained, some were very nervous about the fact that it would mean a physical intervention to their system. Concerns ranged from warranty aspects, which we dealt with directly by speaking to the installer, to detrimental effects on their system.

A number of the social housing trialists were concerned about the term ‘monitoring’ and whether it involved taking pictures, video footage or recording what was happening in the home. In future the term ‘monitoring’ needs to be carefully considered.

Those with ground source heat pumps were most concerned as they had experienced many problems with leaks and balancing the system immediately following installation. This led to two potential trialists deciding not to take part following the site survey.

Explaining the process in detail during the house survey was generally appreciated by most participants although some felt that the amount of time required of them was an issue.

The Householder Agreement was a ‘friendly’ rather than legal sounding document which seemed to work well with participants. Following the advice of the agreement some requested a statement for their insurance companies detailing what equipment was to be installed in their property.

The only other reasons found for persons not being willing to take part in the trial were of a personal nature (such as looking to move) rather than the fact that they were concerned about the process or the equipment being installed.

In a future trial it may be advisable to use a small number of ‘controlled’ but occupied test homes, such as from a university campus.

Site Survey

A detailed site survey of each home was undertaken ahead of planning the installation. This provided the opportunity to collect comprehensive details of the DE equipment in the home, its position and how it should be monitored ahead of the installation.

The survey attempted to identify hazards before to the attendance of the installation team so that potential homes could be declined if there were potential significant risks such as the presence of asbestos or lead plumbing.

The site survey was carried out on the test site before being used on other homes and the information required was updated a number of times during the process to ensure as much detail as possible was collected. Further recommendations for improvement have subsequently been identified in the Data Analysis phase – such as a diagram of the plumbing of the DE technology and the space heating.

Monitoring System Components

Wherever possible, wireless components were selected for the monitoring system but, due to the immature market for wireless sensors it was not possible in all cases. This meant that some components had ‘local’ wiring to a wireless relay box and some needed a wired attachment to a power source. The participants were generally happy with the installations although white rather than black or grey wire was preferred. In all instances the homeowners were consulted on

positioning before the installation of any kit. On only a few occasions were there issues with positioning the equipment, mainly of CO_2 sensors, according to original plans.
One wired installation was carried out in a bungalow to test whether signal strength and reliability of data readings could be improved and whether this type of installation was suitable for properties where the internal signal strength was poor due to construction or internal insulation. Accessibility was difficult with the Health and Safety issues associated with working in a loft space meaning that the installation took longer than expected with no significant improvement to data quality.

As this was a small trial the monitoring system components were purchased in small batches for two or three homes. This enabled further homes to be surveyed while the kit was on order awaiting delivery and enabled the systems to be built and installed in small batches. It was found that suppliers of some items, such as the box to hold the monitoring kit, only kept stock of one or two items requiring careful planning for all orders. Similarly some of the more complex metering equipment was imported from Europe incurring a delay of up to two weeks. A standard system where kits could be bulk ordered in advance would cut down on the time between survey and installation.

Health & Safety

There was a strong emphasis from the ETI on Health and Safety for the project. PassivSystems employed an external Health and Safety Advisor who was able to provide guidance on all aspects including risk assessment, supplier competency and legislation, as well as undertaking random audits during the installation process. Some issues were highlighted in the earlier audits and corrected during the process.

For the duration of each installation PassivSystems had a representative on site for the duration of the installation who had overall responsibility for Health & Safety including maintaining the site logs, ensuring that good practice was undertaken and the site was kept and left in a clean and tidy state. This representative had the authority to stop work if necessary. In order to ensure that all checks were made, a checklist process was introduced for the start and end of each day.

There were a number of existing Health & Safety issues found in the homes which were either rectified, attention paid to when working or the home owners were advised of the situation including:

- Bad/faulty wiring
- Missing or incorrect isolation switches
- Incorrect or missing fusing
- Worn or Corroded safety devices
- Thermostats – *not working, not attached, incorrectly set*
- Lack of crawling boards in loft
- Difficult to access equipment
- Suspect joints in existing installation
- Supplementary heaters
- High levels of CO_2
- Wasp Nests

Other lessons learned from this and previous trials include:

- Wherever possible avoid installing in homes with children during school holidays and keep work carried out after school hours to areas where children are unlikely to be, such as garages or the outside of the house.
- Consider carefully what monitoring equipment is to be used in a home where people have a serious illness and may rely upon a continual electrical supply or where disruption to heating might be a problem.

Installation of Monitoring Equipment

A bespoke monitoring system was required for the forensic monitoring undertaken in this trial. Bespoke systems take time to build for each installation and require individual plans for each site.

The installers and site representatives must refer to the plans in order to install equipment in the correct place. The template for the site plan was updated during the installation process to ensure that all information was captured in a single document, removing the need to refer to the survey document. The Site plan now contained details of the DE technology installed, inventory of equipment, safety and risk assessment sections as well as details of what was to be installed by logical grouping.

The installation of the monitoring equipment requires direct intervention with the DE Equipment in order to install the metering equipment. In some cases (Solar Thermal, Heat pumps) this requires draining of the system and refilling. While the installation is a task that could be undertaken by any qualified plumber it is necessary to have MCS qualified personnel available to ensure there are no resultant performance issues. Having an MCS qualified person on site also allowed any problems with the installed system to be identified up front and any health and safety hazards put right immediately.

Installer training occurred a few days before the first installation. Following a temporary break in the installation schedule after the first two homes, refresher training was required as the installers appeared to have ‘forgotten’ the training and processes put in place for the initial installations.

One of the biggest issues found when installing monitoring equipment was space. When planning the installation it was agreed that wherever possible full flow valves would be inserted each side of any plumbed in meter to make removal a simpler, faster process. In practice this was not possible as the pipe runs were too short to accommodate the meter and the valves. Lack of space has also made it difficult to fit secondary gas meters in most properties and lack of space often made dual working impractical. This meant that the installation took longer than envisaged.

Attaching sensors to walls within the home is always a controversial process and attention should be paid to making as small an impression on the décor as possible. Some trialists prefer the use of sticky pads while others were happy with a small panel or picture pin. The experience from this and other trials is that sticky pads may not adhere to some paint surfaces and lose their effectiveness over time which means that sensors can be knocked off easily and may fall off at unexpected times. It seems that a small pin is the most reliable method and leaves less residual damage.

When going into occupied homes to install equipment, there is a duty of care to advise the occupants, and if possible to rectify, any safety issues within the home. Issues found to date include:

- Incorrect rating or missing fusing of electrical circuits (direct fire risk)
- Incorrect wiring
- Deteriorated gas earthing/bonding
- Leaks or poor joints in existing pipe work

Following the installation of the monitoring equipment any issues found within the home are often attributed, rightly or wrongly, to the installation work as the last person entering the home is seen as the person that has initiated the problem. For future trials it will be important for installers to log and point out to the occupants any problems or safety issues as soon as they are observed. A support desk that can respond to trialists' issues is a priority to maintain good relations with the trial population.

A comprehensive check that all services are working and the home is left in a clean, tidy and safe state should be undertaken before leaving the home at the end of the works and at the end of each day – should the work be carried over

Communications

The monitoring system used in the current field trial was capable of communicating by either Broadband or GSM/GPRS. For this trial the GSM/GPRS option was chosen as it meant that the system gateway could be sited closest to the wired metering equipment and did not interfere with the use of Broadband capability.

Two different carriers were selected in order that the provider with the strongest signal could be used if there were connectivity issues. In a small proportion of the homes the signal strength was low with both providers. This issue was overcome by either positioning a remote antenna in a different position (for instance in the loft) or by fitting a larger external antenna.

In one home where was no GSM coverage, Broadband was used as the Communications medium. The monitoring system gateway was attached to the in-home router by the use of power line carrier units and communications with the server was timed so that it did not occur during the peak broadband usage time for the household. Difficulties were encountered in setting up the system as the homeowners were unable to find the password for their router (necessary to attach the gateway) and when it was changed back to the default setting they had issues with connectivity of their existing devices.

Data

During the initial planning of a monitoring system it is important to include representation from the organisation designated to analyse the data in order that decisions can be agreed before selection of the equipment is confirmed. This includes:

- What to monitor
- Where the monitoring equipment should be sited in relation to the device being monitored
- Data resolution and limits
- Monitoring intervals
- Naming standards
- Collection rules
- Assumptions to be made

Within occupied homes it is very difficult to guarantee perfect, reliable data collection at all times. Experience has shown that issues leading to loss of data include:

- Power removed from sensors or the main monitoring system
- Items within the home may be moved around blocking wireless signals
- Sensors may be knocked off of walls, batteries removed and replaced incorrectly
- Batteries used in external devices fail in extreme cold
- Rodents chewing through cables
- GSM connectivity may be compromised randomly – such as parking of a large vehicle close in the antenna path
- Broadband routers switched off overnight or when occupants away on holiday

Installing the monitoring gateway into a closed box (a consumer unit box was used) meant that the equipment and any wiring connections were out of sight and less likely to be tampered with.

Within this trial each home has approximately 20 monitoring devices resulting in between 27 and 50 data points being collected. At between 5 and 15 minute collection intervals this provides a high volume of data, rendering a manual checking system impractical. A series of automated data checking routines has been devised which provide a Red/Amber/Green dashboard on a daily basis which can be checked relatively quickly by a support resource. The data rules include simple checks to ensure that a meter or sensor is working and within ‘normal’ limits to more sophisticated performance checks of DE Equipment. These rules may be scaled up for use in a larger trial.

There is a necessary step following the collection of data to prepare the data sets for analysis. This involves identifying which data may be imperfect because of loss of data, malfunctioning collection equipment, the equipment being monitored or other abnormality, rectifying where possible or marking as invalid.

Correlation of the timings of data sets, for example comparing sets of data where one set is monitored at 5 minute intervals and another at 15 minute intervals, means that assumptions will need to be made on one set or the other in order to make a comparison.

A tool has been built to analyse the data which may also be used in a larger trial. Data is currently imported into the tool at a comparatively late stage in the process. It is recommended that some data from the occupant interviews, site surveys etc is entered into the analysis tool as it is collected.

The data analysis tool is used for performance analysis only but may be extended to include statistical analysis for a larger trial.

Multi-disciplinary communications

What makes field trials so complicated in the area of low carbon technologies is that if they are to be really successful they need to bring together experts in buildings, people and the low energy technologies. Almost all field trials and their clients underestimate the importance of this and the time required to get the maximum benefit from such a multi-disciplinary way of working. It normally takes up to a year for a multi-disciplinary team to be able to work together effectively for the first time because it takes time to understand, respect, trust and value what other disciplines and partners are doing. All partners need to have time to review the work of other disciplines, comment on it and help to develop it.

It is critical in conducting projects of this nature that significant interaction is built in between data collection, data analysis and the other aspects of this work, so as to integrate working in a constructive way. Very often this key element is ignored and there is insufficient time allocated to the overall learning process.