Programme Area: Smart Systems and Heat

Project: Consumer Response and Behaviour

Title: Environmental Monitoring to inform Social Research

Abstract:

This report was prepared for the ETI by the consortium that delivered the project in 2013 and whose contents may be out of date and may not represent current thinking. Environmental monitoring (the use of technology to automatically record physical, measurable conditions – e.g. temperature, relative humidity, energy consumption, etc.) has been a common part of research into energy use in buildings over recent years, used particularly to record the energy performance and environmental conditions. However, monitoring devices are now increasingly being employed alongside social research methods to assist a better understanding of the way occupants behave in a building and how they interact with their energy systems. This report draws out the lessons learnt from these emerging activities, discusses the design challenges and value of delivering an environmental monitoring project and focusses in some detail on the many practicalities that need to be considered for the successful implementation of environmental monitoring in homes.

Context:

The delivery of consumer energy requirements is a key focus of the Smart Systems and Heat Programme. The Consumer Response and Behavior Project will identify consumer requirements and predict consumer response to Smart Energy System proposals, providing a consumer focus for the other Work Areas. This project involved thousands of respondents providing insight into consumer requirements for heat and energy services, both now and in the future. Particular focus was given to identifying the behaviour that leads people to consume energy - in particular heat and hot water. This £3m project was led by PRP Architects, experts in the built environment. It involved a consortium of academia and industry - UCL Energy Institute, Frontier Economics, The Technology Partnership, The Peabody Trust, National Centre for Social Research and Hitachi Europe.

Environmental monitoring to inform social research

Smart Systems and Heat (SSH) Technology Programme
Work Area 5: Consumer Response and Behaviour

Context

This Report, **Environmental monitoring to inform social research**, is one of the final deliverables of the Energy Technology Institute's Consumer Response and Behaviour project, part of the Smart Systems and Heat (SSH) programme.

The ETI's Smart Systems and Heat programme will create future-proof and economic local heating solutions for the UK. It will connect together an understanding of consumer needs and behaviour with the development and integration of new technologies and with new business models. The associated insight will deliver enhanced knowledge across industry and the public sector, resulting in industry and investor confidence to implement SSH influenced solutions from 2020 and thereby enable a UK energy system transition, focused around effective delivery of heat, with an appropriate policy and support environment to deliver a cost-effective UK energy system transition.

The Consumer Response and Behaviour project is a multidisciplinary research collaboration, combining qualitative and quantitative social research, environmental monitoring, modelling and concept development supported by a thorough review of secondary literature sources.

This report combines the two Deliverables listed below:

D5.4(iii) In-Home Monitoring Technical Report

D5.10(ii) Health and Safety Good Practice Report

into one report titled: **Environmental monitoring to inform social research**

The environmental monitoring aspect of the Consumer Response and Behaviour has been instrumental to a number of areas of work across the project, specifically:

- **Work Package 5.4 and 5.7 Qualitative Insights** – the monitoring of homes was conceived as a way of providing quantitative evidence for internal environment (e.g. temperature, humidity, etc.) and occupant usage of their home and system (e.g. occupancy sensors, radiator and hot water sensors, etc.). These allowed for richer and more trusted insights than relying on self-reporting, diaries and similar methods. Data from monitoring a longitudinal sample of homes has been used and shared with participants throughout the study to draw out integrated findings that are detailed in the following reports: ***Phase 1 Consumer Research*** and ***What people need and do that involves heat energy: findings from qualitative research;***

- **Work Package 5.6 Modelling Work** – the modelling work undertaken by the project has included the use of monitored data in homes, alongside established modelling software, EnergyPlus, to better understand the actual environments created in homes. By combining the two, this work package has been able to present scenarios based on real-world examples, as detailed in the report, ***Modelling Insights***;

- **Work Package 5.8 Solution Characteristics** – through the use of measured behaviours and the integrated qualitative insights mentioned above, the monitoring data has provided one input into the evaluation of how different smart heat solutions might work for different households, as detailed in ***Smart Energy Solutions – The Consumer Perspective***;

- **Work Package 5.11 HEMS Small-scale Field Trial** – the lessons learned from the longitudinal monitoring study helped inform the approach to monitoring undertaken in the small-scale field trial on smarter heating controls. Lessons from that smaller trial are also detailed in this report. For further detail on the monitored insights in the field trial see ***HEMS small scale field trial final report***.

Executive Summary

Overview

Environmental monitoring (the use of technology to automatically record physical, measurable conditions – e.g. temperature, relative humidity, energy consumption, etc.) has been a common part of research into energy use in buildings over recent years, used particularly to record the energy performance and environmental conditions. However, monitoring devices are now increasingly being employed alongside social research methods to assist a better understanding of the way occupants behave in a building and how they interact with their energy systems. This report draws out the lessons learnt from these emerging activities, discusses the design challenges and value of delivering an environmental monitoring project and focusses in some detail on the many practicalities that need to be considered for the successful implementation of environmental monitoring in homes.

Environmental monitoring

The well-designed deployment of effective monitoring systems can allow simple logging devices to be used in a number of ways in order to gain a broad range of useful insights. For example, a basic temperature logger, set to record at the right intervals, can be used on radiators and pipes to identify patterns of use of heating and hot water.

Environmental monitoring for behavioural insights provides an additional or alternative route to the reliance on reported behaviour in diaries and interviews and if used in conjunction with social research methods can be highly effective at reaching deeper insights than by any one single method.

This combination of environmental monitoring and social research has been employed on two projects within the ETI's Smart Systems and Heat Work Area 5 (WA5) programme - 30 Homes and the HEMS small scale field trial. These projects had different aims, extended over different time periods and used different equipment, with the HEMS project deploying a significantly simpler system following lessons learnt from the more complicated 30 Homes project. The learning from both these projects has influenced the monitoring specification for the WA6 Domestic Retrofit Demonstration[1] project to test the effectiveness of a major energy efficiency refurbishment in five homes; monitoring, in this case, is primarily used to compare the before and after environment, to determine change in energy performance and environmental conditions and to identify changes in occupant behaviour.

- **30 Homes** – a longitudinal study of 30 homes in Yorkshire, Manchester, Norfolk and London. This year-long study (incorporating winter and summer heating seasons) used environmental data gathered from a number of sensors in multiple locations in the home to monitor ten different variables[2]. The data richly informed the four in-home interviews leading to greater understanding of needs and behaviours in terms of use of heat energy.

- **HEMS Field Trial** – a three-month study of 12 homes in London to consider the ease of installation and participants" adaptability to two different smart heating control systems[3]. Environmental monitoring - room temperature, humidity and meter readings - was incorporated into the trial to complement in-depth interviews and to record any energy use fluctuations following the installation of the HEMS systems. The data has been used to substantiate behavioural changes following the installation of HEMS systems in homes.

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[1] The environmental monitoring relating to the WA6 Domestic Retrofit Demonstration project is not discussed specifically in this report.

[2] These variables are ambient temperature, relative humidity, occupancy, luminance, door opening, window opening, carbon dioxide levels, electricity consumption, radiator activity and patterns of hot water usage.

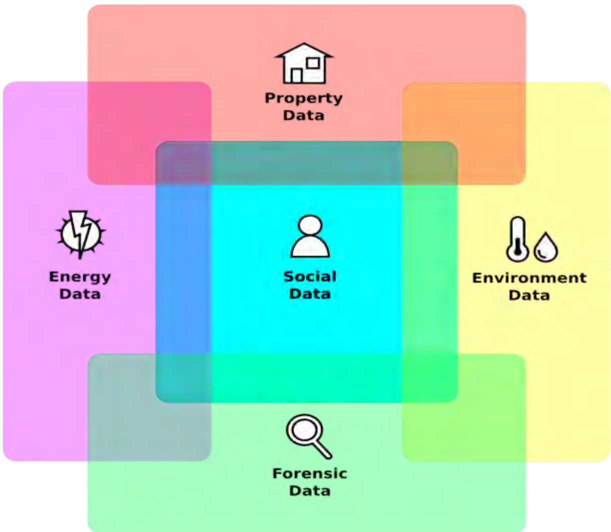
[3] The OWL Intuition-c and the Honeywell evohome were each installed in six properties. The trial is described in detail in *the **HEMS small scale field trial final report***.

While experience and examples have been drawn from both projects, the focus of this report is derived primarily from the **30 Homes** - the largest and most complex of the projects which therefore generated the most learning. It was also the first of the projects to start, and so the key lessons from the early part of this project informed the delivery of the **HEMS** project.

Environmental monitoring in the context of social research

In both these projects, environmental monitoring has been carried out to support a wider programme of research involving social research techniques. The aim has been to use data from each of these strands to build up a stronger picture of the relationship between people, their homes and their heating systems. This approach, represented in Figure 1 below is at its strongest in helping to identify specific instances of occupant behaviour, where putting the technical and social pieces together and combining these with insights from highly specific lines of enquiry (referred to as "forensic data" in this diagram) allow for high levels of success of interpretation of the data to obtain the fullest picture.

Figure 1: Combination of multiple data sources



What worked well?

In both projects the data acquired from the environmental monitoring has contributed significantly to the wider research aims. The **30 Homes** project was successful in its aims to provide useful data to support social interviews and gain deeper insights into how people use heat in their homes. The **HEMS** project has also benefited from these lessons and adopted the best practice from the **30 Homes** project to deliver effective results. Some examples of what worked well on the projects include:

- **Participant retention** – one of the most important successes of both projects has been the positive relationships formed with the participants and their retention – all but three participants[4] of a total of 42 participants remained part of the research for the full period, in addition the 39 remaining participants agreed to be contacted for potential further research involvement with the team should this be required by ETI. This can be attributed to:
    - **Open and effective communication** – a strong emphasis placed on both written and oral communication. All front-line staff received specific training for the project, were well-supported throughout its life ensuring a professional and personable team.

[4] The reasons for the loss of these participants were, respectively: a) unresolvable technical difficulties with the monitoring system; b) participant moving house and being unavailable for visits; c) arising concerns that their landlord may object to the installed equipment. In no case was the reason for attrition related to dissatisfaction or frustrations with the study.

- **Clear agreements** – clear and fair monitoring agreements between participants and the consortium partners conveyed a sense of professionalism.

- **Small teams assigned to each participant** – A strong rapport with participants proved key to their long-term engagement in the project. Typically each participant engaged with no more than 3-5 members of the research team, each with a clear, dedicated role[5].

- **Customer care and remuneration** – a customer-first mentality; participants were respected for their tolerance in allowing the research team's frequent access to their homes, reinforced through frequent expressions of gratitude and fair remuneration for changes – e.g. increasing the incentive payments for additional visits. Home visits always took place at the convenience of participants, with specific timed appointments including early mornings and evenings.

- **Recruitment through other activities** – participants for the **30 Homes** project were recruited from qualitative workshops taking place in the wider Consumer Response and Behaviour project – the research team was well-placed to "pitch" the monitoring project to an engaged audience and allow participants to see the equipment and make an informed decision whether to take part in the project or not[6].

- **Logistics** – although a relatively small sample, the administrative challenge of organising a rolling set of multiple visits across the country including maintaining accurate records of installations, maintenance visits and interviews was significant. Implementation of effective procedures, forms and records by a dedicated project management team guaranteed smooth running of the project.

- **Health and safety best practice** – robust health and safety procedures, installation guidance, well-rehearsed incident protocol, training of staff and provision of safety documentation for participants ensured that the team was always equipped to work safely and participants were never at risk. All health and safety procedures and documentation were approved by the Consortium and ETI's Health and Safety consultants.

- **Data protection** – a detailed data protection protocol for the wider project informed the design of a robust system for maintaining anonymity of participants for any purpose other than direct contact, ensuring secure management of personal data further built trust between the participants and the project team.

- **Engagement with suppliers and manufacturers** – effective engagement with the manufacturers and suppliers of equipment ensured that stock levels and lead-in times were never an issue; problems that arose were quickly solved.

- **Forensic analysis** – integrated data analysis / interview preparation meetings (researcher, analyst, surveyor, etc.) synthesising data insights with social and technical insights. This synthesis proved invaluable to the preparation of interviews providing the social researcher with technical awareness and understanding.

- **Data analysis** – building an understanding of the conditions and behaviour within the monitored homes; and identifying whether occupants were correctly reporting their energy use behaviours. In addition data from all the homes (although the samples were small) was aggregated and cross-compared helping to provide hints of patterns across the stock. The conditions and behaviour within a particular monitored home also fed into the modelling

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[5] Such as social researcher, technical expert, surveyor/installer, project manager, appointment manager.

[6] From 153 workshop attendees, 78 expressed interest in taking part in the longitudinal study, from these the final 30 were selected to meet specific project participant criteria including technical requirements (e.g. mobile phone signal strength). A number of attendees who were given follow-up calls opted out, often due to family concerns about taking part. Interestingly, in London, despite a very high uptake at the workshop, many people decided to opt out when they were re-contacted. There may be some area level factors that could affect uptake.

work[7] and were used both to derive model inputs (for example heating operating hours) and as a check that the model outputs bore some resemblance to realities that may be explored in future larger scale monitoring efforts.

Challenges and practicalities

There are a number of challenges and practicalities to be considered in the preparation and for the successful implementation of an environmental monitoring project in domestic properties, while these are considered in detail in the main report, some of the key areas are set out below.

- **Ensuring adequate lead-in time** – by far the greatest challenge on the **30 Homes** project was the urgency placed on the team at the start of the project to get the monitoring system into the field before the start of the imminent heating season. The project started with a long list of items to be monitored rather than first clearly establishing the research aims and then deciding on the most appropriate form of monitoring to give the required results. Defining the research questions and designing the equipment is an iterative process and the larger and more complicated the project, the greater is the need for generous mobilisation time to fully develop the monitoring solution, test, resolve problems and finally launch of the system. The **HEMS** project, though also with a short lead-in time, benefited from a tighter brief and a clearer understanding of what monitoring was required, making the lead-in, in this case, adequate to deploy an effective solution.

- **Defining the Research Aims** – the core questions that are to be answered by monitoring will determine whether monitoring is an appropriate solution and what things need to be monitored. On both the **30 Homes** and **HEMS** projects, the aim was to engage people in reflecting critically on behaviours that are highly habituated, and embedded in daily routines, and therefore not in the front of mind. While the social research aimed to explore the full extent to which different behaviours could be observed, the monitoring data provided an empirical basis of actual behaviour against which an individual's reported behaviour and needs could be discussed.

- **Establishing the Monitoring Brief** – once the research aims have been identified, the variables that need to be measured can be identified. These can include physical variables such as ambient temperature or behavioural variables such as frequency of opening windows. These variables should also then be prioritised to aid later steps in the planning process. Failing to fully establish a robust brief can lead to misspecification of equipment, sub-optimal deployment parameters, less useful data output and consequent costs to the project.

- **Intellectual Property (IP)** – IP issues can be complicated, particularly with the design of new equipment and open-source platforms, again generous lead-in time to resolve these is essential. In the **30 Homes** project we used off the shelf equipment so no technical development work was required and therefore no risk of 3rd party claims. We stayed away from utilising open-source software because any development work in this area would incur arising IP and would not be solely available to ETI.

- **What could not be monitored** – ETI had asked the team to explore the potential of monitoring real time gas and hot water consumption, however, the installation of optical readers for the gas meter and in-line flow meters for gas and hot water use was considered too expensive and too risky in terms of the necessary invasive works to pipes to install the in-flow meters. Additionally in the case of gas, permission is required from the utility company. Instead we took a simpler, but less effective route, of taking regular energy meter readings and installing iButtons®[8] on hot water pipework (where accessible) to record pipework temperature to determine periods of hot water use. More readily market available and usable gas and hot water use monitoring equipment is needed.

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[7] The ***Modelling Insights*** report is one of the key Deliverables for the Consumer Response and Behaviour Project
[8] The iButton® data loggers are ideal for applications where a non-intrusive data logger is required or where the available location precludes the use of any larger data loggers.

- **Remote or in-situ data downloads** – the **30 Homes** system was required to support four interviews over the period of a year and, in order to minimise disruption to participants and to make efficient use of project team resource, the specification demanded remote retrieval of data, thus eliminating the need for multiple visits to the property. However, in practice, we found that some of the deployed systems were unable to maintain a stable remote connection and additional visits became inevitable. Another reason for the remote access was that monitored homes were spread across different parts of the country rendering the logistics of organising visits challenging (this is true also for the WA6 trial). The **HEMS** three-month trial relied purely on local data storage and data was downloaded upon collection of the monitoring equipment. In this case, the monitoring equipment was installed at the start of the project and remained in situ for the length of the three-month research period. The logger was removed, the data downloaded and analysed ahead of final interviews. This resulted in 100% data capture and was both simple and effective to implement.

- **Health and Safety** – a single incident could jeopardise both the future of the project and the reputation of ETI, therefore monitoring equipment was developed within a highly risk-aware context, inevitably placing restrictions on the specification of equipment. For example, the requirement for hot water monitoring was reduced to hot water temperature monitoring. The former would have required intrusive works (cutting through pipes) to install internal flow-meters, while the latter required fixing iButtons® with tape to hot water pipes below the taps, the health and safety considerations in this case restricted the capacity of the project, but ensured the risk of danger to property was minimised.

- **Participant acceptability** – due to a wide range of data measurement requirements for the **30 Homes** project and the large number of sensors required, a strain was placed on finding equipment that would be acceptable to participants. Considerations included safety, size, appearance and time required to install. Other challenges to participant acceptance included avoidance of mains-powered equipment (taking up plug sockets and using their electricity) and fixing methods (to avoid damage to surfaces). These considerations steered the team to battery-powered sensors that collected multiple data variables and could be installed by using easily removable adhesives.

- **Managing additional visits** – seven visits were initially planned for each household: initial survey / installation, battery change at month six, decommission and four interviews. By the end of the project this had risen to 11 visits, due to two additional battery changes and the installation of HOBOs®[9] (on radiators) and iButtons® (on hot water pipes) at a later stage in the project, and the downloading of data from these prior to the interviews. This introduction of supplementary equipment half way through the project and the subsequent additional extra visits required sensitive management to ensure participants were amenable, only two participants refused these additional sensors.

- **Appointments / logistics** – the logistics of appointment-making and managing the schedules of the surveyors / installers should not be underestimated. The wider the geographic area and the more scattered the properties, the more complicated this becomes. On the **30 Homes** project, as there are considerable driving distances to York, Norfolk and Manchester, careful coordination was required to minimise the installers' travel time while fitting in with the participants' preferences for visits. Appointments were clustered and visits to each area usually took place over two to three days and required car hire and hotels to be organised. On the **HEMS** project while all the properties were in London, these were spread across the capital. In both studies, we found that two to three visits a day was the maximum possible.

[9] A data logger (or datalogger), commonly referred to as a "HOBO," is defined as an electronic instrument that records measurements of all types at set intervals over a period of time. Data loggers can record a wide variety of energy and environmental measurements including temperature, relative humidity, AC/DC current and voltage, differential pressure, time-of-use (lights and motors), light intensity, water level, soil moisture, rainfall, wind speed and direction, pulse signals, and more.

- **Data Management** – for the **30 Homes** project, the number of sensors and variables deployed in each case generated a large amount of data, often in different formats which proved a challenge to process. At the outset of the project, it was not fully understood which data would be the most useful for drawing out key insights to be fed into the social research, exacerbated by multiple organisations responsible for different aspects of the project (the development, installation, analysis and social interviews were each carried out by a different organisation). This challenge was overcome during the course of the project and a strong approach to sharing analysed data insights with the social research team was developed – specifically round-table data briefings and a series of standardised graphs and analysis templates were produced. For the **HEMS** project only two organisations were involved in the process making the management and sharing of data more straightforward, by incorporating lessons learnt from the **30 Homes** project data summaries were rapidly identified and produced.

What we would do differently

- Allow a sufficient mobilisation period.
- Define the research aims and ensure the Brief is fully developed prior to product specification.
- Resolve IP issues at the start of the project.
- Keep the monitoring system simple, where possible use off-the-shelf products – e.g. local loggers.
- Collect only data that is necessary for the research.

Considerations for scaling up

- Management of greater numbers of participants – keep to small dedicated teams with centralised management structure. Registered Social Landlords (RSLs) adopt innovate approaches to 'patch' management of large numbers of properties in specific areas with dedicated teams of surveyors, housing officers, etc.
- Keep the monitoring system as simple as possible and aim to create automated processes for data retrieval / download.
- Cluster properties wherever possible to keep administration of appointments simple. Consider the use of specific software to assist with the management of route-planning and multiple visit-sequencing for managing large number of properties.
- Maintain clear, consistent and open communication with participants – put them first.
- Create and utilise robust H&S and Incident protocols.
- Where environmental monitoring is used to support social research, integrate the skills e.g. technical, social, data analytics.
- The use of 3G connectivity in the context of environmental monitoring needs further research

Contents

1 Introduction 10
1.1 Purpose of this report 10
1.2 Context of environmental monitoring within the wider project 10
1.3 How this report is structured 11
2 Establishing what needs to be monitored and how 12
2.1 Establishing the Brief 13
2.2 Identifying Equipment 14
2.3 Trialling Equipment 15
2.4 Recommendations 15
3 Designing a whole-house multi-parameter monitoring system 18
3.1 Overview 18
3.2 Health and Safety 18
3.3 Intellectual Property (IP) 21
3.4 Data Reporting 21
3.5 Data Protection 21
3.6 Participant Acceptability 22
3.7 Procurement 22
3.8 Recommendations 23
4 Data 24
4.1 How data adds value to social research 24
4.2 Data collection 25
4.3 Data analysis 25
4.4 Understanding individual homes 28
4.5 Recommendations 34
5 Practicalities 36
5.1 Data Protection 36
5.2 Health and Safety 38
5.3 Bench-marking Health and Safety 40
5.4 Installing Safely 41
5.5 Recommendations 45
6 Participant Retention 46
6.1 Managing good relationships 46
6.2 Incentives 49
6.3 Recommendations 49
7 Main findings and Scaling up implications 50
7.1 Challenges and practicalities 51
7.2 What we would do differently 53
7.3 Considerations for scaling up 53
8 Supporting Information 55

1 Introduction

1.1 Purpose of this report

This report consolidates the lessons learnt from environmental monitoring[10] exercises carried out by the members of the Energy Endeavours Consortium for the ETI's Smart Systems and Heat Programme. It draws on aspects of the experience from the technical design of equipment through to the deployment, management, data analysis and eventual removal of monitoring devices in homes. From this experience it aims to provide advice for those considering environmental monitoring projects from small-scale experiments up to large-scale field trials.

The advice is based on lessons learnt and best practice gained from carrying out environmental monitoring in two projects:

- **30 Homes** – a longitudinal study of 30 homes in Yorkshire, Manchester, Norfolk and London. This year-long study (incorporating winter and summer heating seasons) used environmental data gathered from a number of sensors in multiple locations in the home to monitor ten different variables[11]. The data richly informed in-home interviews leading to greater understanding of needs and behaviours in terms of use of heat energy.

- **HEMS Field Trial** – a three-month study of 12 homes in London to consider the ease of installation and participants'' adaptability to two different smart heating control systems[12]. Environmental monitoring - room temperature, humidity and meter readings - was incorporated into the trial to complement in-depth interviews and to record any energy use fluctuations following the installation of the HEMS systems. The data has been used to substantiate behavioural changes following the installation of HEMS systems in homes.

While experience and examples are drawn from both projects, the focus of the report is primarily on experience gained from the **30 Homes** - it is the largest and most complex of the projects which therefore generated the most learning. It was also the first of the projects to start, and so the key lessons from the early part of this project informed the delivery of the **HEMS** project.

1.2 Context of environmental monitoring within the wider project

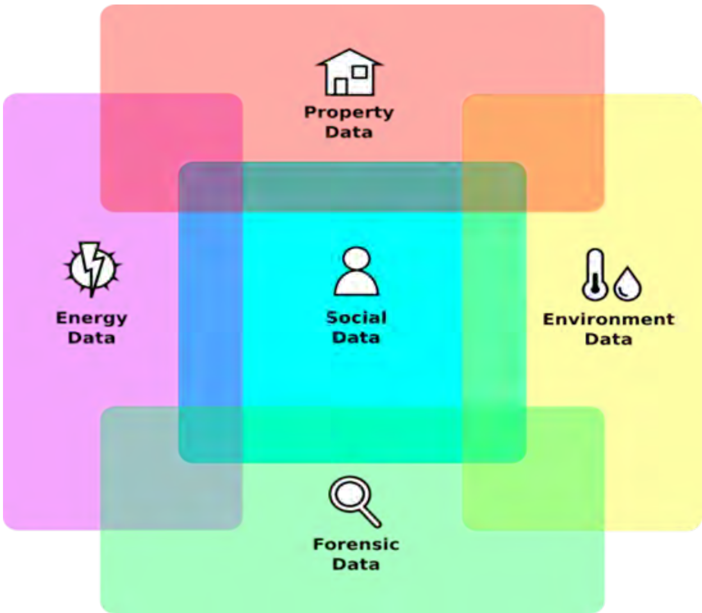
In each of these projects, environmental monitoring has been carried out to support a wider programme of research involving social research techniques and technical observations from surveyors. The aim has been to use data from each of these strands to build up a stronger picture of the relationship between people, their homes and their heating systems. This approach, represented in Figure 1 is at its strongest in helping to identify specific instances of occupant behaviour, where putting the technical and social pieces together and combining with insights from highly specific lines of enquiry (referred to as "forensic data" in this diagram) allow for high levels of success in interpreting the data to obtain the fullest picture.

[10] For the purpose of this report, **environmental monitoring** refers to the use of sensor technology to gather data in homes to support a better understanding of the internal environment and how occupants interact with this environment (through heating systems and related behaviours).

[11] These variables are ambient temperature, relative humidity, occupancy, luminance, door opening, window opening, carbon dioxide levels, electricity consumption, radiator activity and patterns of hot water usage.

[12] The OWL Intuition-c and the Honeywell evohome were each installed in six properties. The trial is described in detail in *the* ***HEMS small scale field trial final report***.

Figure 1: Combination of multiple data sources



For the purpose of the **30 Homes** data, the synthesised information from the monitored homes has informed the bulk of the qualitative insights from the wider Consumer Response and Behaviour project and has been carried forward into eight case studies. These insights and case studies are presented in the final project report: ***What people need and do that involves heat energy: Findings from qualitative research.***

The data has also informed the development of the project's modelling work where it has been used to develop real world parameters and create virtual test properties where variables can be altered to examine the impact of various changes to occupants and the system on energy usage. Key insights from this modelling work are included in the final report deliverable ***Modelling Insights***.

1.3 How this report is structured

The report is set out in six chapters:

- **Establishing what needs to be monitored and how** (Chapter 2) highlights the key steps that should be taken in any project where monitoring is being considered.
- **Designing a whole-house multi-parameter monitoring system** (Chapter 3) focusses on the most complicated project, the **30 Homes**, describing a number of factors which influenced the development and procurement of the equipment.
- **Data collection and analysis** (Chapter 4) describes the different methods of data collection used on the **30 Homes** project, the pros and cons of different approaches and how data has been used to enhance the social research.
- **Practicalities** (Chapter 5) moves into the logistics of managing an environmental monitoring project and discusses the protocols that need to be set up and practical considerations that need to be considered well before installation visits to properties.
- **Participant retention** (Chapter 6) discusses the importance of a strong communications strategy in the delivery of participant-focussed research projects. It describes some of the processes adopted by the consortium in terms of recruitment and management of participants to ensure maximum retention.
- **Main findings and scaling up implications** (Chapter 7) draws out some of the most important findings from the previous chapters and provides a bullet point list of the key recommendations in terms of scaling-up environmental monitoring studies in homes.

2 Establishing what needs to be monitored and how

While it might seem obvious, deciding ***what*** really needs monitoring and ***how*** is often missed from the planning stages of research projects. In such cases, it is usually intended that monitoring will be an added way of gathering data on a project, rather than seen as integral to the programme of work. Failure to fully establish a robust brief can lead to misspecification of equipment, sub-optimal deployment parameters, less useful data output and consequent costs to the project. This chapter highlights some of the key first steps that should be taken in any project where monitoring is being considered.

As a reference point, an overview of the systems deployed on the two projects is outlined below[13].

- **30 Homes** - the aim was to monitor ambient temperature, relative humidity, occupancy, luminance, carbon dioxide levels at 16-minute intervals from multi-sensors placed in all the rooms and the CO_2 sensor placed in the main bedroom; to record external door and window opening by locally placed event-driven sensors. The sensors were paired with a central Hub which received data reports and sent these via a Cloud Server to the consortium's technology sub-contractor, The Technology Partnership's (TTP), offices for download. Data was then passed on to UCL Energy Institute for analysis and initial interpretation and finally to the combined technical / social research team detailed interpretation. Later in the project HOBOs® were added to measure radiator activity and iButtons® to record hot water patterns of usage. Electricity consumption was measured through power clamps on the mains cable adjacent to the meter. The equipment used is illustrated in Figure 2 below.

Figure 2: Environmental monitoring equipment initially installed in the 30 Homes.

Clock-wise from bottom left: Aeon Labs Multi-sensor, Siegenia Senseair CO_2 sensor, Central Hub with lid removed – comprising MiCasaVerde Vera Lite and Raspberry Pi, onset HOBO® data logger; Maxim Thermochron iButtons® Aeon Labs Clamp Power Meter; Everspring two-part window / external door sensor.

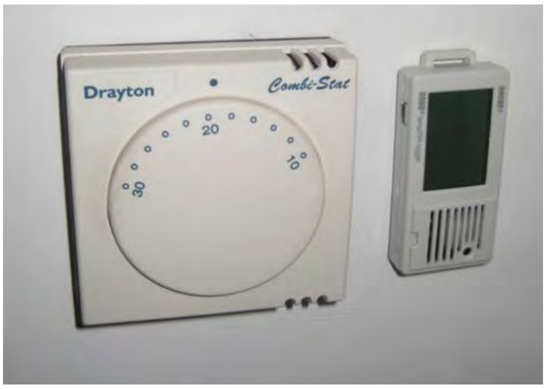
HEMs Field Trial – the HOBO® UX100-003 Temp / RH data logger was used in both the OWL and evohome trial homes to record temperature and relative humidity (within 3.5% accuracy). The loggers were installed next to the thermostat in both homes. Thermochron iButtons® were placed on radiators in the main living zone in the OWL trial homes and in four living zones in the evohome trial homes. Both HOBOs and iButtons® logged temperatures at regular intervals and stored data was then downloaded to a computer. HOBOs® were set to record data once every 10 minutes and iButtons once every 20 minutes (due to memory capacity). Electricity and gas meter readings were also taken at intervals throughout the trial to support the data gathered by the monitoring devices. The

[13] For further details on monitoring specification for **30 Homes**, please refer to Supporting Information.

equipment used is illustrated in Figure 3, and examples of their locations in the homes are shown in Figure 4.

Figure 3: Left, HOBO® UX100-003 Temp/RH data logger. Right, Thermochron iButtons®

Figure 4: Left, HOBO temperature and humidity sensor mounted to the right of original thermostat . Right, iButton temperature sensor mounted behind radiator.[14]



2.1 Establishing the Brief

Before considering any monitoring at all, a project should define its research aims and questions – the core questions that define what you are trying to find out. Without clear research questions, it is impossible to determine whether monitoring is necessary at all, let alone the variables that need to be monitored. Copies of the Research Questions for both the **30 Homes** and the **HEMS** project are to be found in the Supporting Information.

On both the **30 Homes** and **HEMS** projects, the aim was to engage people in reflecting critically on behaviours that are highly habituated, and embedded in daily routines, and therefore are not in the front of mind. While the social research aimed to explore the full extent to which different behaviours could be observed, the monitoring data provided an empirical basis of actual behaviour against which an individual's reported behaviour and needs could be discussed.

Once research questions have been identified, the variables that need to be measured should be considered. These could include physical variables such as ambient temperature or behavioural variables such as frequency of opening windows. These variables should also then be prioritised to aid later steps in the planning process.

Crucially, this step should be carried out in conjunction with planning the wider research activities. For instance, if the scope includes, or could include, other methods of data collection than monitoring (e.g. interviews, participant self-completion, etc.), these should be identified alongside to fully identify how each method helps build evidence towards answering the research questions and how each method should best interact.

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[14] Images from PRP library

For each variable it should be considered whether the variable can be directly measured and whether such measurement is realistic based on how data will be analysed and whether this method will be accepted by participants (e.g. determining who uses a bathroom and at what times could theoretically be monitored by a camera but this is unlikely to be accepted by participants). For problematic variables a directly measurable proxy could be considered as an alternative or otherwise a non-technical solution (such as a self-completed diary).

Once each measurable variable or proxy has been identified it is critical to be as specific as possible about the required dimensions for each, it is not sufficient enough to state for example, that 'ambient temperature' will be monitored. For each, the following should be considered:

- Time dimension:
  - Event driven? (e.g. record every time a condition is met – e.g. door open) or periodic measurement?
  - Frequency? (If periodic) e.g. every five minutes or once per day.
  - For how long? I.e. the total monitoring period.
- Space dimension:
  - In how many locations is monitoring required?
  - Where in each location?
- Resolution:
  - To what granularity does the measurement need to be collected? E.g. to the nearest 0.5°C?
  - How accurate does the measurement need to be? E.g. is an accuracy of ±5% acceptable?

For each of the above considerations, the guiding principle should be to anticipate how the collected data will be analysed and used. If, for example, all that is needed is an average ambient temperature in a single room over a winter heating season, it is unnecessary to collect readings every minute, in multiple locations in the room to 0.01°C ±0.1% - a single device, collecting a few times per hour to a lower resolution would still serve the purpose.

2.2 Identifying Equipment

Once the required parameters have been identified and defined in detail, suitable equipment can be identified. While off-the-shelf equipment is usually preferable to designing specific equipment, in some instances, where the brief is very detailed and / or there is a lack of suitable equipment on the market, building bespoke equipment might be preferable or necessary. In such a case, consideration should be given to whether there is sufficient budget and lead-in time to develop and fully test the system as well as any IP considerations associated with developing new technology.

For off-the-shelf solutions, there are a number of factors which should be considered in the identification of suitable equipment.

- **Affordability** – can the required number of devices be purchased within the total budget for monitoring? Is the cost justified by the benefits?
- **Procurement** – if ordering in bulk, the capacity of suppliers may be stretched. Do you need to go to multiple suppliers? Does the purchase lead-in time compromise the programme?
- **Capacity** – does the device have enough memory to capture the required number of measurements over the required monitoring period? Does it have enough battery power?

- **Interoperability** – if using multiple devices for monitoring, does selection of one device impact the choice of others (e.g. communication frequency between units, bespoke analysis software, hardware requirements for accessing data, etc.)
- **Health and Safety** – are there any issues related to Health and Safety that cannot be managed within the protocols set out for the project? (e.g. risk of participant tampering, non-certified components, etc.)
- **Participant Acceptability** – are there any issues with the equipment that will be difficult to manage? These could include:
  - Unsightly, indiscreet equipment.
  - Sensors looking like surveillance cameras.
  - Size of equipment – very small equipment vulnerable to children / pets.
  - Flashing lights or noise that might disturb participants.
  - Loss of amenities (e.g. power sockets).
  - Potential damage to home (e.g. from fixing to walls).
- **Practicalities** – are there any other practicalities relevant to the functioning of the equipment that cannot be managed? (e.g. signal range / propagation for wireless solutions, requirement for permanent fixtures, any supply issues at the scale required for the trial?)

If there are any issues with the equipment based on the above, there are no alternatives and there is no scope to build a bespoke solution, a proxy should be considered (e.g. a light sensor mounted inside a ceiling lampshade to identify occupancy patterns in the evenings, supported by reported behaviour) otherwise, non-technical alternatives (e.g. diaries) may be preferable and should be considered.

2.3 Trialling Equipment

Once a suitable solution or multiple solutions have been identified we recommend a comprehensive trialling / piloting period in real homes (preferably during the winter heating season). Not only will this ensure that the equipment works as expected, it will also help test installation procedures and health and safety compliance, identify any significant participant acceptability issues and confirm that the data can be usefully recorded, downloaded and analysed as intended.

Failing to programme in an adequate trial period and subsequent period to address any arising issues from the pilot opens the project up to risk especially if deploying at scale. A solution that becomes problematic during the main stage of research could lead to significant additional project costs, damage to reputation and loss of useful outputs; the costs and resources required to maintain a problematic system could easily outweigh the costs and resources required to develop it to a fully satisfactory standard.

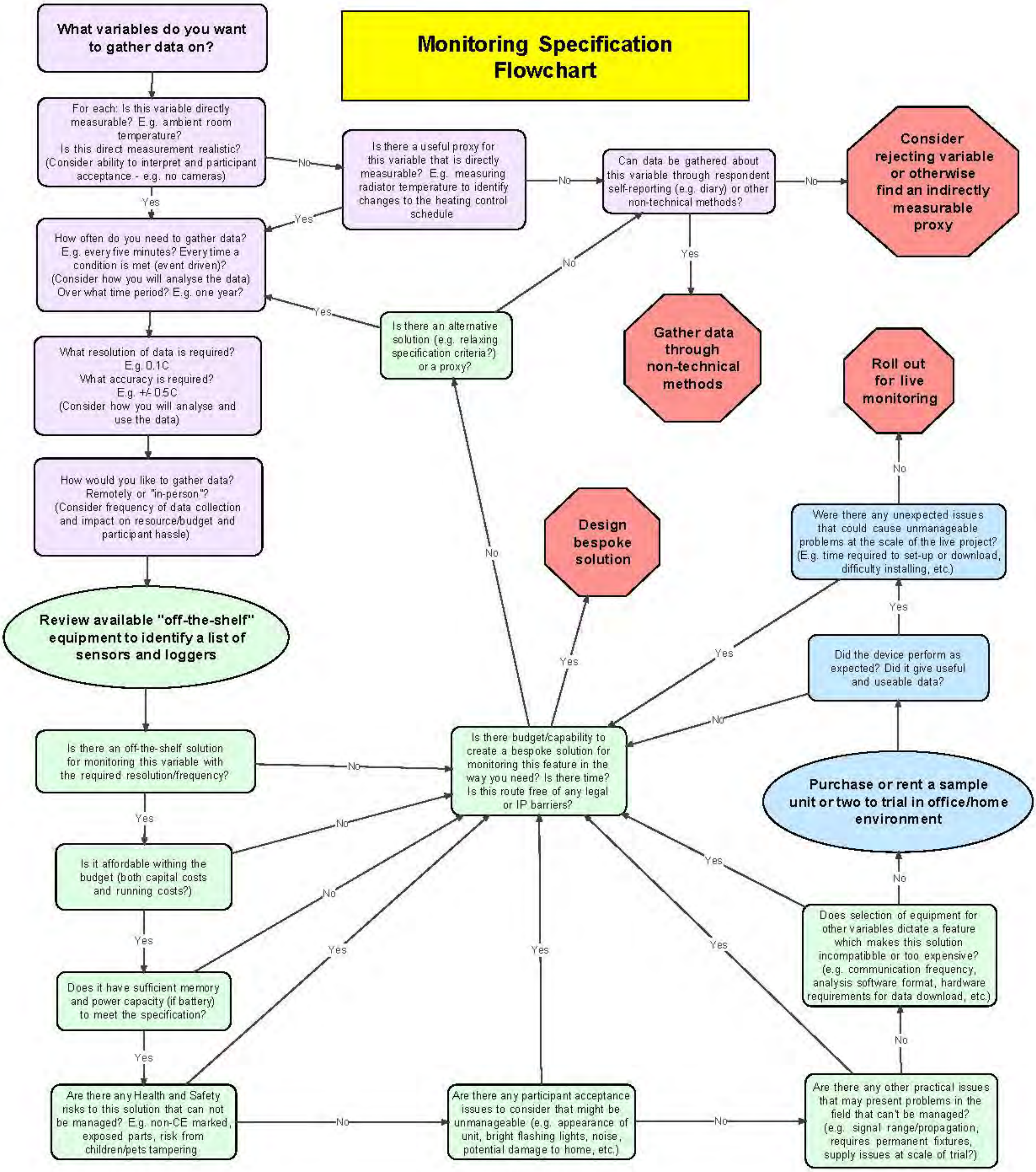
2.4 Recommendations

While the steps outlined in this chapter suggests a linear decision-making process, in reality decisions are more likely to be an iterative process with the weighing up of costs and benefits of a short list of different solutions for each parameter. For instance, two solutions for monitoring relative humidity could be identified – one that is twice as accurate, but costs four times as much as the other. In this case, it may be decided to opt for the less accurate solution and monitor in four locations for the same price as the benefit of adding more locations might outweigh the cost of a loss in accuracy.

Nonetheless, following the steps set out in this chapter will ensure that a full range of factors in the specification of the equipment are taken into consideration and, as a result, a solution will be deployed that best meets the needs of the project. To summarise, these steps are:

- Define your research aims or questions and extent of interdependence with social research methods.
- Ensure generous mobilisation time and agree the budget.
- Identify the required variables to be monitored.
- Define the required dimensions of each variable (e.g. how often to collect, what resolution, etc.).
- Identify suitable equipment and supply chain.
- Trial selected equipment to confirm that it meets requirements.
- Review the efficiency of the equipment, installation process and acceptability to participants.
- Finalise the design and installation processes. A Monitoring Specification flowchart summarising the specification of monitoring systems, as laid out in this chapter, is illustrated in the Figure 5, a larger scale A3 version is included in the included in the Supporting Information.

Figure 5: Monitoring Specification flowchart design by PRP



3 Designing a whole-house multi-parameter monitoring system

3.1 Overview

This chapter considers the significant challenge of designing a whole-house multi-parameter monitoring system drawing on the experience of the **30 Homes**. A number of factors, which are described below, influenced our decisions in relation to the procurement and development of the monitoring solution.

Our aim was to develop a robust system which would provide the data required for the project, entailed minimal maintenance, and was safe and acceptable to the participants, this was most important as the kit would stay in-situ for twelve months. Since there was not an off-the-shelf system available from one supplier which met the project requirements one had to be developed using components from various suppliers.

We provide an overview of the technical system design, software development, procurement, physical build, health and safety issues and IP challenges faced during the project[15]. Finally we make some suggestions for scaling-up considerations for the next phase of the Smart Systems and Heat programme.

The system was designed to collect the following parameters determined by the 'forensic research' required to inform the social research and participant interviews at four points of time over the year:

- Temperature, humidity, light level and movement for most, and preferably all, rooms in a house;
- CO_2 levels in the master bedroom;
- External door and window opening; and
- Total electricity use at the input to the house, especially useful if under-floor or electric heating existed or an electrical power heating source.
- In technical terms the designed system used low power radio frequency communications systems with battery powered sensors to remove the need for fixed wires to each sensor. Data was collected and aggregated at a central unit in the house which was then transmitted to a cloud-based server over the GPRS network.

There were a number of influencing factors in the design of the monitoring solution which are outlined in the following sections in this chapter.

3.2 Health and Safety

Health and safety considerations formed a major component of the design decisions and are discussed in more detail in TTP's final report[16]. The protection of the participants, their children and pets and the protection of the research team were paramount. The key design considerations were:

- Use of wireless connectivity,
- Minimal use of power cables to monitoring equipment, and
- Choice of light weight, integrated, sensors.

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[15] A far more detailed description of the development of the equipment for the 30 Homes is attached in the Supporting Information, TTP's report - ***Final Report on the Monitoring Equipment for the ETI's Smart Systems and Heat Programme***

[16] Ibid.

3.2.1 Multi-sensors and the Hub

These considerations pushed the design team towards the use of either Zigbee or Z-wave based multi-sensors because they were available off-the-shelf in compact integrated units with CE markings.

As the data collection Hub was mains powered, concerns relating to electrocution and fire (initially identified in a Hazards Risk Workshop) had to be designed out. These were mitigated through the Hub equipment being contained in a fire retardant box with tamper proof screws and the low voltage power supply connection being via a small plug which would detach from the socket in the outside face of the fire retardant box should the power cable be pulled with force. This approach was proven to work when an incident occurred in one property; the shelf on which the Hub was located collapsed due to poor installation of the shelf by the participant and the Hub fell to floor with the result that the Hub remained intact with only minor damage caused to the power socket in the box face as the power lead detached itself. Consequently risk to the participant household members or the property was not increased by the monitoring equipment during this incident.

3.2.2 Carbon Dioxide (CO_2) sensors

There were not many market ready CO_2 sensors that were compatible with data reporting frequency used by the developed monitoring system. The one that was most suitable had a potential safety defect - the power cable was hard wired in the sensor housing and the housing could be easily prised open. The sensor was adapted to incorporate an additional housing at the rear which allowed a detachable power supply lead to be used, although a practical solution it was not aesthetically pleasing. The original outer casing was fixed with clips and considered not safe to install in homes, the solution was to glue the two part of the casing together to prevent the casing being easily opened (however this resulted in data readings for a while being incorrect due to off gassing from the glue). A more robust and acceptable CO_2 sensor is required.

3.2.3 Power supply

There were two options for powering the monitoring system - mains power and battery. It was decided that battery power should be prioritised to reduce health and safety issues (connecting to mains power and the array of cables that would be required to link the sensors to power socket.) However, some of the equipment on the **30 Homes** project (and also WA6) had to be mains powered due to the power consumption (data Hub, CO_2 sensor and the data repeaters with a plug through facility installed to extend the wireless capacity).

We experienced instances (about a third of the properties) where the power supply to the Hub was turned off, typically at the start of the project by a participant household member who was not the one who was briefed by PRP at the time of installation. We subsequently applied a sticker to the plug which reminded participant household members that it needed to be left plugged in and switched on for the project and in a few homes timer plugs were installed.

3.2.4 Battery lifetime

Most manufacturers advertise that their sensors will run for 12 months without a battery change but this depends on the signal strength needed to reach the Hub unit from the sensor, the interval at which measurements are reported, and the amount of “housekeeping” data traffic required to manage the network rather than actually transmit data. We did not have time to test the life of the sensor units in a realistic operating environment and in the field found it substantially lower than the 12 months claimed by the manufacturers – despite using high quality Lithium Ion batteries. It is thought that this was due, in part, to over ambitious specification claims by the manufacturers but also to the need for regular network “reboots” to ensure the stability of the network to prevent “crashes” found in early trials, placing greater demands on the units than envisaged by the manufacturers. This created a need for two additional battery replacement cycles[17] during the project, which added additional purchasing and installation costs and inconvenience to the participants.

Battery life is an important consideration in terms of how frequently data is collected. Battery life in the HOBO®s is expected to last a year at typical data collection rates (e.g. every 15 minutes) and, due to the lower and more predictable demands on the logger (e.g. no need for wireless connection) have been found to be more reliable. On the **HEMS** project we reduced the 8-minute data collection frequency rate to 15-minute to ensure that no battery changes would be needed over the three-month trial.

3.2.5 Fixing methods

To minimise the risk to the installer and potential damage to the property, fixing methods for the sensors were developed which did not include screws or nails due to the risk of puncturing electricity cables or water pipework. Participants were given a choice of two fixing solutions at the time of installation, Tacker pins (small pins pushed into the plaster wall finish with a proprietary tool) or 3M Command™ strips (adhesive strips which can be removed without damage to the wall finish). The 3M strips cannot be used on wallpaper or newly painted surfaces and in these cases Tacker pins were used. As the project developed we determined that the hook-and-eye two-part 3M Command™ strips were the most appropriate for installation and decommissioning of sensors including the fixing of HOBOs® to radiators. No damage was caused to any surface through the use of the Tacker or 3M Command™ products. We experienced supply problems with the Command™ products particularly at Christmas time, when they were used by the general public for decoration fixing. Images of fixing equipment used are shown in Figure 6.

Figure 6: Picture Hanging Kit by Takker™ [18] and 3M Command™ instructions [19]

We had been requested by ETI to monitor real time gas and hot water consumption but the installation of optical readers for the gas meter and in-line flow meters for gas and hot water use were not possible for a number of reasons including disruption and costs, and additionally in the case of gas, permission required from the utility company. Instead we took regular energy meter readings and installed iButtons® on hot water pipework were it was accessible to record temperature and of hot water use. More readily market available and usable gas and hot water use monitoring equipment is needed.

[17] In all a total of around 4,000 batteries were used on the **30 Homes** project over the course of the year (3,228 AAA lithium batteries for Multi-Sensors; 87 AA lithium batteries for Electricity Clamps and 1,014 coin cell batteries for Window Sensors). Safe disposal of batteries is also an issue to be considered.

[18] Image from http://www.takker.com

[19] Image from http://www.command.com

3.3 Intellectual Property (IP)

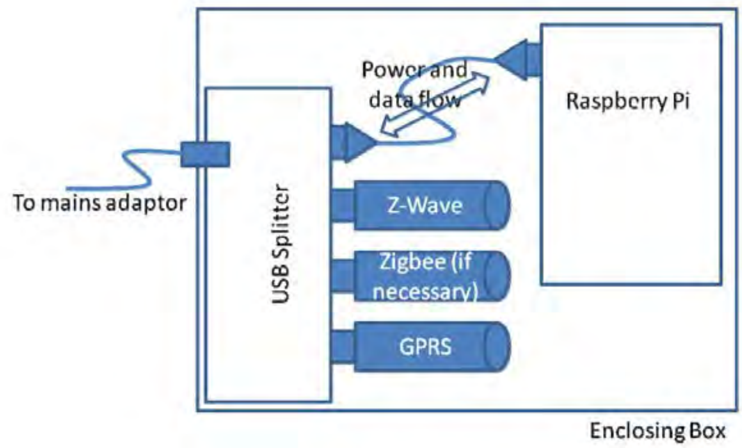
IP issues can be complicated, particularly when the design of new equipment and open-source platforms are concerned, again generous lead-in time to resolve these is essential. In the **30 Homes** project we used off the shelf equipment so no technical development work was required and therefore no risk of 3rd party claims. We stayed away from utilising open-source software because any development work in this area would incur arising IP and would not be solely available to ETI.

3.4 Data Reporting

The remote collection of data to allow real time analysis, minimise costs and disturbance to participants was initially part of the design aims for the project. Data had to be collected automatically in the homes and then communicated externally to a secure place of storage for data protection reasons. The option to connect the in-home data collection Hub to the internet router in the home (if available) was dismissed. It would have provided a more reliable solution to data communication than the 3G solution that was selected but we wanted to avoid a connection to the participant's router. In future this could be explored as an option. WA6 uses mix routes connections and 3G (where no routers).

The Raspberry Pi was considered the best platform for this application because it is CE marked, unlike other models. For the rest of the system the Z-wave, Zigbee and mobile phone systems were attached as standard dongles via their USB connectors to a USB splitter box which also provides power to the components of the Hub unit as shown in Figure 7.

Figure 7: Diagram of preferred design of the Hub Unit which integrates standard parts linked via the USB interface inside a plastic box to conceal contents. The final design was more complex due to IP considerations



However, there were problems with getting many of the systems to communicate externally (more than 50% over the year), but data was backed up on a SD card in the Hub requiring manual download. Communication problems were down to a number of factors including mobile phone mast proximity to the house, the form of construction of the house (dense materials or those with steel components) and the density of surrounding buildings. In some cases mobile phone mast location maps assisted the relocation of Hubs to another area of the house, or the research team called on its technical knowledge of building materials and how these could interfere with reception. Where problems of communication between the sensors and Hub in the house were experienced due to the building construction or large size of homes mains-powered repeaters were added to improve the internal signal reach.

3.5 Data Protection

The IT architecture was designed to ensure that only organisations registered to handle personal data could see data in a form that can link a sensor's output to a street address. To facilitate this the system allocated a unique ID to the output of each sensor when the Hubs and sensors were boxed into house kits and only organisations licensed to hold data on people had access to the database which connected sensor ID and street address. Data Protection is described in more detail in 5.1.

3.6 Participant Acceptability

The monitoring trial relied on the informed consent of those being monitored and was on a strictly voluntary basis. Participants had to be comfortable with what was being monitored, the equipment used and its location within their homes. For these reasons we avoided installing cameras or other image forming sensors with a view to keeping equipment unobtrusive and therefore acceptable to participants.

We found that the housing of many of the off-the-shelf sensors had not been designed for use in the residential market and often consisted of matt beige plastic boxes with visible LED's, aerials and plug in sockets, these were more suited to industrial or academic uses.

After some research, we were able to source a multi-sensor which provided four of the required data collection functions (temperature, relative humidity, movement and light levels) which reduced the need for a number of separate sensors. However this large PIR multi-sensor unfortunately had the appearance of security camera raising concerns for some participants who covered the sensor or turned it towards the wall. There were mainly household members who had not been present when the equipment was installed and had missed the explanatory induction by the installer. Further explanation and reassurance from the project team to these participants was required.

Another design consideration was the need to eliminate the use of the participant’s broadband connection due to concerns about the cost to them of transmitting the data over their network and that such a criteria could exclude a household without broadband internet connectivity. It was recognised that connectivity rates are still significantly lower in low income and older demographics, and these groups were important segments that we could not afford to dismiss in our research work.

The flashing LED's or red LED lights on the Hub and CO_2 sensor initially caused concerns for some participants (they thought they were hazard lights), and disturbed the sleep of others. Participants were advised to stick tape over the lights. A further issue for participants emerged during the trial relating to these units. Some participants thought that the units were measuring Carbon Monoxide, CO, and became concerned when they saw flashing lights. This was resolved by issuing clarification letters to the participants.

3.7 Procurement

Procurement of parts on the open market proved more difficult than expected. We found that the home monitoring, automation and control industry is still a small market limited largely to enthusiasts and hobbyists. Due to the international manufacturing locations of many of the sensors and quantity of sensors required for the **30 homes**, supply times took longer than expected and ranged from 2-6 weeks. The requirement for 300 Aeon Labs Multi-sensors proved the most difficult to meet but support from Aeon Labs itself was very good and extra staff were drafted in to their Chinese manufacturing operation on short term contracts to meet demand, and parts were shipped directly to TTP for incorporation into the systems in time for deployment.

However, typically, the equipment suppliers did not readily provide support when technical issues arose with the equipment and it was apparent that the supply chain was not geared up to support a project of this size. However, we found that most suppliers provided price discounts for bulk purchases and 3M was particularly helpful at the project outset with regard to the use of its strip fixing products.

Software configuration proved more difficult and the need to maintain a rolling deployment programme to meet the schedule of installations meant that nearly all the systems had to be reconfigured and retested at TTP before delivery to PRP for installation at considerable extra cost and time. The photographs in Figure 8 are taken by TTP during this reconfiguration period.

Figure 8: System reconfiguration and testing by TTP[20]

3.8 Recommendations

- Carry out a Risk Hazards Assessment early in the design to identify health and safety issues which will influence the specification.
- Specify, where possible, off-the-shelf functional sensors.
- Research the merits of mains power versus batteries. Battery life is an issue; data over-loading may result in a number of battery changes causing logistical problems including additional installer visits, inconveniencing participants, and extra costs.
- Engage with suppliers as early as possible, especially on larger monitoring programmes, to ensure that supply quantities can be met and in time periods (average 5-8 weeks procurement time) that do not impact on the project programme.
- Keep the supply chain (designers, suppliers, installers) tight in order to reduce communication and administration time.
- Establish the fixing methods during the design process.
- Identify and resolve IP issues early in the design process.
- Use flow-charts to work through Data Protection issues.
- Keep equipment to the minimum and avoid using participants' broadband. Explore potential of 3G and other networks as an alternative.
- Keep the use of mains plugs to a minimum.
- Explore alternative CO_2 monitoring products.
- Consider how all participant household members will be briefed on the operation of the monitoring system and how they pass this briefing on visitors. This could be through a web-site tutorial / system overview pack, an animation or hardcopy information sheet.
- Package systems in a well-labelled single box for each home.

[20] Photos from TTP Image Library

4 Monitoring Data

This chapter describes how the different environmental data collected was used on the two projects and how it enhanced the social research.

4.1 How data adds value to social research[21]

The research aims presented the team with a number of challenges. Above all, we needed to be able to engage people in reflecting critically on behaviours that are highly habituated, and embedded in daily routines, and therefore are not in the front of mind. For this reason, and others, there may be a disconnection between reported and actual behaviour. The environmental monitoring was geared towards addressing this challenge.

Analysis of the **30 Homes** data produced a bespoke set of information for each household including heating and occupancy patterns, ventilation behaviours, cooking and washing, and wasted heat energy which was shared with participants during 'data-led' interviews, in narrative and graphic form. While the research aimed to explore the full extent to which different behaviours could be observed by the research team, the monitoring data provided an empirical basis of actual behaviour against which a participant's reported behaviour and needs could be discussed.

We summarise below some examples where the in-home monitoring added value to the **30 Homes** project.

- **Interrogating reported patterns of behaviour** – the data, when available, provided a rich story of 'normal' patterns of behaviour in a given household. This provided stimulus material that could be used to corroborate reported routines, and explore inconsistencies with participants.
- **Confirming reported patterns of behaviour, and deepening understanding** – even where data confirmed reported patterns of behaviour (which was not uncommon), the data could be used to engage the interest of participants, and encourage more prolonged and deeper reflection on these, and the needs that they serve.
- **Identifying exceptions or breaks in routine behaviour** – the monitoring data was useful in identifying and shedding light on atypical or occasional behaviour, which participants did not always mention spontaneously.
- **Identifying behaviours that participants may not consciously link with heat energy use** – in some cases, the role of heat energy may be distant in people's minds from the need it serves, or the behaviour through which the need is met. For example, one participant was surprised to learn from the data how frequently they opened and closed external doors and windows to let the cat out – which prompted them to think about how much heat was lost in the process.
- When overlaid, the data could help generate a richer picture of **how different dimensions of the monitoring data play out in interaction** – for example, data that showed when the heating was on, overlaid with occupancy data, allowed for discussions about instances when the home was heated but unoccupied.
- **Zoning behaviours** – the room-by-room data enabled us to develop further insight into how and why heat is used differently across a single home, through follow-up discussions with participants.

[21] For further examples of how data has added value to the social research refer to the report ***What people need and do that involves heat energy: findings from qualitative research.***

4.1.1 How data empowers participants

Participants mentioned learning, empowerment and effecting change as key motivators and / or benefits relating to the project, for example:

- **Learning something new** - in some cases the data drew participants' attention to their habitual behaviour or helped them to learn something new or surprising about their behaviour. For example, one participant said his attention was drawn to how frequently he opened and closed external doors for the cat, and about overnight power consumption.

- **Confirming existing knowledge** - even where data corroborated what participants already knew about their behaviour, rather than telling them something new, this could still be viewed as a positive validating experience. For example, one participant felt that the data corroborated that some of the strategies he used were effective, for example trying to keep the child's bedroom at a constant, low temperature.

- Linked with the above, participants were also keen to be able to **put their learning into action and effect change** - for example, one participant wanted to be able to approach those responsible for setting the communal heating and show them 'scientific' evidence that the system was currently inefficient.

4.2 Data collection

In both the **30 Homes** and the **HEMS** projects, data was downloaded, consolidated and analysed in advance of interviews in the home. For the **HEMS** project, this occurred once (two weeks before the final interview) with researchers visiting the homes to retrieve monitoring devices so they could be downloaded and data analysed at the office. (NB two participants asked if they could send the small devices back by post, in both cases this occurred without any problem through loss, damage or otherwise).

In the **30 Homes** project, preparation for the first interview relied on the remote download system. However, as previously mentioned, in many cases the remote facility was not functioning as intended and in some cases required telephone calls to participants asking for them to switch the Hub on and off in an attempt to reset it. Data to inform the first interview was in some cases patchy. In preparation for the later interviews visits were arranged to properties where the remote download system was unreliable to retrieve SD cards from the Hubs where data was backed-up locally. These SD cards were subsequently scraped of data which was uploaded to the main database, ready for analysis.

For the last two interviews, local loggers were installed to monitor radiator temperature and hot water usage. In each case, these necessitated additional visits to install and collect / swap loggers prior to the scheduled interviews thus increasing the total number of visits required. These additional visits, however, were aligned where possible with battery replacements for the wireless sensors and, where necessary, collection of the Hub SD card and on-site troubleshooting to try and re-establish the remote link.

4.3 Data analysis

There are three broad areas in which the collected data was used:

Firstly, data analysis verified that the monitoring equipment was reporting correctly and that it was providing sensible data. Sensor functionality was an on-going issue, while this was initially associated with installation and connectivity, later we found that working sensors could stop reporting correctly at any time, and that sensors that had been producing erroneous data suddenly started to work correctly again.

Secondly, data analysis was used to build an understanding of the environmental conditions and behaviour of participants within the monitored home. In the context of the **30 Homes** project, data was primarily used to inform the social research interview and to provide a stimulus for interaction with participants (e.g. letting participants know their actual annual energy use compared to national averages) and to provide discussion points around perceived and actual energy use behaviours (e.g. window opening records compared with a participant's observations on when and why they opened windows). This combination of data and behavioural observations within a specific home also fed into the project's Modelling work and was used both to derive model inputs (for example heating operation hours) and as a check that the model outputs bore some resemblance to reality (NB it is important to recognise that a model cannot accurately reproduce the reality of conditions inside a home). On the **HEMS** project, data was incorporated into the trial (room temperature and humidity and meter readings) to inform and complement in-depth interviews and to identify changes in environment and energy use following installation of the new HEMS controls.

Thirdly, the data accumulated from the many homes could be aggregated and cross-compared, to start to form a picture of typical patterns across the stock. Although the sample size was small in both projects it was enough to provide hints of patterns that could be further explored in future, larger scale monitoring efforts.

4.3.1 Data accuracy and error checking

The data analysis started with a simple check for each sensor: was it producing enough data to be useful? There are two levels of "usefulness":

- Is there enough data to get an impression of conditions in the space? Generally relatively few data points are required in order to plot a chart that can be interpolated by eye.
- Is there enough data to calculate aggregate statistics? Calculating statistics such as mean internal temperature requires fairly continuous periods of data to avoid biasing the results (for example if the sensor tended to work better at night than during the day).

There are two ways in which the quantity of data may be sub-standard. The sensor may continuously lose some proportion of the expected readings (e.g. 50% of all readings are randomly lost), or the sensor may experience extended "black out" periods, where no data is received at all.

The installed sensors could be divided into two categories: those that reported data on a regular interval (including temperature, relative humidity, power & CO_2 sensors) and those that were event-driven, and reported data whenever the observed state changed (including occupancy and window opening).

In the case of sensors with a regular reporting interval, it was straightforward to identify periods with missed readings. For the temperature and relative humidity sensors, measuring quantities that were generally fairly slow to change in a home, it made sense to interpolate short periods of missing data - missing periods of up to two hours were interpolated. As power data can change almost instantaneously from very high to very low values, generally no interpolation is applied to fill in the blanks.

Occupancy and window opening sensors were more complicated to deal with. In the case of a rarely used window, if a "window closed" signal was missed, then it could be several days or weeks until another reading ("window opened") was broadcast. In this case there would be a long period where the window state was unknown. Unfortunately the situation became further complicated as the next "window opened" broadcast could also be missed so there was no reliable way of telling from the readings whether there were missing values. Instead, the sensors broadcast a regular "heartbeat", and an assumption was made that if most of the heartbeat signals had been received then most of the "window opened" and "window closed" readings would also have been received. This did occasionally lead to missed readings and therefore an incorrect window state being assumed. There is no obvious way of avoiding this situation with this type of sensor.

Once the availability of data had been established, simple checks were made to confirm that the readings were logically possible. For example, relative humidity could not be below 0% or above 100%. Internal temperatures were unlikely to drop below 0°C or rise above 40°C. Also these temperatures would tend to vary relatively smoothly, so sudden "spikes" in the measurements were likely to be incorrect.

Several of the temperature and relative humidity sensors were found to produce the same reading throughout the monitored period. These were also assumed to be incorrect data. Several of the door / window sensors were dislodged from where they were mounted, resulting in an “always open” reading (these were generally identified and rectified at the home visits).

Finally, several of the occupancy / motion / infra-red multi-sensors indicated that the rooms were occupied continuously. This seemed unlikely in rooms such as living rooms. On closer inspection it was discovered that these sensors were producing a regular “tick” approximately every 16 minutes. Diagnosis suggested that the sensor was triggering whenever it sent a heartbeat signal. A Fourier transform[22] was applied to data from one of the faulty sensors to decompose it into its frequency components. A spike in the Fourier transform was observed at the same frequency as the ticking occurred. As there was no reason why occupants or room contents might cause such a regular ticking, it was decided that all infra-red sensors exhibiting a peak in the frequency domain at this frequency should be classed as not working. The Fourier transform was therefore applied to all of the infra-red sensor data, and many more were found to suffer from this problem, including many that suffered from it only part of the time. Approximately 35% of the installed sensors were found to suffer from this fault. (These examples are illustrated in see Figures 9a and 9b).

In theory it could be possible to at least partially reconstruct the correct data from the faulty infra-red sensors. It was assumed that whenever the ticking occurred, the sensor should be in the “off” state, hence replacing periods of regular ticking with “off” would give close to the correct data, however this approach could clearly miss occasions when occupants entering and leaving a room corresponded with a tick. This filtering was not applied to the data.

Figure 9a: An example of a constantly triggering IR sensor.

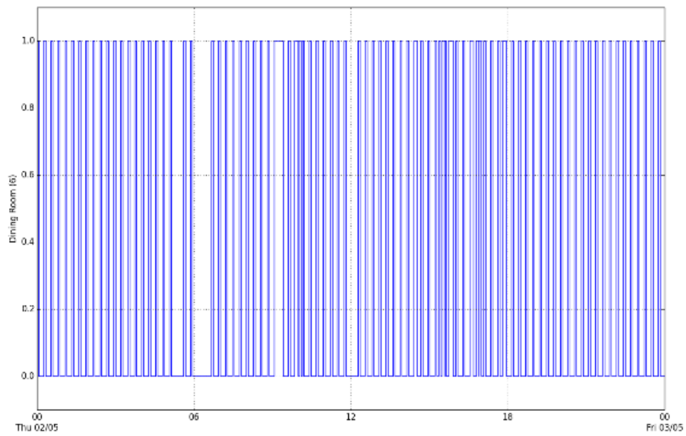
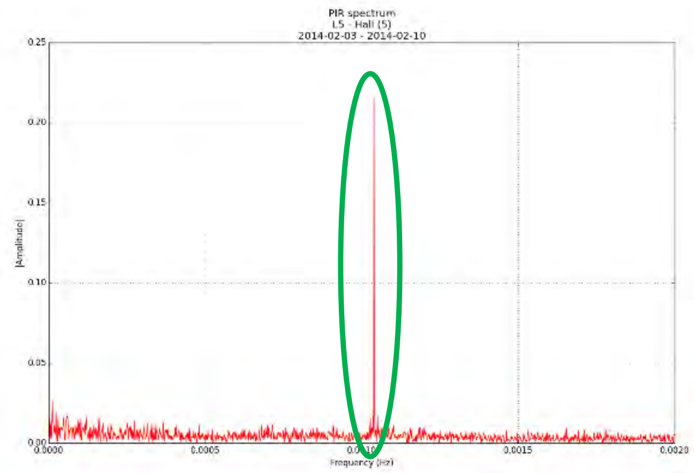


Figure 9b: An example of frequency analysis of data showing clear



[22] The Fourier transform, named after Joseph Fourier, is a mathematical transformation employed to transform signals between time domain and frequency, which has many applications in physics and engineering. (wikipedia)

4.4 Understanding individual homes

The purpose of combining the data analysis with the participant interviews was to establish what the systems in the home were doing and why and the effect they had on the internal environment. The data could tell us fairly precisely what the internal environment was like (though smaller scale effects such as temperature variations within a room could not be measured with the installed sensors). In many of the homes the operation of the systems (primarily the heating system) could be determined from temperature measurements of the heat emitter (e.g. radiator). Determining why the systems are operating was much harder: was it on a timer or was it manually triggered? Why was the timer set how it was? We outline below the main analysis undertaken for each home and the types of follow up questions that this lead to.

Once the bad data points had been removed and any interpolation applied, the data could start to be analysed. The data could be analysed on different timescales. At the lowest level, looking at the raw data for one day up to one week showed at a high level of detail what happened in the home (e.g. the typical daily temperature fluctuations which give an idea of internal comfort, and could indicate rooms with high solar gain, etc.). This type of analysis was useful for pointing out specific behaviours at precise times and events which could be pin-pointed. This type of data therefore formed the core of the data presented to participants at interviews. However one week's data was not enough to observe broader patterns of behaviour and could be misleading if the chosen week was unrepresentative of normal behaviour (e.g. the Christmas holiday period).

Over a longer period, such as four weeks, average behaviours could start to be observed, for example did the heating system switch on at exactly the same time every day (suggesting it was operated by a timer) or did it switch on at slightly (or very) different times (suggesting that the occupant was switching it on manually).

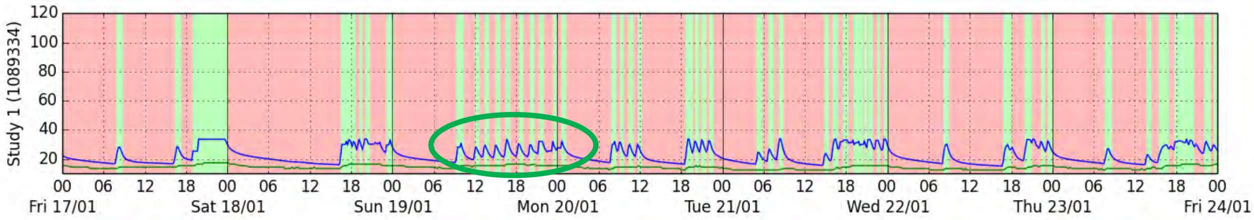
Over periods of several months, trends in average behaviours could be observed (e.g.as household composition changed, or as the weather changed). It was also possible to start calculating annual averages for comparison with national statistics.

4.4.1 Heating system operation

Where possible, heating system operation was monitored primarily by attaching portable temperature loggers (HOBOs®) to heat emitters such as radiators. By looking at the change in temperature it was possible to identify when the heat emitters were switched on. In the **30 Homes** project an algorithm proposed in the Energy Saving Trust report, ***Powering the Nation***[23] was used to do this. It is important to understand that the resulting on / off signal was for when the heat emitter was switched on and off and did not necessarily correspond exactly with the central heating system operation – due to thermostatic operation, (thermostatic radiator valves (TRVs) and central thermostats) the heating system may have been switched on, but not necessarily producing heat.

Radiator temperature measurements were sufficiently accurate that TRV operation could be observed in several homes as a rapidly cycling in the radiator temperature.

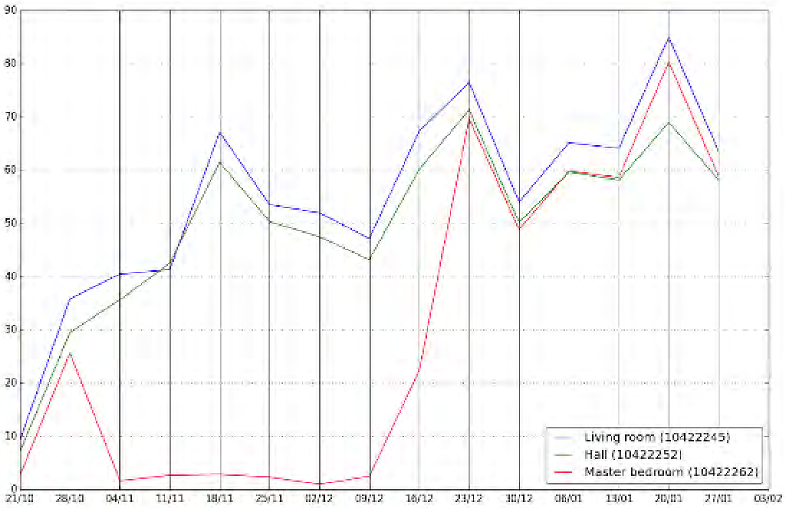
Figure 10: Operation of thermostatic radiator valves (blue line shows radiator temperature, green areas are where radiator is assumed to be on, red areas are where radiator is assumed to be off).



[23] Powering the Nation - household electricity-using habits revealed. *EST, DECC, DEFRA,* June 2012.

Once enough data had been collected it was possible to look for patterns in the heating system operation. For example, how many hours per week was each radiator switched on for? Were all radiators on for a similar amount of time or did some operate less frequently? This was a good way of identifying whether occupants had switched off some radiators in the home (perhaps in unused rooms).

Figure 11: Number of hours of heating for each week. Note how the master bedroom radiator is turned on early in December through the use of the radiator valve



It was also possible to calculate the probability that each radiator was switched on at different times during the day. Again this plot could be used to identify radiators that were operated differently from others in the home, but the main use was to establish how the heating system was controlled. If the system was mainly controlled by a timer then the timing would be substantially the same every day (perhaps with variations at the weekend if the controller allowed it) which would show very clearly in the plot. Commonly the plots would show two or three very clear heating periods, with periods of less frequent heating around it, representing periods when the occupants had manually overridden the timer. If the timer was not in use and the operation was entirely manual, then this would also be fairly clear in the plots, as even occupants with a regular routine would have some variation in exactly when they switched on their heating. These plots could also be used to identify weekend versus weekday behaviour, with the heating often being activated later in the morning at the weekends and being used more during the day.

Figure 12a: Probability that radiators are on throughout the day- two clear heating periods suggest timer operation.

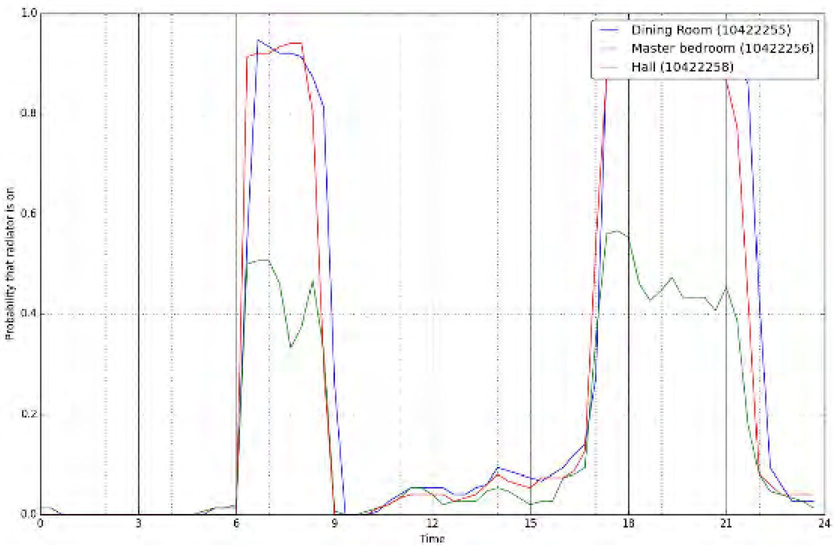
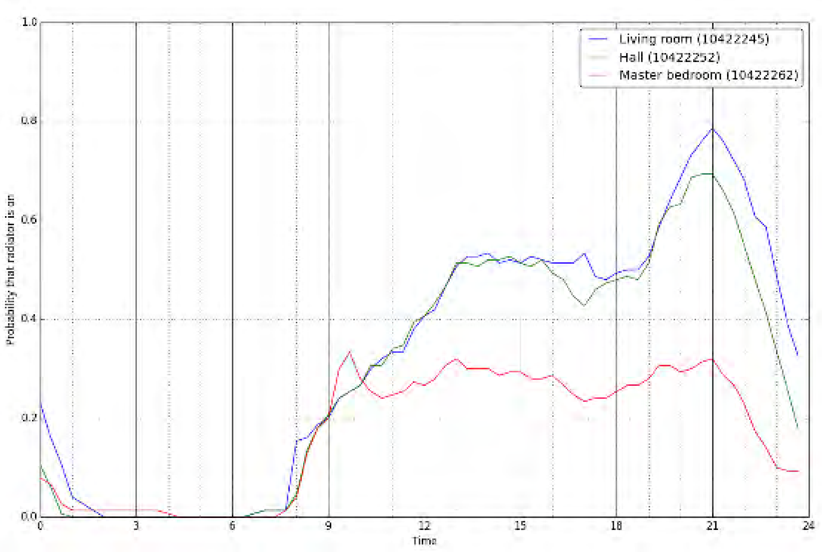


Figure 12b: Probability that radiators are on throughout the day - no sharp on/off times, suggest manual operation.



Several common control strategies can be easily identified from the data:

- Timed operation for two to three relatively short periods each day (typically two to four hours each).
- Timed operation for much longer periods (e.g. from 5pm to 11pm), with temperature controlled by thermostats.
- Manual operation, where heating was switched on and off as required by the occupant.

Finally, for gas heated homes, gas meter readings could be used to compare annual consumption to national averages (the NEED dataset was used to provide benchmarks).

4.4.2 Internal temperatures

Internal temperature is one of the key drivers of comfort in homes, and can vary widely depending on the design of the home, its heating system and occupant preference.

There are two key statistics of interest for internal temperature: the mean internal temperature and the variation in internal temperature (which can be quantified using either standard deviation or daily temperature swings) as demonstrated in Figures 13a and 13b.

It was interesting to look at how the mean internal temperature varied with the external temperature. Typically it was expected that internal temperature would drop slightly as the external temperature dropped, caused by a number of factors:

- In cooler weather homes get colder overnight (when the heating system is typically switched off). This lowers the average temperature in the home.
- In very cold weather the heating system may be unable to achieve the same temperatures as it did in warmer weather.
- Occupants' *neutral temperature* (the temperature at which they feel neither too hot nor too cold), tends to reduce slightly as external temperatures reduce, and occupants may also tend to wear warmer clothing within the home.

The spread in mean temperature between spaces within a home is an indicator of *temperature zoning*, i.e. are some spaces in the home consistently kept at cooler temperatures that other spaces.

Figure 13a: Mean internal temperature over time in two homes - temperatures gradually decrease through winter.

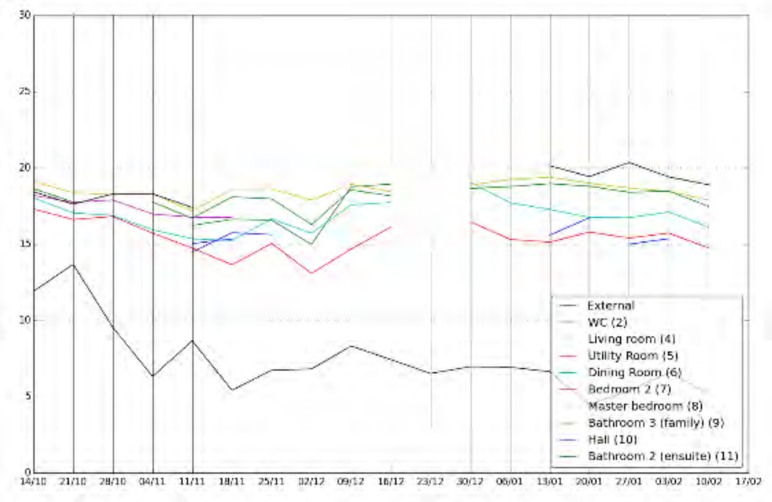
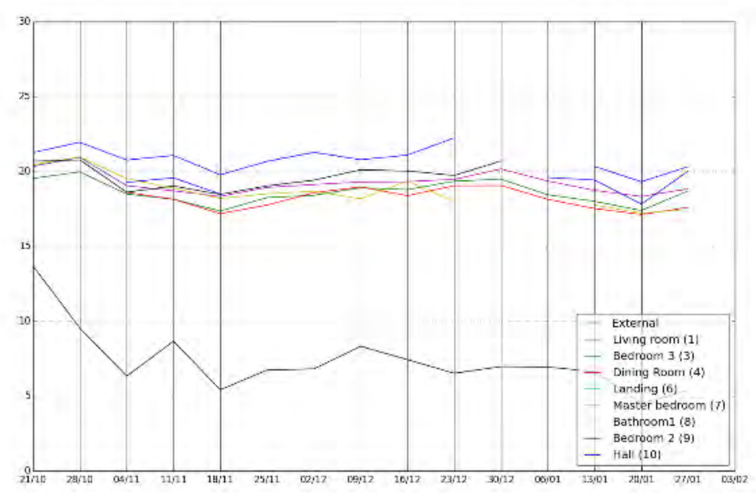


Figure 13b: Mean internal temperature over time in two homes - temperatures generally increase slightly through winter and spread increases significantly.



Daily temperature swings give an idea of home heat loss. Homes with a very low heat loss (such as modern flats) tend to maintain a more stable temperature. Homes with higher heat loss will exhibit larger temperature swings as they cool down more overnight. Even a highly insulated modern home can have a high heat loss rate if the occupants often open the windows when it is cold outside, so large temperature swings may be indicative of a poorly insulated home, or may indicate occupants with a preference for keeping windows open. The window opening data helped to distinguish between these cases.

4.4.3 Occupancy

The installed infra-red multi-sensors were used to build a picture of when the home was occupied, and which rooms tended to be used at what times. In practice this analysis was hampered by many of the infra-red sensors not working, however in principle the occupancy data could be used to investigate questions such as how often spaces were heated, when they were not used and whether spaces were kept at comfortable temperatures when they were occupied (a house with a low mean internal temperature may still be comfortable if spaces were warm when the occupants were present). Examples of heating systems compared to occupancy are shown in Figure 14 and Table 1.

One way of approaching this was to classify each time period for each space into one of four categories:

- The space was heated and in use.
- The space was not heated and not in use.
- The space was heated and not in use – representing wasteful operation of the heating system.
- The space was in use and not heated – representing periods when the occupant under other circumstances might have chosen to turn the heating on.

These last two categories indicated how effectively the heating system in a home was being operated. Long periods when the heating was on and the space not in use suggested that with a suitably flexible control system, heating in the home could be reduced ("traditional" heating timer controls in UK homes usually only allow heating for the entire house to be switched on and off, with that type of control system long periods of rooms being heated while vacant are inevitable).

Long periods where the space is being used but not heated could indicate one of a few possibilities:

- The house had naturally achieved a temperature that the occupant finds comfortable.
- The occupant had consciously decided to leave the heating off, perhaps to save money or energy.
- The occupant did not know how (or was otherwise unable) to operate the heating system.

Whatever the reason, if upgrades were made to the home, there is a possibility that during equivalent periods in the future the heating system would be switched on (counteracting any improvement in energy efficiency due to the upgrade, otherwise known as the rebound effect or "take back").

Figure 14: Heating system operation compared to occupancy. Red areas indicate periods when the heating was on but the space was unoccupied, green periods when the heating was not on and the space was occupied. More red areas means more scope for reducing heating system hours of operation, more green areas mean higher potential of increased heating system operation due to take back/rebound.

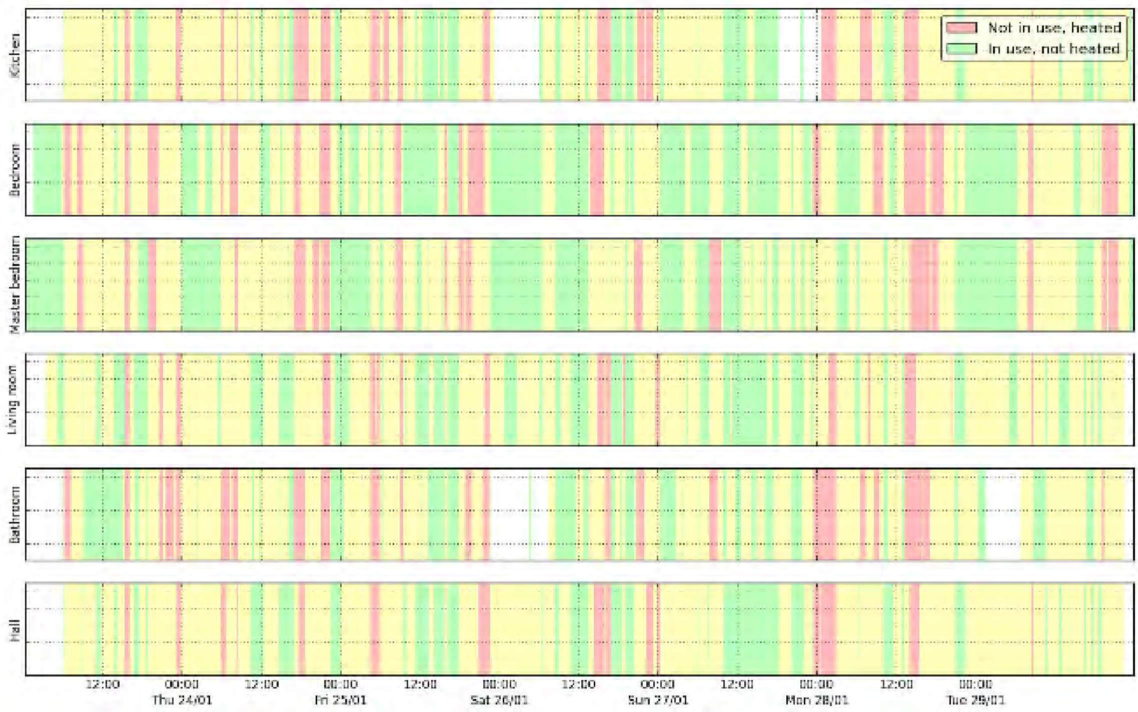


Table 1 – An example of heating operation compared to occupancy

	Not in use		In use	
	Not Heated	Heated	Not Heated	Heated
Kitchen	40%	14%	20%	25%
Bedroom	24%	16%	39%	21%
Master Bedroom	26%	12%	37%	24%
Living Room	34%	8%	28%	30%
Bathroom	36%	18%	24%	23%
Hall	39%	10%	23%	29%

4.4.4 Internal moisture levels

The relative humidity (RH) of air inside homes is of interest for two reasons. If the relative humidity is too low, it can cause various health problems such as dry eyes and skin. In practice only one of the monitored homes had a humidity level approaching the threshold at which this might be a problem.

If the relative humidity is too high (if it is on average higher than 80% at a surface, i.e. room RH greater than 70%) then there is a high risk of mould growth which can cause or exacerbate several serious health problems such as asthma and can cause physical damage to the property. House dust mites whose faeces also exacerbate asthmatic symptoms can thrive at room RH's above 60%. There are four potential causes of high relative humidity:

- If the external air has a high moisture content (which is common in late autumn in the UK), then internal relative humidity for a given temperature will be higher.
- As air cools its ability to hold moisture decreases, and so the relative humidity increases. Colder homes or colder surfaces (cold / thermal bridges) within warm homes are therefore more at risk of mould growth.
- There are many sources of moisture in homes, including respiration, clothes drying and cooking. These high levels of moisture generation will result in high relative humidity.
- Homes with low air exchange between inside and outside will result in high levels of moisture because the moisture concentration will not be diluted with less moisture laden air from outside. This may be due to very low air infiltration or poor control of ventilation systems (window opening, trickle ventilators, extract fans or whole house mechanical ventilation systems).

The ***vapour pressure excess*** (an indicator of the concentration of moisture in the space relative to outside) can be calculated from the internal and external temperatures and relative humidity, which gives a temperature independent measure of how much extra moisture there is in the internal air compared to external air. This was typically found to be in the range of 200kPa to 500kPa (positive values indicate that the internal air contained more moisture than external air, as expected). Homes which had a very low vapour pressure excess were typically very highly ventilated or mechanically ventilated. Vapour pressure excess was also often observed to drop towards 0kPa when homes were unoccupied for several days. A high vapour pressure excess indicated homes that were either poorly ventilated or had excessive internal moisture generation. Active dehumidification will also influence internal humidity.

4.4.5 Window and door opening

Window and door opening behaviour in homes is complicated and not well understood. Windows may be opened for a variety of reasons including temperature control, to let in fresh air, to allow pets access, etc.

In the context of the **30 Homes**, we were primarily interested in how often the windows were open and whether this opening coincided with the heating being switched on. Ideally the size of opening should have been measured but this was difficult with the current sensors. Window opening measurements were also useful in providing prompts to help interviewers identify specific behaviours – for instance opening windows in bathrooms and kitchens to purge water vapour and unwanted smells.

4.4.6 Electricity consumption

Many UK homes are primarily gas heated (87%), however a significant proportion are fully or partially electrically heated (33%) and many gas heated homes make use of portable electric heaters during cold periods[24]. The sub-hourly electricity consumption that was collected in many of the monitored homes also helped to provide further insights or confirmation of occupant behaviour. For example it was often possible to identify longer periods where the home was vacant, from the electricity consumption data. It was also sometimes possible to identify when electric heating systems were activated, for example some primarily gas heated homes also had electric under-floor heating in some areas.

Electricity consumption data was highlighted for discussion with participants where the total electricity consumption was compared with a UK benchmark value (accounting for home size and occupancy) and average overnight electricity consumption.

4.5 Recommendations

The environmental monitoring was reasonably successful, but inevitably there is scope for improvement.

- Due to the short time scales involved, commissioning of the monitoring system was not as comprehensive as it could have been. In particular having more time to troubleshoot sensors that were not reporting data and perhaps more time spent optimising the positioning of signal boosters might have improved the data quality. We recommend that the design / development process, set out in 2.1 Establishing the Brief, is followed when planning an environmental monitoring project.

- Similarly, the fault that occurred in many of the infra-red sensors (probably down to a fault in the software and bug in the sensors) might have been picked up with more time available to test the systems prior to installation. It may have been possible to source replacement sensors. Unfortunately the number of malfunctioning sensors meant that in many homes reliable occupancy data was compromised.

- Although the temperature and relative humidity sensors were re-calibrated by the project team (the manufacturer's calibration was not relied on), ideally these could have been independently tested in climate chambers or similar and more time allowed for this exercise (the necessary speed of the roll-out programme compromised this recalibration period).

- The way in which the window and infra-red sensors operated meant that it was impossible to reliably detect missed readings. For sensors which might be infrequently triggered and also operated on a potentially unreliable wireless network, this was not ideal.

[24] Percentages based on a sample of 2,182 homes, Consumer Response and Behaviour Quant. Survey, February 2014.

- The accuracy of the temperature sensors was limited to the nearest degree, due to the manufacturer's firmware on the sensors. While this was accurate enough to extract a lot of useful information, higher accuracy (perhaps to a quarter degree or less) would have been desirable (typically the multi-sensors were not used for the kind of monitoring we undertook).

- Most of the data collected provided valuable insight into how the homes operated. Two items of data which were not heavily utilised were CO_2 readings and luminance. The CO_2 monitors were problematic as they seemed to cause concern for occupants (who confused the poisonous gas carbon monoxide with the common gas carbon dioxide) and there were concerns from the research team about the accuracy of the data being recorded. These monitors were therefore removed in some homes. The luminance data potentially could have been useful, however it proved difficult to extract meaningful information from the raw data, due to a difficulty in identifying specific conditions (e.g. did the reading suggest natural light versus artificial light, was light leaking from different rooms or outside, etc.) and given the time constraints of the project this was not pursued.

- Direct observation of the heating systems (through temperature loggers attached to heat emitters) significantly improved the usefulness of the data. It is highly recommended that this system is included in future monitoring studies. Even more detailed monitoring of the heating system would be beneficial, for example monitoring thermostat and timer on / off signals, however this would require a more invasive installation process.

- The power clamp information, while not directly monitoring heat related behaviour, was very useful in confirming behaviours in the home; however the clamps that were located outside the building fabric reported less consistently than those within the building fabric. It is recommended that power clamps are included in future studies.

5 Practicalities

This chapter moves into the logistics of managing an environmental monitoring project, discusses the data protection and health and safety protocols that need to be set up, and outlines the practical considerations to be considered well before the installation of any monitoring kit in residential properties. We provide an overview of the data protection and health and safety documents we developed for the **30 Homes** project and make suggestions, following a bench-marking exercise with industry partners, of how health and safety could be brought even further into the hearts and minds of the project delivery team.

This section also addresses some of the practical and technical processes in terms of installing, maintaining and decommissioning monitoring equipment safely.

Finally, it considers the process of commissioning and installing monitoring equipment by third parties, the importance of keeping the supply-chain tight, the challenge of finding the right installers and due diligence considerations in terms of their appointments.

5.1 Data Protection

One of the major challenges when carrying out environmental monitoring in homes is to ensure that participants' data is protected at all times.

5.1.1 Data Protection Protocol

One of the main Data Protection considerations was the management of the information flow between Consortium partners. On the basis that the more people involved the greater the risk of a data breach became, there was a conscious effort to keep the information flow between individuals and companies to the minimum. It was recognised that physical monitoring presented a more complicated data protection consideration than social research alone due to the need for both researchers and installers to visit participants' homes, in addition there was the requirement for the live transmission of monitoring data on top of the usual consumer research interview information.

On the 30 Homes project, the lead researcher NatCen, who is ISO27001[25]compliant and registered under the Data Protection Act (DPA) 1998, led the Consortium to ensure that the project complied with industry best practice procedures in terms of data security and trusted management of participants' data and a specific Consortium Data Protection Protocol was developed in accordance with the principles set out in the DPA (to be found in the Supporting Information). This Policy was reviewed regularly and updated as necessary, all staff involved in environmental monitoring undertook in-house training.

In terms of data management, only PRP and NatCen (on the 30 Homes project) knew the names and addresses of the participants and these details were kept within password-protected folders accessible only to a few named staff. Information containing personal information was transferred between the two companies via a secure File Transfer Protocol (FTP) site. Each household was referred to in all correspondence and reporting by a unique reference code (e.g. Y27) and never by the name of the participant. The environmental equipment (Hub and paired sensors) were also given unique codes ensuring the secure but anonymous referencing of data transfer from Hub via Cloud to TTP.

Figure 15 shows the Data Protection flowchart drawn up at the start of the 30 Homes project to demonstrate how members of the Consortium would keep the flow of monitoring data between partners to the minimum and would keep it separate from the personal data of the participants .

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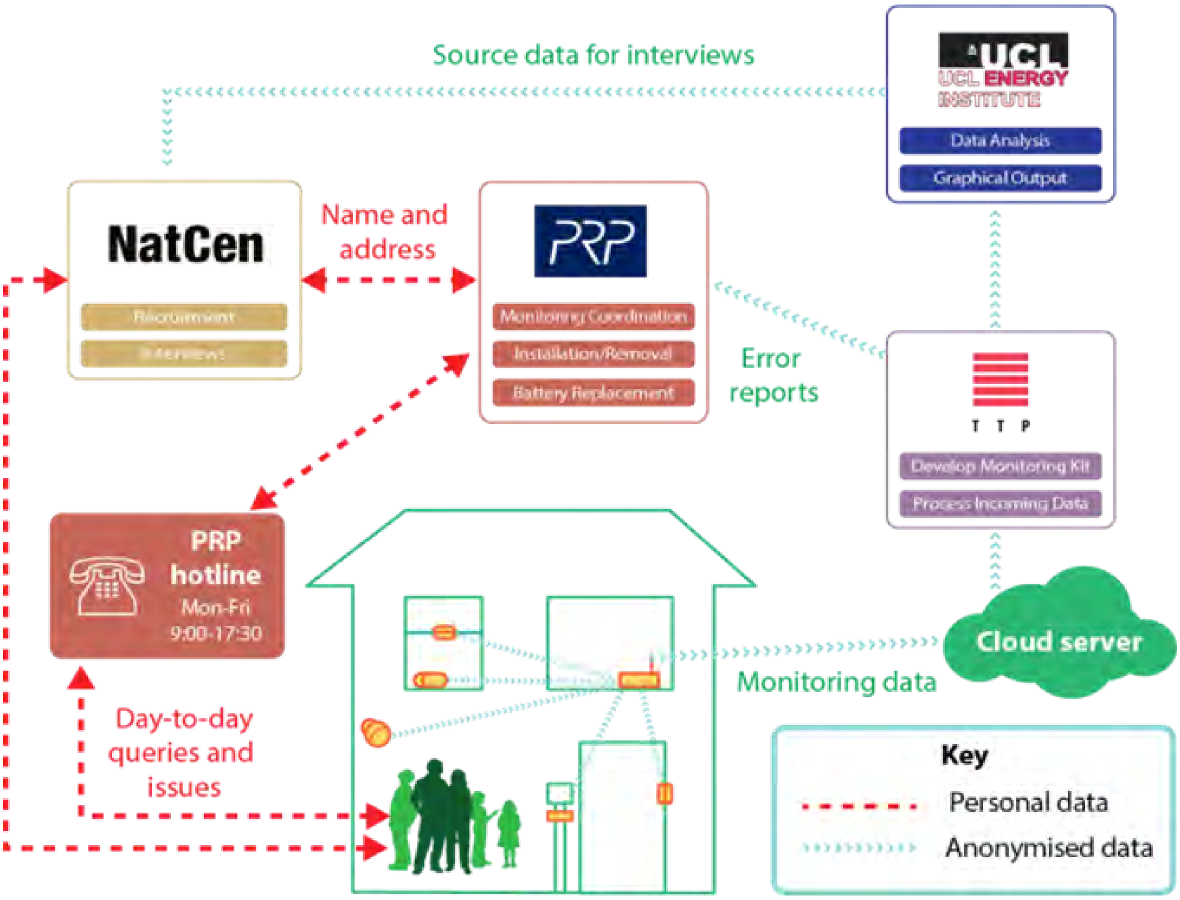
[25] **ISO/IEC 27001:2005**, part of the growing ISO/IEC 27000 family of standards, is an information security management system (ISMS) standard published in October 2005 by the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC). Its full name is *ISO/IEC 27001:2005 – Information technology – Security techniques – Information security management systems – Requirements*

Figure 15: EEC Data Protection structure



An overview of the Consortium's approach to Data Protection is set out below:

- **Getting consent** – permission from participants to hold and use their personal data was sought by NatCen, at either the recruitment or research activity stage, and by PRP at the point of installation of data monitoring equipment.
- **Specifying the purpose** – information leaflets specifying what their personal data would be used for and by whom were given to participants at the recruitment stage by NatCen and again at the installation stage by PRP.
- **Collecting only what is needed** – only personal data which was necessary for the purposes of the project in terms of meeting the research goals for this project was to be collected by the Consortium.
- **Ensuring accuracy** – personal data that was collected was as far as possible accurate and, where appropriate, kept up to date.
- **Keeping data** – personal data was to be retained only for the length of the research project and then deleted. However, at the end of the project consent was given by all participants to retain their personal details for further contact should ETI wish to revisit or open up news areas of research. In retrospect a fixed timescale should have been given to participants (12 months?) with a commitment to delete their personal data at this point.

- ETI - received copies of **anonymised data** only. This commitment caused problems on the **30 Homes** project when ETI wished to attend workshops or visit homes with the researchers and further written consent from participants was required. The wording of the data protection clauses on the **HEMS** project was reworded to include ETI as part of the research team to allow them to attend participant interviews.

- **Secure storage of data** – personal data was kept in electronic form on NatCen and / or PRP secure systems and would only be accessed by those necessary to complete the specified purpose.

- Keeping personal data within the UK – personal data would not be transferred to third parties outside of the UK where different data protection laws may apply.

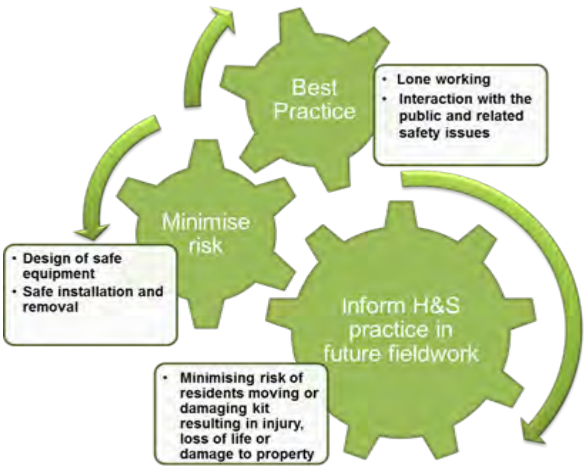
As the relationships developed between the project team there was a greater need to ensure that data protection of participants did not slip. Where appointments were made with participants by email or where joint interviews (technical / social research) were being discussed between members of the research team by email the risk of personal data being available on the Web was significant. This was mitigated by the secure filing and / or deletion of emails immediately, and by NatCen staff taking on a 'policing role' with colleagues whenever data protection breaches occurred.

5.2 Health and Safety

5.2.1 Health and Safety considerations

Health and Safety is high on the agenda for all ETI projects and from the start we aimed at achieving health and safety best practice on this project. This was important as there were a number of areas where the safety of researchers, installers, participants and members of the public could be compromised. A single health and safety incident could jeopardise both the future of this project and the reputation of ETI. Our aim was three-fold: to minimise risk in every aspect of the project; to achieve the highest of health and safety standards and to inform health and safety practice in future fieldwork. Figure 16 illustrates the interdependence of these aims:

Figure 16: Consortium's Health and Safety three-fold aims.



The bullet points below set out the four health and safety priority consideration areas for WA5 identified by the Consortium in an initial Risk Workshop:

- **Interaction with the members of the public** during consumer research activities; lone working and the unknown factors of going into unfamiliar neighbourhoods, residential properties and working with residents from a range of socio-democratic groups including older and infirm residents, families with children, residents with eccentric behaviours such as hording, and pet-owners.

- The process of **installing, managing and decommissioning monitoring equipment** within the participants' homes and the potential of causing damage to property.
- **The integrity and safety of the equipment** once installed and the likelihood that it could cause damage to person or property.
- **Behavioural risks associated with residents** moving or damaging monitoring equipment with the associated hazard of an incident resulting in injury / loss of life and / or damage to property.

5.2.2 Health and Safety Protocols

A number of protocols and procedures were developed at the start of the project and these are to be found in the Supporting Information to this report. These documents were kept 'live' and were regularly reviewed and updated throughout the course of the project. An Issue Log and Version Control table incorporated into the front of the documents ensured quick access to the latest version of documents and provided an immediate overview of changes that had been made.

The key documents developed were:

- **Health & Safety Plan** – contains the core project specific arrangements for managing health and safety on this project providing clear, concise and specific information. It describes the project's activities, refers to the relevant legislation and defines roles and responsibilities of consortium partners and individuals.
- **Incident Protocol** – sets out the procedures to manage and respond to incidents involving members of the public or the research team in the course of the field work, for example: workshops with members of the public; lone working; installing and leaving in place monitoring equipment in domestic homes. An Incident Response Team (IRT) was identified and contact details for members of the team included in the document. The Protocol was supported by an Incident Report Form to be completed by any member of the team if an Incident was experienced. Training was given to the entire Consortium at the start of the project and update training including Incident Rehearsals provided before all key events involving the public – workshops and field work visits. There were no major incidents recorded on this project.
- **Hazard Risk Register** – focusses on the design, development and management of the environmental equipment to be installed in participants' homes. The Hazards Risk Register is supported by a Log of sub-contractor Risk Assessments and Method Statements (RAMS) - these were reviewed and held by the Consortium's Health and Safety consultants.
- **Working Safely – Installer's Guide** – offers best practice guidance to installers visiting participants' homes. As with any role that involves being out and about in public places, making contact with members of the public and entering their homes, installers face a slightly increased risk of exposure to difficult or threatening situations. The guide aims to minimise these risks wherever possible by considering a number of situations which could potentially impact on either their safety and well-being or the safety of the people they come in contact with and offers guidance on how to prepare for home visits to carry out assignments as safely and confidently as possible.
- **Monitoring Equipment – Installers Guidebook** – provides a specific guide for this project, including check-lists of equipment required and protocols and procedures for specific tests, such as electrical safety and asbestos checks, to be carried out prior to installation. It also contains guidance on the functioning and instruction on the installation of specific pieces of kit, battery changing and decommissioning.

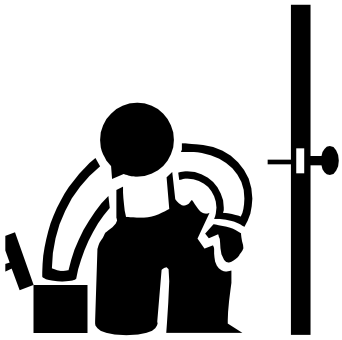
5.3 Bench-marking Health and Safety

An exercise was carried out in June 2014 to bench-mark the WA5 H&S documents, processes and procedures re the safe installation and removal of environmental monitoring equipment in residential homes with those of comparative health and safety practices of industry players involved in similar practices.

A number of industry players were contacted with a view to sharing good practice, however their reluctance to formally share documents, for competitive and copyright reasons, soon became apparent. Nevertheless we were handed some relevant documents from three national industry players - a property maintenance contractor; a telecoms services provider and installer, and a security services company, with the agreement that we would treat the documents confidentially and not reveal their source. We have therefore preserved their anonymity in this report.


Property Maintenance


Telecoms Provider


Security Services

The documents received ranged from a comprehensive health and safety manual to specific risk assessment flow-charts, process flow-charts, check-lists and last minute briefing power-point presentation for staff about to carry out works in residential properties. A full H&S Bench-marking report is to be found in the Supporting Information where we have listed the documents received from the three companies and reviewed each of these firstly under ***Contents*** and secondly under ***Assessment and applicability***.

We concluded that while the WA5 H&S documents provide a comprehensive set of core protocols and procedures which served their purpose, the bench-marking exercise demonstrated that there is the place for a further layer of documentation which would help keep health and safety at the front of minds of everyone involved in the project; this further layer would include bringing in flow-charts to record work processes and risk assessments, using additional check-lists to cover different aspects of key work stages, and using power-point presentations to provide last minute or top-up briefings. In addition we would explore further ways of keeping essential H&S documents up to date and part of the Installer's immediate tool-kit.

To summarise, the four suggestions below suggest areas where our current approach to H&S could be improved:

- **Risk Assessments and Method Statements (RAMS)** - use of flow-charts at different stages of the project - briefing, design, installation, decommission - to identify risks, procedures and protocols that need to be developed and the roles and responsibilities of different named players.

- **H&S Installer manual** - to be reproduced in an easy-to-use indestructible format, one that can be taken out on jobs and forms part of the essential tool-kit. Format to be A4/A5 or similar, laminated pages and ring bound so that it can be opened flat. Good use of graphics to ensure that text is kept to a minimum, and installation instructions and H&S messages can be easily and clearly understood.

- **H&S power-point presentation** - prepare power-point presentation using shock tactics, memorable phrases and acronyms to get over last minute H&S messages for those about to work on site.

- **Installer appointment sheets** - include key H&S messages in simple clear format using symbols and acronyms, alongside other information (e.g. client contact details, works to be done, etc.) to highlight specific H&S risks.

5.3.1 Recommendations - taking H&S one stage further

The addition of these four suggestions would no doubt reinforce the team's awareness of health and safety and help to convey key health and safety messages, however we set out below a further suggestion - the development of a Health and Safety App for portable equipment, i.e. iPhone, iPad, electronic notebook or laptop.

A H&S App could be used to support the day-to-day work of the installers in the field, as well as their managers and administration team to provide information and advice at their fingertips. Longer-term as the App was developed and confidence with the technology proved, it would support the move to paperless working systems.

The fundamentals of the App would include:

- **Health and Safety documents, flow-charts and check-lists** accessed by the App on your iPhone, iPad, electronic notebook or laptop. App users would receive trigger alerts and emails when policy or protocol changes or updates were made. To arrest the trigger alerts and to ensure readership alerts would need to be opened, read and responded to by completion of a mini feedback 'test' which would be automatically sent through to the change-instigator or manager-in-charge.

- **Installation / Decommission appointment details** would be managed through the App to include the appointment, household information and works details. Key words would be used to trigger specific H&S protocols, check-lists and procedures. Following completion of works a feedback form would need to be filled in by the Installer on the App which would be issued directly and remotely to the manager-in-charge who would sign it off and/or take further action as necessary.

- **Incident Protocols** would also be handled through the App. The Incident Report Form would be completed via the App. The relevant procedure for dealing with the Incident (according to its level of importance) would be flagged up immediately, with a built-in flow-chart of required actions. Contact details for the Incident Response Team would be stored on the App.

- Members of the **Incident Response Team (IRT)** would receive immediate notice of an Incident on their iPhone, iPad, electronic notebook or laptop. The notice would provide the IRT member the necessary questions as prompts for their further investigation and details of any subsequent actions required.

The advantage of this App would be that the relevant procedures, protocols, contact details would always be accessible and at hand, there would be no danger of protocols being missed by installers in the field; changes and up-dates to H&S protocols could be managed efficiently.

5.4 Installing Safely

5.4.1 Installation Pilots

On both the **30 Homes** and **HEMS** projects, pilot installations were carried out to test the efficiency of the equipment, the protocols identified in the health and safety guides, and also the confidence and of the installers in following equipment installation protocols in an actual residential property. These pilot installations were observed by senior representatives of the team, the Consortium's Health and Safety consultant and in some cases (**HEMS** pilot installations) ETI staff.

The pilots proved invaluable in many ways and tested method statements and installation processes. They also identified the most suitable locations within the home for equipment to be placed, the best fixing methods, and the length of time a typical installation took. Once installed, equipment was tested for functionality and, data validity. The pilots were also used to gauge the competency of the installer in terms of both technical and social skills and finally the participants' acceptability of the equipment that had been installed.

Risk workshops and training were carried for all involved prior to the pilot and all attendees debriefed afterwards with the installer training packs, method statements and health and safety protocols amended / updated accordingly.

5.4.2 Initial sign-up visits

Initial visits to participant homes were undertaken by the social research team to confirm both participant commitment to the research project and the suitability and safety of the home. The social researchers talked through the details of the trial and showed participants the equipment before participation agreements were signed. Researchers also prepared preliminary layout sketches indication the numbers and position of rooms, windows and external doors which helped the technical team with the development of the specification for the monitoring equipment.

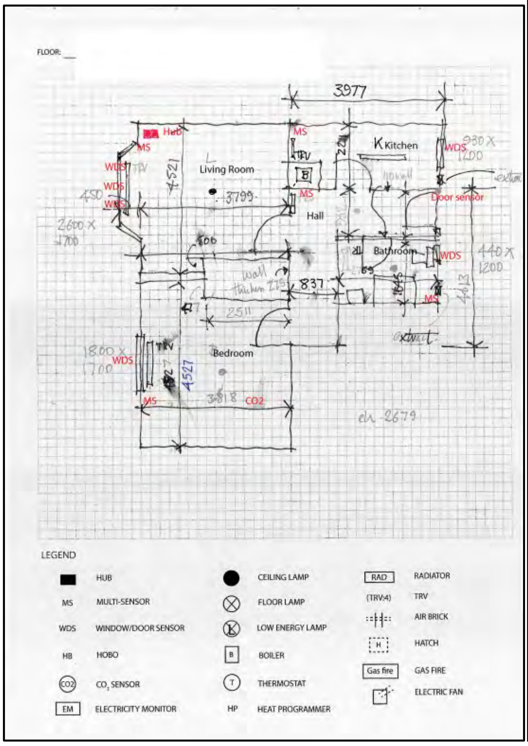
At this stage a couple of participants were withdrawn from the trial - one failed to keep several appointments for this initial visit, and the other's property was considered unsafe due to a huge amount of 'hoarding'. A third home was considered 'risky' due to some strange mannerisms of the participant and also an unsafe bathroom (no floor), however the social researchers were keen not to lose this participant and the risks were mitigated by ensuring no further lone visits to this property by installers and sensors not being placed in the bathroom.

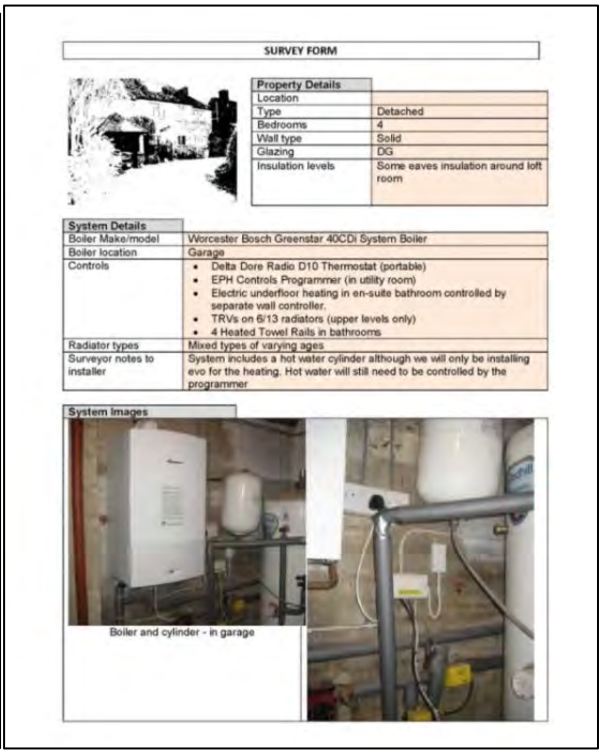
5.4.3 Surveys

Once participants were signed up, the technical team arranged second visits to survey the homes and install the monitoring equipment. Typology, build period, size and structure were confirmed, electrical systems tested (polarity and socket wiring checks) with Tester Plugs with a view to rejecting properties that identified faults (none were rejected) and asbestos checks carried out. The technical team had been trained in asbestos awareness with a view to rejecting properties with asbestos in locations where equipment might be installed, in these cases participants would be handed a Consumer Asbestos Guide and urged to get a full inspection (none were rejected for asbestos).

Once these preliminary tests had been carried out accurate layout sketches were prepared as shown in Figure 17, detailing room measurements, location of internal and external doors and windows. Heating systems including boiler model, make and capacity, controls and thermostats, radiators and TRV's, type and number were photographed and their location recorded on the drawings.

Figure 17: Left, PRP Floor Plans showing location of monitoring equipment; Right, PRP survey capturing typology and record of heating systems[26]





SURVEY FORM

Property Details	
Location	
Type	Detached
Bedrooms	4
Wall type	Solid
Glazing	DG
Insulation levels	Some eaves insulation around loft room

System Details	
Boiler Make/model	Worcester Bosch Greenstar 40CDi System Boiler
Boiler location	Garage
Controls	• Delta Dore Radio D10 Thermostat (portable) • EPH Controls Programmer (in utility room) • Electric underfloor heating in en-suite bathroom controlled by separate wall controller. • TRVs on 6/13 radiators (upper levels only) • 4 Heated Towel Rails in bathrooms
Radiator types	Mixed types of varying ages
Surveyor notes to installer	System includes a hot water cylinder although we will only be installing evo for the heating. Hot water will still need to be controlled by the programmer

System Images

Boiler and cylinder - in garage

5.4.4 Managing Technical visits

The technical visits included the surveys, installation of the monitoring equipment, battery changes and finally decommission. The bullet points below provide an overview of the key considerations when planning and managing these visits:

- **Training** - prior to the initial installation visits, the technical team were given copies of the Installer's Guide and Handbook and these were followed up with safety training and technical briefings and installation rehearsals in terms of using the 3M products.

- **Security** - all installers wore customised t-shirts / sweat-shirts and wore name badges with their photos. (Appointment letters to participants had also included the name and photos of the staff were visiting).

- **Dispute avoidance** - photographs were taken before and after equipment was fixed in place to record the state of surrounding surfaces etc. to avoid potential disputes with participants.

- **Record-keeping and check-lists** - co-ordination of the technical visits and keeping up-to-date records of the location and reference numbers of sensors, when batteries were last changed, meter readings and ensuring paired sensors were kept in the right place proved to be complicated. To ensure accurate record-keeping, technical packs were prepared by the project management team for each home and passed to the technical team before each visit. These packs contained all the information needed for each property and were managed through a series of specific check-lists covering property details, equipment needed and a schedule of tasks. In addition a battery change schedule was developed keeping track of the state of the multiple batteries in the various sensors as well as systematic recording of meter readings etc. Examples of these check-lists are shown in Figure 18 and full copies included in the Supporting Information.

[26] Images form PRP library

Figure 18: Technical Team Checklist and Battery Change schedule

Technical Team Checklist for XX

Information Pack Checklist

- ☐ 1 File Note
- ☐ 2 Location Map
- ☐ 3 Google Image
- ☐ 4 Battery Change Schedule
- ☐ 5 Floor Plans (marked up with Hobo)
- ☐ 6 Floor Plans (clean)
- ☐ 7 Background Information
- ☐ 8 Letter (with address removed)
- ☐ 9 Electrical Safety Guidance
- ☐ 10 Consumer Asbestos Guidance
- ☐ 11 Repeaters Pairing Procedure
- ☐ 12 Blank Copy of Incident Report Form
- ☐ 13 Hub debug guide

To Do

- ☐ Change Batteries for Multi-sensors
- ☐ Change Batteries for Window / Door sensors
- ☐ Change Batteries for Electric Clamp
- ☐ Read Gas / Electricity Meters
- ☐ Install iButtons (after checking with householders)
- ☐ Take photos of iButtons installation (before & after)
- ☐ Hub not reporting – check and debug the hub

Equipment Checklist

- ☐ 1 Lithium AAA Batteries for Replacement – Multi-sensors **x [ ] packs**
- ☐ 2 CR2450 Coin Cells for Replacement – Window / Door Sensors **x [ ] packs**
- ☐ 3 Lithium AA Batteries for Replacement – Electric Clamp **x [ ] packs**
- ☐ 4 iButtons for installation
- ☐ 5 Torx Tx20 security screwdriver
- ☐ 6 Replacement dongle
- ☐ 7 Replacement SD card
- ☐ 8 Electrical socket tester
- ☐ 9 Extension cable
- ☐ 10 Camera
- ☐ 11 3G phone (helpful)
- ☐ 12 FB2 key and gas meter key
- ☐ 13 Torch
- ☐ 14 Masking tape
- ☐ 15 Tape and bag for used / dead batteries
- ☐ 16 Scissors
- ☐ 17 Paperclip
- ☐ 18 Clipboards and pens
- ☐ 19 Photo identity badge and PRP polo shirt
- ☐ 20 Copies of Installer's Handbook and Working Safely
- ☐ 21 Small Phillips Screwdriver
- ☐ 22 3M Command fixing tape / hooks / Velcro for hubs and sensors
- ☐ 23 Camera
- ☐ 24 Alcoholic wipes
- ☐ 25 Two-step ladder
- ☐ 26 First aid kit

ETI Smart Systems and Heat | **Battery Change Schedule**
Consumer Response and Behaviour

Property Reference	N6	Room type			
Type of sensor		Kitchen/Living	Hall	Main Bedroom	Bathroom
Bath	iButton ref (if replaced) Tick if removed				11/02/2014
Dishwasher (if applicable)	accessible for hot water monitoring?				
	Photo?				
Washing Machines (if applicable)	accessible for hot water monitoring?	Coldfeed			

Hot Water Monitoring				
	Boiler Type	Cylinder (Yes, No)	Pipe Access (Yes, No, Maybe)	Make and model
Notes from interview prior to installation	Notes refer to immersion heater in bathroom	Unclear whether photo is boiler or cylinder (Elson – rectangular?)	Maybe	
Notes from visit on 18/9/13	In cupboard outside bathroom		Yes	Water cylinder Elson Maxistone cold pipe insulated

Meter Reading						
		17-Apr-13	18/09/2013	23/10/2013	13/11/2013	15/01/2014
Gas Meter						
Electricity Meter	1	44927	60151	60301	60425	61217.28
Electricity Meter	2	14535	14882	14953	15024	1501.14
Thermostat			Rad controller at 20 degree C	20 degree C		

5.4.5 Installing safely

The installers faced a number of social, health and safety, and technical challenges when making home visits. The bullet point list below provides an overview of these challenges.

- Untidy homes, unsafe areas and hoarders. Equipment became dusty and greasy in some homes. (These could be cleaned at maintenance visits in future, but additional time would need to be allowed.)
- Stressed residents, children, pets - visits were often scheduled for the end of the working day; some participants were infirm; residents needed to get on to other appointments or school schedules; children needed feeding; dogs walking etc.
- Problem solving participant concerns - sensors were thought by some to be cameras, LED flashing lights were thought to signify danger and / or kept people awake, confusion that the CO_2 monitors were CO monitors and the red lights showing hazardous levels of CO.
- Participants switching plugs off, particularly at the start of the project, and usually by members of the household who had not been present at the initial briefing. This was usually resolved through phone calls asking them to switch the plug back on and followed up with reminder stickers - to keep the plug on at the next maintenance visit.
- When the iButtons were installed on water pipes, some participants forgot that they had been installed by the Project Team due to their insignificant size. One participant became concerned that this was something her landlord had put in.
- Moving equipment / moving house - a few participants moved equipment when decorating, or took it all down prior to decommission; one participant moved flats during the study and took all the equipment with her - this was later re-installed in her new flat.)
- Meter reading accuracy (this is harder than it seems and it became apparent that all staff needed substantial training).
- Managing battery changes; recording of battery status; recycling batteries.
- 3M strips and different surfaces – in some homes parts of the equipment fell off (particularly the small light window sensors) due to grease, UPVC, newly decoration, condensation and window opening.

5.5 Recommendations

To summarise this section, the following list of bullet points provides an overview of some of the key practicalities to be addressed when considering an environmental monitoring exercise:

- **Data Protection** - identify a lead researcher to ensure data protection complies with industry best practice and is comprehensively managed across the research team.
- **Health and Safety** - ensure protocols and procedures are kept live and useful by updating them regularly; use Issue Logs and Version Control tables to ensure quick access to the latest version of documents and immediate overview of changes that had been made.
- **Installer Training** - run regular training session, pre-installation and incident management. De-brief installers following installation visits and update the training materials and supporting documents accordingly.
- **Record-keeping and check-lists** - keep good records, provide installers with property packs with check-lists of tasks to be done, property details, equipment installed, and battery changes, etc.

6 Participant Retention

This section discusses the importance of having a strong communications strategy in place for the delivery of participant-focussed research projects. It describes some of the processes adopted by the consortium in recruitment and management of the studies. It refers to examples (to be found in the Supporting Information) of recruitment letters, information packs and contracts. It considers the challenges of managing multiple visits and the value of incentives.

6.1 Managing good relationships

Managing good relationships with participants is essential to maintain their interest and involvement throughout the length of the project. Although incentives (cash or vouchers) is an acceptable and necessary prerequisite to participant involvement, equally important is the value participants feel they have gained from the project, in terms of environmental 'lessons learnt', and also less tangibly the social value or 'worth' participants feel at the end of the project - *yes, my time spent has been worth it*. The unsolicited email (see below) from one of the participants on the **30 Homes** year-long trial received at the end of the project sums this up well.

> *Just a quick email to extend my gratitude to you and your whole team and to let you know how much I enjoyed working with all the lovely helpful people that I came into contact with throughout the year.*
>
> *Please send my regards especially to Andrew Mellor and Jerome whom I learnt so much from.*
>
> *It was a pleasure to invite you into a year of my life and I hope the research produced helpful information for everyone involved. Please do not hesitate to contact me in the future and I wish you all success.*

This positive feedback was the result of the trust the participant had developed with the research team. She had invested her time, had opened up her home, and shared details of her family life with us. Most importantly, she did not feel we had betrayed this trust. We set out below how we went about developing and maintaining such trust.

6.1.1 Written communication

From the start of the recruitment process to the end of the project all written information was consistent - spelling out clear messages, concisely and simply: this is what we want to do; this why we want to do it; this is how long we want to do it for; this is why your involvement is important; this is what we are going to do with the research material; this is who you should contact for further information etc. The design of all correspondence was visually appealing and clear from first glance what the literature was about. Examples are shown in Figure 19 and actual samples are included in the Supporting Information.

6.1.2 One-to-one communication

Inevitably much of the initial recruitment and follow-up work (appointments, clarifications, advice, etc.) was done face to face, by phone or by email. It was therefore vital that all those who were likely to come into contact with participants were fully briefed about the aims of the project, the details of the monitoring exercise and the requirements for the participants taking part. All contact with participants needed to be imparted in a knowledgeable and friendly manner. Getting the 'register' right was also important - we started off on a semi-formal basis and took guidance from the participant of how much this semi-formality could be relaxed. The rule-of-thumb was to treat participants how we would like to be treated.

We maintained a small core team of those in contact with the participants. Where possible, appointments were made by the same person, battery change visits by the same installers and interviews carried out by the same researcher. This built up a 'team-effort' - project team members and the participants they were in contact with all belonged to the same small club - and wanted the project to succeed.

At the end of both the **30 Homes** and **HEMS** projects we received positive feedback from 100% of the participants. On the **30 Homes** many regretted the end of the project having enjoyed the relationships formed over the year with the core team. All participants were open to being re-contacted and taking part in further research.

Figure 19: Example of Information given to residents (Recruitment Leaflet)

6.1.3 Appointments

The **30 Homes** project entailed 11 visits per home over the course of the year's study - initial surveys, equipment installation, data download and battery changes, interviews and finally decommission. With the participants' homes spread across the four geographical focus areas: Yorkshire, Norfolk, Manchester and Greater London and the research team based in London, the organisation of 330 visits took considerable organisation and administrative time. The importance of allocating sufficient resources to this element of the study should not be underestimated. Good systems were needed to track appointments (and participant preferences for times of visits, etc remembered.). The efficient sequencing of visits around the country was important in terms of resource management. A larger project would benefit from the purchase and use of specific software to assist with the management of route-planning and multiple visit-sequencing.

Appointments were all made at the convenience of the participants and included out-of-hours appointments – early mornings and evenings. These were arranged initially by phone and confirmed by letter or by email. Specific times were always agreed, with researchers ringing 30 minutes before the appointment to confirm they were on the way.

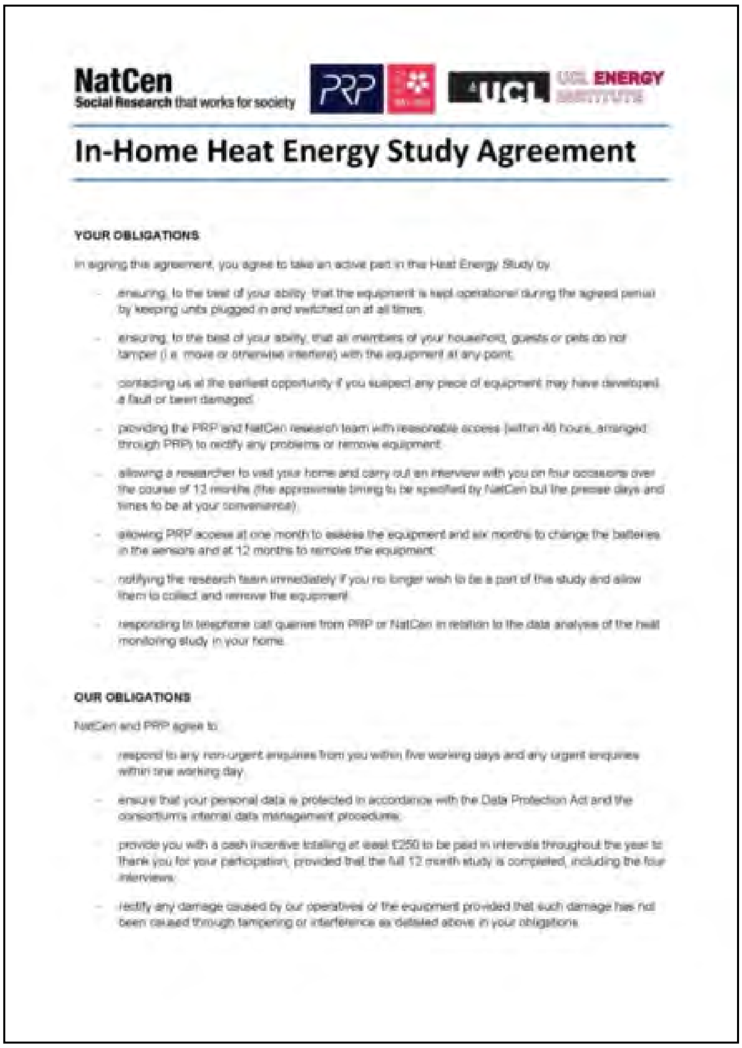
On the **HEMS** project, appointments for the installation of the six OWL systems were made by a centralised administrative team of a large company (who advertised themselves as "UK's leading energy experts"). Participant feedback was not complimentary - they found the service inflexible, remote and unfriendly; appointments offered in 4-hour morning or afternoon slots caused problems for those who were working or dependent on school routines, etc. Although only a small sample, the dissatisfaction of the residents with this service confirmed our view that a hands-on, customer-focussed team was a vital component in appointment-making and in building trust with the participants.

6.1.4 Formal Agreements

Our customer-focussed approach was under-lined by the more formal process of contracts. Participants were required to sign agreements at key stages of the project - to allow the equipment to be installed in their homes; to ensure to the best of their ability that the equipment would not be tampered with; to allow members of the research team into their homes at regular intervals, etc. In turn the obligations of the research team were also spelt out - to respond swiftly to any participant concerns, to ensure participants' personal data is kept safe at all times; to rectify any damage caused by the installers etc.

These clear concise documents using plain English, no jargon and non-legalise vocabulary were issued to participants in advance of visits. Time was spent with each participant at the start of the initial visit to ensure that the Agreement was fully understood before the signing by both parties. Examples of sign-up and decommission agreements are illustrated in Figure 20, with full copies to be found in the Supporting Information.

Figure 20: **30 Homes** In-Home Study Agreement developed by the Consortium (Full size documents in Supporting Information).



In-Home Heat Energy Study Agreement

YOUR OBLIGATIONS

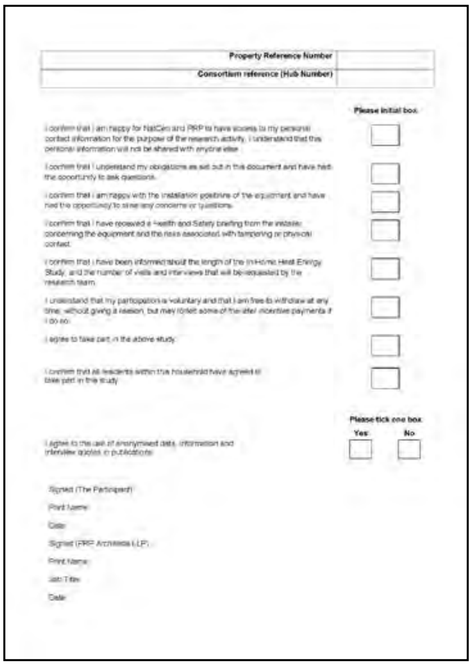
In signing this agreement, you agree to take an active part in the Heat Energy Study by

- ensuring, to the best of your ability, that the equipment is kept operational during the agreed period by keeping units plugged in and switched on at all times
- ensuring, to the best of your ability, that all members of your household, guests or pets do not tamper (i.e. move or otherwise interfere) with the equipment at any point
- contacting us at the earliest opportunity if you suspect any piece of equipment may have developed a fault or been damaged
- providing the PRP and NatCen research team with reasonable access (within 48 hours, arranged through PRP) to rectify any problems or remove equipment
- allowing a researcher to visit your home and carry out an interview with you on four occasions over the course of 12 months (the approximate timing to be specified by NatCen but the precise days and times to be at your convenience)
- allowing PRP access at one month to assess the equipment and six months to change the batteries in the sensors and at 12 months to remove the equipment
- notifying the research team immediately if you no longer wish to be a part of this study and allow them to collect and remove the equipment
- responding to telephone call queries from PRP or NatCen in relation to the data analysis of the heat monitoring study in your home

OUR OBLIGATIONS

NatCen and PRP agree to:

- respond to any non-urgent enquiries from you within five working days and any urgent enquiries within one working day
- ensure that your personal data is protected in accordance with the Data Protection Act and the consortium's internal data management procedures
- provide you with a cash incentive totalling at least £250 to be paid in intervals throughout the year to thank you for your participation, provided that the full 12 month study is completed, including the four interviews
- rectify any damage caused by our operatives or the equipment provided that such damage has not been caused through tampering or interference as detailed above in your obligations



Property Reference Number

Consortium reference (Hub Number)

Please initial box

Please tick one box

Yes No

Signed (The Participant)

Print Name

Date

Signed (PRP Architects LLP)

Print Name

Job Title

Date

6.2 Incentives

As with all research projects (cash) incentives were offered to participants to encourage initial sign-up and retention, and also as a token of thanks for their valuable time. The level of cash incentives varied from £355 for the **30 Homes** - paid out at intervals throughout the year, to £500 for the intensive **HEMS** three-month project paid on completion (participants were required to keep daily Blogs and occasional video diaries in addition to partaking in three 3-hour interviews).

While the incentives were necessary and may participants on the **30 Homes** project looked forward to the next payment, for many the experience of taking part in an environmental monitoring project and the value of the environmental awareness they gained was of equal importance. At the final interview in the **30 Homes** project, participants were verbally given personalised 'Energy Tips', which were followed up in writing. An example is included in the Supporting Information.

6.3 Recommendations

To summarise this section, the following list of bullet points provides an overview of some of the key practicalities to be addressed when considering participant retention:

- **Communication skills -** prioritise the importance of oral and written skills across the research team.
- **Formal agreements** - non-legalise contracts establish parameters and trust.
- **Core team -** maintain a small highly-skilled team who will interface with participants.
- **Appointments** - be flexible, provide specific times (not morning / afternoon slots).
- A larger project would benefit from the purchase and use of **specific software** to assist with the management of route-planning and multiple visit-sequencing

7 Main findings and Scaling up implications

In both projects the data acquired from the environmental monitoring has contributed significantly to the wider research aims. The **30 Homes** project was successful in its aims to provide useful data to support social interviews and gain deeper insights into how people use heat in their homes. The **HEMS** project has also benefited from these lessons and adopted the best practice from the **30 Homes** project to deliver effective results. Some examples of what worked well on the projects include:

- **Participant retention** – one of the most important successes of both projects has been the positive relationships formed with the participants and their retention – all but three participants[27] of a total of 42 participants remained part of the research for the full period, in addition the 39 remaining participants agreed to be contacted for potential further research involvement with the team should this be required by ETI. This can be attributed to:
    - **Open and effective communication** – a strong emphasis placed on both written and oral communication. All front-line staff received specific training for the project, were well-supported throughout its life ensuring a professional and personable team.
    - **Clear agreements** – clear and fair monitoring agreements between participants and the consortium partners conveyed a sense of professionalism.
    - **Small teams assigned to each participant** – A strong rapport with participants proved key to their long-term engagement in the project. Typically each participant engaged with no more than 3-5 members of the research team, each with a clear, dedicated role[28].
    - **Customer care and remuneration** – a customer-first mentality; participants were respected for their tolerance in allowing the research team's frequent access to their homes, reinforced through frequent expressions of gratitude and fair remuneration for changes – e.g. increasing the incentive payments for additional visits. Home visits always took place at the convenience of participants, with specific timed appointments including early mornings and evenings.
    - **Recruitment through other activities** – participants for the **30 Homes** project were recruited from qualitative workshops taking place in the wider Consumer Response and Behaviour project – the research team was well-placed to "pitch" the monitoring project to an engaged audience and allow participants to see the equipment and make an informed decision whether to take part in the project or not[29].
- **Logistics** – although a relatively small sample, the administrative challenge of organising a rolling set of multiple visits across the country including maintaining accurate records of installations, maintenance visits and interviews was significant. However, implementation of effective procedures, forms and records by a dedicated project management team guaranteed smooth running of the project.

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[27] The reasons for the loss of these participants were, respectively: a) unresolvable technical difficulties with the monitoring system; b) participant moving house and being unavailable for visits; c) arising concerns that their landlord may object to the installed equipment. In no case was the reason for attrition related to dissatisfaction or frustrations with the study.
[28] Such as social researcher, technical expert, surveyor/installer, project manager, appointment manager.
[29] From 153 workshop attendees, 78 expressed interest in taking part in the longitudinal study, from these the final 30 were selected to meet specific project participant criteria including technical requirements (e.g. mobile phone signal strength). A number of attendees who were given follow-up calls opted out, often due to family concerns about taking part. Interestingly, in London, despite a very high uptake at the workshop, many people decided to opt out when they were re-contacted. There may be some area level factors that could affect uptake.

- **Health and safety best practice** – robust health and safety procedures, installation guidance, well-rehearsed incident protocol, training of staff and provision of safety documentation for participants, ensured that the team was always equipped to work safely and participants were never at risk. All procedures and documentation were approved by the Consortium and ETI's Health and Safety consultants.

- **Data protection** – a detailed data protection protocol for the wider project informed the design of a robust system for maintaining anonymity of participants for any purpose other than direct contact, ensuring secure management of personal data further built trust between the participants and the project team.

- **Engagement with suppliers and manufacturers** – effective engagement with the manufacturers and suppliers of equipment which ensured that stock levels and lead-in times were never an issue and problems that arose were quickly solved.

- **Forensic analysis** – integrated data analysis / interview preparation meetings (researcher, analyst, surveyor, etc.) synthesising data insights with social and technical insights. This synthesis proved invaluable to the preparation of interviews providing the social researcher with technical awareness and understanding.

- **Data analysis** – building an understanding of the conditions and behaviour within the monitored homes; and identifying whether occupants were correctly reporting their energy use behaviours. In addition data from all the homes (although the samples were small) was aggregated and cross-compared helping to provide hints of patterns across the stock. The conditions and behaviour within a particular monitored home also fed into the modelling work[30] and were used both to derive model inputs (for example heating operating hours) and as a check that the model outputs bore some resemblance to realities that may be explored in future larger scale monitoring efforts.

7.1 Challenges and practicalities

There are a number of challenges and practicalities to be considered in the preparation and for the successful implementation of an environmental monitoring project in domestic properties, while these are considered in detail in the main report, some of the key areas are set out below.

- **Ensuring adequate lead-in time** – by far the greatest challenge on the **30 Homes** project was the urgency placed on the team at the start of the project to get the monitoring system into the field before the start of the imminent heating season. The project started with a long list of items to be monitored rather than first clearly establishing the research aims and then deciding on the most appropriate form of monitoring to give the required results. While defining the research questions and designing the equipment is an iterative process, the larger and more complicated the project, the greater the need for generous mobilisation time to fully develop the monitoring solution, test, resolve problems and finally launch of the system. The **HEMS** project, though also with a short lead-in time, benefited from a tighter brief and a clearer understanding of what monitoring was required, making the lead-in, in this case, adequate to deploy an effective solution.

- **Defining the Research Aims** – the core questions that are to be answered by monitoring which will determine whether monitoring is an appropriate solution and what things need to be monitored. On both the **30 Homes** and **HEMS** projects, the aim was to engage people in reflecting critically on behaviours that are highly habituated, and embedded in daily routines, and therefore are not in the front of mind. While the social research aimed to explore the full extent to which different behaviours could be observed, the monitoring data provided an empirical basis of actual behaviour against which an individual's reported behaviour and needs could be discussed.

[30] The *Modelling Insights* report is one of the key Deliverables for the Consumer Response and Behaviour Project

- **Establishing the Monitoring Brief** – once the research aims have been identified, the variables that need to be measured can be identified. These can include physical variables such as ambient temperature or behavioural variables such as frequency of opening windows. These variables should also then be prioritised to aid later steps in the planning process. Failing to fully establish a robust brief can lead to misspecification of equipment, sub-optimal deployment parameters, less useful data output and consequent costs to the project.

- **IP -** IP issues can be complicated, particularly when the design of new equipment and open-source platforms are concerned, again generous lead-in time to resolve these is essential. In the **30 Homes** project we used off the shelf equipment so no technical development work was required and therefore no risk of 3rd party claims. We stayed away from utilising open-source software because any development work in this area would incur arising IP and would not be solely available to ETI.

- **What could not be monitored** – ETI has asked the team to monitor real time gas and hot water consumption, however, the installation of optical readers for the gas meter and in-line flow meters for gas and hot water use were not possible for a number of reasons. These include disruption to participants and cost. Additionally in the case of gas, permission is required from the utility company. Instead we took regular energy meter readings and installed iButtons® on hot water pipework (where it was accessible) to record pipework temperature, to enable us to determine periods of hot water use. More readily market available and usable gas and hot water use monitoring equipment is needed.

- **Remote or in-situ data downloads** – the **30 Homes** system was required to support four interviews over the period of a year and, in order to minimise disruption to participants and to make efficient use of project team resource, the specification demanded remote retrieval of data, thus eliminating the need for multiple visits to the property. However, in practice, we found that some of the deployed systems were unable to maintain a stable remote connection and additional visits became inevitable (the reasons for these are detailed in the full report). Another reason for the remote access was that monitored homes were spread across different parts of the country. This made the logistics of organising multiple visits challenging (this is true also for the WA6 trial). The **HEMS** three-month trial relied purely on local data storage and data was downloaded upon collection of the monitoring equipment. In this case, the monitoring solution was able to be installed at the beginning, log data for a single, uninterrupted period, and be removed to be downloaded and analysed ahead of final interviews. This resulted in 100% data capture and was both simple and effective to implement.

- **Health and Safety** – a single incident could jeopardise both the future of the project and the reputation of ETI, therefore monitoring equipment was developed within a highly risk-aware context. While understandable this placed restrictions on the specification of equipment. For example, the requirement for hot water monitoring was reduced to hot water temperature monitoring. The former would have required intrusive works (cutting through pipes) to install internal flow-meters, while the latter required fixing iButtons® with tape to hot water pipes below the taps, the health and safety considerations in this case restricted the capacity of the project, but ensured minimum risk.

- **Participant acceptability** – due to a wide range of data measurement requirements for the **30 Homes** project and the large number of sensors required, a strain was placed on finding equipment that would be acceptable to participants. Considerations included safety, size, appearance and time required to install. Other challenges to participant acceptance included avoidance of mains-powered equipment (taking up plug sockets and using their electricity) and fixing methods (to avoid damage to surfaces). These considerations steered the team to battery-powered sensors that collected multiple data variables and could be installed by using easily removable adhesives.

- **Managing additional visits** – 7 visits were initially planned for each household: initial survey / installation, battery change at month 6, decommission and 4 interviews. By the end of the project this had risen to 11 visits, due to two additional battery changes and the installation of HOBOs® (on radiators) and iButtons® (on hot water pipes) at a later stage in the project and downloading the data from these prior to the interviews. The introduction of supplementary equipment half way through the project and extra visits required sensitive management to ensure participant acceptability, although 2 of 30 participants politely refuse these additional sensors as they were an addition to the original contract.

- **Appointments / logistics** – the logistics of appointment-making and managing the schedules of the surveyors / installers should not be underestimated. The wider the geographic area and the more scattered the properties, the more complicated this becomes. On the **30 Homes** project, as there are considerable driving distances to York, Norfolk and Manchester, careful coordination was required to minimise the installers' travel time while fitting in with the participants' preferences for visits. The visits to each area usually required 2-3 days therefore hire car and hotel arrangement were also required. On the **HEMS** project while all the properties were in London, these were spread across the capital. On average no more than two visits a day were possible across the 42 homes involved.

- **Data Management** – for the **30 Homes** project, the number of sensors and variables deployed in each case generated a large amount of data, often in different formats which proved a challenge to process. At the outset of the project, it was not fully understood which data would be the most useful for drawing out key insights that could be built into the social research approach. This was exacerbated by multiple organisations responsible for different aspects of the project (the development, installation, analysis and social interviews were each carried out by a different organisation). This challenge was overcome during the course of the project and a strong approach to sharing analysed data insights with the social research team was developed – specifically round-table data briefings and a series of standardised graphs and analysis templates were produced. For the **HEMS** project, only two organisations were involved in the process. As such, the management and sharing of data was much more straightforward and, by utilising the learning from the **30 Homes** project, the most useful data summaries were rapidly identified and produced.

7.2 What we would do differently

- Allow a sufficient mobilisation period.
- Define the research aims and ensure the Brief is fully developed prior to product specification.
- Resolve IP issues at the start of the project.
- Keep the monitoring system simple, where possible use off-the-shelf products – e.g. local loggers.
- Collect only data that is necessary for the research.

7.3 Considerations for scaling up

- Management of greater numbers of participants – keep to small dedicated teams with centralised management structure. Registered Social Landlords (RSLs) adopt innovate approaches to 'patch' management of large numbers of properties in specific areas with dedicated teams of surveyors, housing officers, etc.
- Keep the monitoring system as simple as possible and aim to create automated processes for data retrieval / download.
- Cluster properties wherever possible to keep administration of appointments simple. Consider the use of specific software to assist with the management of route-planning and multiple visit-sequencing for managing large number of properties.
- Maintain clear, consistent and open communication with participants – put them first.

- Create and utilise robust H&S and Incident protocols.
- Where environmental monitoring is used to support social research, integrate the skills e.g. technical, social, data analytics.
- The use of 3G connectivity in the context of environmental monitoring needs further research

8 Supporting Information

These include documents relating to various stages of the environmental monitoring process:

1. Research Questions	A. 8 Research Questions agreed for the Consumer Response & Behaviour Project as a whole
	B. Monitoring Questions and Answer for the 30 Homes project
	C. Research Questions for the HEMS project
2. Key Health & Safety Documents	A. Health & Safety Plan
	B. Hazard Risk Record
3. Data Protection	A. Data Protection Protocol
4. Incident Protocol	A. Incident Protocol
	B. Reported Incidents
5. Monitoring Equipment Specification	A. Environmental equipment specification flowchart
	B. Radiator Monitoring Installation Decision Tree
	C. Monitoring Specification
	D. TTP's Final Report on the Monitoring Equipment for ETI's SSH Programme
6. Health & Safety Guidance Documents to Installers / Workshop Leaders	A. Monitoring Equipment – Installer's Handbook
	B. Working Safely – Installer's Guide
	C. Working Safely – Consumer Workshop

7. 30 Homes – Agreement with Residents	A. In-Home Heat Energy Study : Consent to be contacted
	B. In-Home Heat Energy Study Agreement
	C. In-Home Heat Energy Study – Exit Agreement
8. 30 Homes – Information Issued to Residents	A. In-Home Heat Energy Study Info Sheet
	B. Sample Letter re: Installation Appointment
	C. Monitoring Equipment Safety Sheet
	D. Sample Letter re: Battery Changes
	E. Explanatory Letter re: CO and CO_2
	F. Explanatory Letter re: Additional Visits
	G. Explanatory Letter re: Additional Hot Water Monitoring
	H. Sample Letter re: Decommission Appointment
9. 30 Homes – Information Pack for Installers	A. Installation Pack Checklist
	B. File Note Template
	C. Background Information
	D. Consumer Asbestos Guidance
	E. Electrical Safety Guidance
	F. Incident Report Form
	G. Battery Change Pack Checklist
	H. Sample Sensor Schedule
	I. Digital Time Plug Guide
	J. Repeaters Pairing Guide

	K. Hub Debug Guide
	L. Decommission Pack Checklist
10. 30 Homes - Data Outputs	A. Sample Data Pack for Household Interview
	B. Sketch Floor Plan showing locations of monitoring equipment
	C. Sample Energy Tips
11. HEMS – Agreement with Residents	A. In-Home Heating Controls Study Agreement
	B. HOBOs and iButtons Removal Agreement
	C. In-Home Heating Controls Study – End of Project Agreement
12. HEMS – Information Issued to Residents	A. In-Home Heat Control Trial – Info Sheet
	B. Sample Letter re: Installation Appointment
	C. Sample Email re: Decommission Appointment
13. HEMS – Information Pack for Initial Survey	A. Survey Pack Checklist
	B. Background Information
	C. HEMS Survey Form – to do list
14. HEMS – Data Outputs	A. Completed Survey Form