WESTERN POWER DISTRIBUTION

INNOVATION

NEXT GENERATION NETWORKS

FREEDOM

CLOSEDOWN REPORT

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Contents

Glossary

Term	Definition
BAU	Business as Usual
BEIS	Department for Business Energy and Industrial Strategy
CDM	Construction Design Management
CEP	Customer Engagement Plan
COP	Coefficient of Performance
DG	Distributed Generation
DNO	Distribution Network Operator
Freedom	Flexible, Residential, Energy, Efficiency, Demand, Optimisation & Management
GATC	Gas Assessment and Training Ltd
GB	Great Britain
HCI	Human Computer Interaction
HV	High Voltage
IPR	Intellectual Property Register
ITT	Invitation to Tender
kV	Kilo Volts
LCT	Low Carbon Technologies
LV	Low Voltage
NIA	Network Innovation Allowance
Ofgem	Office for Gas and Electricity Markets
PEA	Project Eligibility Assessment
RHI	Renewables Heat Incentive
RFI	Request for Information
TWh	Terra Watt hour
ULEV	Ultra-Low Emission Vehicles
WPD	Western Power Distribution
WWHA	Wales and West Housing Association
WWU	Wales & West Utilities

Executive Summary

The Freedom Project has concluded following a two year programme, installing 75 PassivSystems smart hybrid heating systems in Bridgend, South Wales that ran over the 2017-2018 heating season. Western Power Distribution (WPD), Wales & West Utilities (WWU) and PassivSystems, have been working closely to turn the concept of low carbon domestic heating into a reality. Using an air-source heat pump and high-efficiency gas boiler hybrid system in 75 residential properties, the project clearly demonstrates the value that an integrated approach to deploying low- carbon smart technologies can deliver. Project learning indicates that a hybrid approach to decarbonising our heating that is combined with green gas growth could lead to the total decarbonisation of domestic heat. The Freedom Project set out to investigate the role of multi-vector solutions in the form of a hybrid heating system. The combination of a conventional gas boiler and an air source heat pump (ASHP) with PassivSystems optimised smart controls has addressed these issues and presents a cost-effective decarbonisation pathway, where reinforcements to the electricity grid can be avoided by utilising the existing energy storage capability of the gas grid at times of peak demand and when renewable power generation output is not delivering. The project has addressed all aspects of the energy trilemma, with a specific focus on heat and the potential for hybrids to be transformational in delivering solutions that will shape future energy market dynamics.

As a result of the work delivered in the Freedom Project, hybrid heating systems have demonstrated that they are a complementary solution across the various futures of heat pathways, providing the opportunity for partial electrification combined with hydrogen in major cities and other decarbonised gas elsewhere. The findings of the project will contribute to the challenge of reducing carbon emissions at the lowest cost impact for domestic consumers by delivering increased heating system efficiencies and a reduced unit cost from the energy supplier for energy consumed by the hybrid heating system. To address the objectives of the Freedom Project, WPD, WWU and its project partners developed and improved their energy systems modelling to consider and optimise the operation of hybrid heating systems served by a combination of electricity and gas.

The optimal split between the two energy sources is intrinsically determined by finding the lowest-cost choice to meet the heating demand while also considering the costs in other parts of the system, such as seasonal storage, interconnection and reinforcement. This cost-optimal split will generally vary from one hourly interval to another and will be driven by the assumed price of gas as well as the endogenously driven cost of generating electricity in a given hour.

The global recognition of the challenges of climate change, in particular the ambitious reductions in carbon emissions proposed by the UK Government (i.e. 80% reduction relative to 1990 levels), are driving significant changes across the energy landscape. Significant progress is being made in decarbonising electricity generation and seeking low-carbon gas alternatives.

However, in the UK, domestic heating remains largely unaffected by attempts to lower-carbon outputs, aside from the considerable progress made through increased boiler efficiency. Gas boilers are the predominant technology for the provision of domestic space heating and hot water in the UK with a market penetration of 80% of homes. In order to meet ambitious carbon reduction targets, our high dependency on fossil gas heating will need to reduce, with hybrids offering the flexible solution to make best use of renewable gas and electricity.

1. Project Background

Gas boilers are the predominant technology for the provision of domestic space heating and hot water in the UK with a market penetration of ~80% of UK homes. In order to meet ambitious carbon reduction targets this high penetration of domestic gas heating is likely to reduce. In comparison to gas boilers electric heat pumps have significantly higher capital costs. Heat pumps may also have higher running costs compared to gas unless a seasonal performance factor of 3 or higher is achieved, unlikely without investment in insulation and upgrades to the heat delivery system (larger radiators etc.). Where mains gas is not available comparisons are somewhat more favourable.

The electrification of domestic heat has the potential to lower the carbon intensity of heat production through the use of renewable power generation, but at wide-scale deployment it is likely to have a significant impact on the electricity grid during times of peak demand: either exceeding the capacity limit of the distribution network or leading to counter-productive increases in the carbon intensity of electricity generation when intermittent renewable sources of generation aren't able to meet the additional demand for heat.

The electrification of heat combined with uncontrolled electric vehicle charging and heat load would increase winter peak electricity demand far above the current carrying capacity of networks, meanwhile gas networks risk becoming redundant. The increasing penetration of renewable energy sources, together with the decommissioning of coal-fired power plants, is resulting in an increase in volatility in the electricity system, which is relying on gas as the flexible enabler to the growth of intermittent low-carbon generation sources. Additionally, the electrification of the heat and transport sectors is expected to have a further impact on the energy system demand leading to substantial investments in network reinforcement and flexible generation. In a future low-carbon electricity market, flexibility will be fundamental to ensure a cost-efficient decarbonisation of the energy sector. Currently, due to the higher peaks of demand on the electricity network occurring on winter days compared to summer days, the utilisation level of power system assets is about 55%. Potential electrification of residential heat demand (associated with a much stronger seasonal swing) will further increase the peaks in demand during winter and aggravate power system utilisation levels. Thus, while significant investments in electricity network reinforcements will still be required to accommodate the increment in winter demand, during summer months the additional capacity will not be utilised. This aspect, among many others, will considerably increase the value (and need) for flexibility from end-users.

With the majority of the homes in the UK being heated by combustion of fossil fuels, a heat generating system that could improve domestic energy efficiency significantly has the potential to deliver dramatic reductions in primary energy consumption and CO_2 emissions. Hybrid heating systems have the potential to address these issues:

1. Peak heating and hot water demand can be delivered by the fossil fuel boiler meaning:

- A smaller heat pump can be installed reducing capital costs
- Less/no impact on winter electricity peak demand as the heat can be supplied by the fossil fuel boiler.
- The gas network, with its inherent storage capability, retains an important role in the energy system, offering the equivalent benefit of 210TWh of seasonal storage.

2. The household gains the ability to participate in price arbitrage reducing running costs by running their heating system on gas when electricity is expensive renewable generation is low or temperatures are very cold, and visa-versa.

3. The additional flexibility provided by utilising multiple fuel sources provides further opportunities to reduce the cost of operating energy networks and receive a share of the benefits generated.

Electricity is the most expensive fuel available in the UK, an energy savings trust report in 2013 found that rising costs for electricity hit poorer households with electric heating the hardest. Gas boilers typically emit 2-4 tons of carbon per year, depending on boiler and house type. Converting 10,000 homes to hybrid heating could save between 10,000 and 20,000 tons of carbon per year. The hybrid heating system has the potential to help meet the EU's ambitious environmental targets of achieving a 20% cut in greenhouse gas emissions compared with 1990 levels and a 20% reduction in energy consumption by 2020. The technology, which combines domestic gas boiler and air-source heat pump heating, has the capability to use either fuel or both and can be used as fully flexible loads capable of providing significant energy system value.
Using predictive control algorithms the technology manages the heating load and fuel type to achieve the best cost and carbon outcome based on real-time energy market prices without the consumer engaging in the market complexity. As well as not seeing an increase in their energy charges, the consumer wouldn't have to pay for the hybrid system up-front. The use of aggregated load control helps reduce the peak demand, thereby having a disproportionate reduction on carbon intensity and system costs and increasing the security of supply.
These technologies may also provide an opportunity to support network management and may be suited to provide system services because of the flexibility in their operation. National Grid predicts that the uptake of heat pumps in homes in the UK will keep on increasing. These devices can be used as a way of enabling flexible energy supplies to deal with demand on the local electricity network, improve domestic energy efficiency, reductions in primary energy consumption and CO_2 emissions.

2. Scope and Objectives

The project will develop a capability that is capable of delivering DSR aimed at both day-in day-out reduction at peak times and reduction during critical peaks. By developing the technology that enables the full value supply chain, the project will deliver the world's first demonstration of fully flexible domestic heating load management services through the use of hybrids. The control enhancements will move well beyond current hybrid technology that makes a simple switching decision based on fixed tariff information and will provide accurate load forecasts by fuel type by quarter hour to the energy supplier. Consumers will for the first time be able to see a forecast of spend on heating for the coming period, based on their individual home, occupancy patterns, weather forecast and comfort settings.

This project aimed to investigate the feasibility of the use of hybrid heat pump in order to:

- Determine the technical potential and impacts for heat pumps to provide network services - to create headroom for the growth in the connection of LCTs and maintain peak loading within the rating of the network
- Look at the technical and commercial barriers to widespread implementation;
- Determine the potential benefit to asset owners and examine the possible commercial models for service provision - to deal with an occasional peak load above rating, for which a dynamic response would be required;
- Switch between gas and electric load to provide fuel arbitrage and highly flexible demand response services;
- Demonstrate the consumer, network, carbon and energy system benefits of large-scale deployment of hybrid heat pumps with an aggregated demand response control system;
- Gain insights into the means of balancing the interests of the consumer, supplier, DNO and TSO when seeking to derive value from the demand flexibility;
- Addressing elements of the Energy Trilemma i.e. Energy Security, Energy affordability and Energy Sustainability. With a potential to make market transforms in delivering solutions that will shape future energy market dynamics.

The project’s contribution to the energy trilemma is discussed below:

- The integration of PassivSystems temperature predictive heating controls with highly flexible (electricity and gas) hybrid heat pump heating loads and half-hourly metering systems will enable energy suppliers to achieve lower wholesale energy costs. Optimising the hybrid control strategy against wholesale electricity price fluctuations creates cost savings that can be passed back to consumers; the demand flexibility (switching between gas and electricity) of the hybrid will be used to lower network charges through triad avoidance and red rate distribution charging mechanisms. Additional demand response services will be provided to WPD to improve security of supply by reducing demand peaks; integration of PassivSystems control and aggregation platform with metering technology and energy supplier systems combined with the enhancement of PassivSystems existing demand forecasting technology allows the optimisation of these outcomes. It is estimated that an energy supplier with 10,000 controllable hybrid heat pumps would provide approximately 50MW of flexible heating load. Reducing electric load at peak will reduce the requirement for non-spinning reserve. The control regime will also take account of the impact of volume switching of fuel type on the gas network; methods for increasing diversity in fuel switching will be investigated. The academic research will provide valuable insights into the impact on DNOs of wide scale heat pumps adoption through modelling of network impacts based on the real-world data collected from the field trial. It will also identify methods to raise technology adoption and consumer trust and will propose the new approaches to information provision during the consumer journey, a key enabler required to allow the energy supply chain to benefit from the flexibility of the consumers' heating assets. The heating system will be able to manage to a consumer budget rather than a set point, truly empowering consumer spending decisions.

- The creation of a high volume route to market for hybrid heat pumps which will greatly increase the market penetration of this renewable heating technology. Hybrid heat pumps form a key component of BEIS's Future of Heating model which forecasts hybrids meeting 29% of domestic heating load by 2020 and 53% by 2030. The Freedom project will demonstrate the consumer and network benefits and will model the potential carbon benefits and whole system economic benefits of large scale, long term adoption of the technology.

- Providing consumers with better tools to manage their heating bills to a budget and only heating homes when required will increase energy efficiency, lower domestic heating demand and reduce consumer bills. Research into building customer trust for new business models and improving market adoption rates will maximise the uptake of the technology.

Objective	Status
Demonstrate the ability of the hybrid heating system to switch between gas and electric load to provide fuel arbitrage and highly flexible demand response services	✓
Demonstrate the consumer, network, carbon and energy system benefits of deployment of hybrid heating systems with an aggregated demand response control system	✓
Gain insights into the means of balancing the interests of the consumer, supplier, distribution and transmission network when seeking to derive value from the demand flexibility	✓

Table 1: Objectives and achievement status

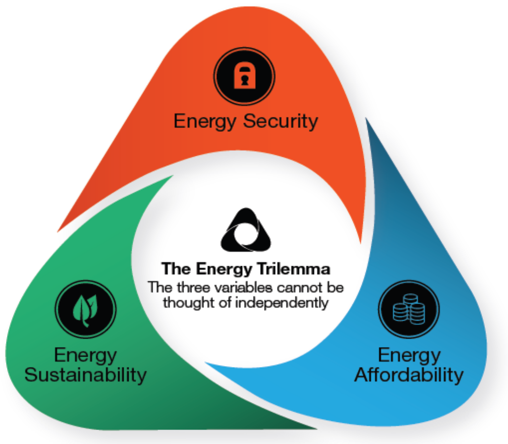

Figure 1: Energy Trilemma

3. Success Criteria

The details of all successes through the lifecycle of Freedom are provided throughout the report with commentary against each item and its underlying deliverables and criterion. In summary Freedom met all of its Success Criteria. There were targets set throughout each of the phases and the team delivered against each of them. The Success criteria covered a broad range of subjects and are summarised below:

- Customer Engagement Plan (CEP): The project required an approved Consumer Engagement Plan by Ofgem. We could not commence the household recruitment until this was approved. We sought early engagement with Ofgem to speed the review process of the CEP. We received approval from Ofgem on the 18th of January 2017.

- Recruitment: As part of the Household Recruitment Review, WPD and WWU received evidence from Passiv that 148 homes had been secured for the main trial: 100 homes – Wales and West Housing Association, 44 homes – Hafod Housing and 4 private homes. For the pilot trial all the 4 homes were private. For the whole Freedom project, we only wanted 75 participants for the trial.

- Project Management: The successful delivery of the Freedom Project was ensured through the implementation of best practice project management, governance and effective controls. This was facilitated by the appointment of a project manager from each of the partners including WPD and WWU.

- Purchasing and Legal: For the Freedom project to be a success, we needed to select a suitable hybrid heat pump. To provide the benefits promised in the project of efficient operation and demand flexibility services, it was necessary that we followed a selection process that was transparent and robust. We also needed to understand our requirements, both in terms of the high level control interface and the physical connection. PassivSystems had worked in the past with a number of heat pump manufacturers and that was really useful at the selection stage. Considerations that were given to each hybrid type are discussed in subsequent chapters. PassivSystems' worked with Delta-ee to develop the RFI for the suppliers. RFIs were sent to hybrid heat pump supplier's week commencing 17th October 2016. RFI returns were scheduled for 04th of November 2016. Interviews and shortlisting were planned for the week commencing 07th November 2016.

- Construction Process: All installations adhered to the CDM process. Throughout the project we had 0 - health and safety issues, 0 - incidents/accidents and 1 - complaint. The main hybrid system installation phase started at the end of June, 2017. Focus was placed on planning and coordination to ensure a smooth project delivery. This included detailed processes, a thorough assessment of the technical specification and the creation of installer instructions. Following the feedback received from the pilot trial survey, there was extra focus on educating all installer stakeholders thoroughly about the Freedom Project, ensuring everyone was fully briefed and aligned prior to project commencement. Three different installers were used in the project.ie. WDS Green Energy, Master Therm and Spire Renewables.

- Technology and Equipment: 43 MasterTherm/Vaillant, 16 Samsung/Worcester and 16 Daikin Altherma hybrid systems were installed with the final split of customer types being 40 social tenants and 35 private homeowners.

- Identify the solution and benefits to networks: The Freedom project was able to demonstrate the consumer, network, carbon and energy system benefits of large-scale deployment of hybrid heating systems with aggregated demand response controls. We were able to use the ability of the hybrid heating system and PassivSystems controls to switch between gas and electric load to provide fuel arbitrage and highly flexible demand response services.

- People and Culture: One of the biggest challenges of deploying any new heating technology is getting the end-users (i.e. householders) engaged with it and trusting that the system is working properly and to their advantage (i.e. keeping them warm while saving them money). Part of the research stream of the Freedom Project was looking at hybrid heating systems from the perspective of the consumer, (a) to ensure that they are engaged throughout the project, and (b) to ensure that the heating system user interfaces are friendly and gain consumer trust. Delta-ee designed a Customer Engagement Framework that included effective communication throughout the trial, including recruitment, understanding how to control the heating system, and providing feedback to the project partners helping householders to communicate their comfort requirements in a straightforward way and explaining some of the counterintuitive ways in which hybrid heating systems are controlled for highest efficiency.

- Produce a proven architecture for the hybrid heating system: As an industry first, Distribution Network Operator (DNO), Western Power Distribution and Gas Distribution Network (GDN), Wales & West Utilities formed a partnership with PassivSystems to deliver the Freedom Project, and that was the birth of the hybrid technology. Due to uncertainty about the outcomes and the technology we embarked on a two-phased approach, Phase 1 and Phase 2 to carry out forensic models from which hypotheses of system performance, detailed market assessments, and consumer research were derived. Starting with a pilot trial involving 4 homes and eventually extending the trial to the rest of the 75 homes in Phase 2. During this period we were able to assess the selected hardware and installation contractors.

Success Criteria	Status
Present a comprehensive review of the technology	✓
Produce a case study of how the technology contributes to the reduction of carbon emissions and compares with previous energy bills for domestic consumers through increased heating system efficiencies and a reduced unit cost	✓
Identify if the solution can bring benefits to WPD's & WWU's networks	✓
Deploy trials subscribed to by up to 75 participants	✓
Produce a proven architecture for the hybrid heating system	✓
Develop a business process (polices, standard techniques etc.) for the use of hybrid heating system	✓

Table 2: Success Criteria

4. Details of Work Carried Out

4.1. Project Proposal

PassivSystems Limited and its partners submitted a proposal to deliver a technically and commercially innovation project to realise the benefits of using the hybrid heating system (heat pump and gas boiler) for the electricity (WPD) and gas networks (WWU) and our customers. Project Freedom was registered on the 27th of September 2016 and the contract signed on the 20th of October by all parties. The trial was conducted in 75 domestic housing units in the Bridgend area of South Wales. For the first time, this NIA-funded project brought together gas and electricity network operators in the field trial region and has provided both parties with robust, field-tested data which has provided useful insight into long-term network investment planning. The cross-sector scope makes this a unique project which has set the benchmark for holistic 'whole-system' projects, as articulated in Energy UK's Pathways for the GB Electricity Sector to 2030 (February 2016). The Freedom project did not involve us offering or modelling the provision flexibility services to the System Operator or wider market by either WPD or WWU.

4.2. Aims and Objectives of the Project

The Freedom Project aimed to gain a greater understanding of hybrid (electric and gas) heat pumps through conducting a range of experiments. Experiments that involved a different approach to heating and hot water supply and how to plan for and switch to the most effective energy source. Additionally across a group of homes it aimed to explore demand aggregation and planning utilising both electricity and gas fuels.

The project was proposed on the following premise:

- Heating bills will be lowered as a result of the energy supplier using the flexible load to optimise wholesale energy procurement;
- Advanced heating control algorithms and clear, accessible user interfaces will help the consumer match their demand to their requirement and reduce their energy consumption;
- Aggregated load control will deliver a network balancing capability that allows the GDNO, DNO and TSO to make greater use of demand-side services
- The in-home controls will allow for a variety of demand control services without impacting comfort levels;
- Results and outputs developed by the partners involved in this project will contribute to the reduction of carbon emissions and lower energy bills for domestic consumers through increased heating system efficiencies and a reduced unit cost from the energy supplier for energy consumed by the hybrid heat pump.

From the outset, the project aimed to create a technology that would produce:

- A PassivLiving product for controlling hybrid heat pump solutions and monitoring both electricity and gas usage for heating,
- New service for demand aggregation and planning,

- Improved user interfaces for the PassivLiving Portal and App that explores how scheduling for comfort and demand management can be communicated with users of the solution,
- Improved installation and commissioning tools that assist with the effective installation and configuration of more complex heating control systems,
- The ability to capture and analyse large volumes of event data for the purposes of aggregation, demand planning and outcome reporting.

4.3. Methodology

The methodology for the delivery of this Project was defined at the start and followed the process below:

- Selection of the area for the trial
- Customer Engagement Plan
- Selection of the type and size of the heat pump
- Network modelling
- Mobilisation (procurement of equipment and services)
- Trials or field test, including measurements (install equipment)
- Analysis and close down (Analyse results, evaluate)

The Freedom project ran for 27 months defined in 14 work packages, WP1-14. The 14 work packages were split in two separate phases (1 & 2). The phasing reflects the contractual break clause prior to installations commencing. Phase 1 covers all work required to produce the models, hypotheses, plans and recruitment actions required for the heat pump procurement and installation activity to commence. Phase 1 also includes a 4 home pilot installation which will assess the hardware and installation risk and collect the baseline data required for the advanced control development. At this milestone PassivSystems will present evidence to the Project Partners on whether sufficient homes have been successfully recruited for the project to proceed. Phase 2 covers the work of installation, commissioning, aggregated control development, field experiments, data capture and analysis, reporting and knowledge dissemination.

4.4. Customer Engagement Plan

On January 18th, the project received formal approval of the Customer Engagement Plan from Ofgem. This triggered several project dependencies including the pilot trial; recruitment, terms and conditions, literature, property surveys, the purchase of hardware and hybrid systems and the installation hybrid systems. In addition to project activities, we were working with Bridgend MP, Madeleine Moon and the Welsh Assembly to support the Freedom Project. Both will raise awareness of the Freedom Project in the local community through their supporters, network and provide media coverage.

4.5. Customer Engagement Plan

As part of the Household Recruitment Review, WPD and WWU received evidence from PassivSystems that 148 homes had been secured for the main trial: 100 homes – Wales and West Housing Association, 44 homes – Hafod Housing and 4 private homes (pilot trial homes). We had established a Recruitment Review Project Milestone due at the end of January 2017. This was the basis for the project to proceed to Phase 2.

In Section 15.3.b of the contract we said:

Without prejudice to clause 15.1, either Industrial Party may by notice in writing immediately terminate or suspend the Collaboration Partner's involvement in the

Project:

Following the household Recruitment Review Project Milestone (as defined in the SOW's) if a total of less than 50 homes have been recruited and either Industrial Party does not wish, at its sole discretion, to proceed with the pilot scheme and the remainder of the project (as defined in the SOW's);

4.5.1 Recruitment Considerations

The recommendation on which design(s) to select was dependent on information on the current heating systems installed in homes in the trial area. Assuming that many had wall-hung combi gas boilers, the integrated / split design was most suitable, but the other options could also be relevant where there are older heating systems and/or more available space.

The following considerations were made during the recruitment process:

1. House type
    - Smaller dwellings will likely need a more compact system; no physical limitation in larger dwellings
    - All dwellings need space for a hot water tank, but is not a mandatory requirement
    - Outside space is needed for an external unit;
    - Density of dwellings may present an issue due to noise regulations?

2. Age of dwelling
    - Housing developers could enable lots of dwellings to be targeted at once, but low thermal demand means low savings
    - Recently built dwellings are less likely to want installation hassle or to rip out a relatively new boiler
    - Older dwellings likely to have on older boiler meaning a new efficient heating system could be appealing.
    - Older dwellings may be less well insulated, meaning scope for energy bill savings. Appeal of a hybrid could be high.
    - Thermal demand / insulation level could influence the share of heat demand met by HP vs boiler meaning more scope for controls to influence this. Fuel bill savings linked to how efficiently the HP can operate.

3. Tenure

- Registered Social Landlords (RSL) could help target lots of dwellings at once, decision making by RSL, fuel bill savings would be an attractive proposition
- RSL dwelling more likely to be smaller (flats/terraces) –needs a compact hybrid system
- Private rental would be tough –landlord decision to install, no real motivation. Owner-occupier will likely be the biggest market, owner is the decision maker, a 'free boiler' could be an attractive pitch

4. Socio-economic group

Group will likely influence the importance of fuel bill savings, the appeal of 'free boiler', and awareness of low carbon energy sources

5. Customer behaviour / occupancy pattern ('the way heat is used')

- Depends on what the trial wants to test (e.g. different control approaches, 1 control approach across different customer)
- Multiple 'heating periods' offers more scope for controlling / influencing operation of boiler vs Heat Pump & filling the Hot Water Tank.
- High versus low heating demand, high vs low Hot Water demand presents different opportunities for Heat Pump vs boiler operation
- 'Greener' customers likely to be more interested or engaged in low carbon –hybrids may be more attractive
- More technical orientated customers may engage more with low carbon and be more interested in controls

6. Existing heating system

- Age of the boiler will influence willingness to replace existing boiler & efficiency (potential for energy savings)
- Condensing vs non-condensing – energy saving opportunities

Combi versus system boiler –an existing hot water tank means space is less of an issue.

4.6. Phasing of the Project

Actual details of each phase are discussed below.

4.6.1 Phase 1

4.6.1.1 Pilot Trial Recruitment

Phase 1 of the project included a 4 home pilot installation which was subject to the approval of the Customer Engagement Plan. We successfully recruited 4 homes for the pilot trial within a week of the approval. 4 hybrid heat pumps were installed in private homes: 1xDaikin, 1xSamsung and 2xMasterTherm. In the week that followed, terms and conditions were sent, signed and returned to PassivSystems. The 4-home pilot trial was completed by 17/02/17.

We delivered to a strict timeline:

- 1 week was allocated for installing the hybrid system.
- 1 week was allocated for contingency and assessing the locations of the meter and monitoring equipment (Supplied by PassivSystems).
- 1 week to connect Passiv hub, the heat pump and meter and monitoring equipment.

After the trial, we received signed documents from all 4 homes to confirm they were satisfied with the products supplied, installation services and commissioning documentation.

4.6.1.2 Phase 1 Work Packages

Phase 1 includes work packages 1-9, which are explained below:

- Work Package 1- System Modelling/Controls: The main output of this work package is to develop a tested code for hybrid heat pump control.
  Innovations – 15 minute demand forecasting by fuel type by home; fuel and load shift to market signals with guaranteed service levels

- Work Package 2 - High Level Design: During the system design, the project partners will collaborate to produce the Use Case Specification, Process Flows and the High Level Design.

- Work Package 3 - Market Integration Strategies/Market Optimisation/Projections
  Innovations – hybrid load modelling against demand side market value. The main outputs in this work package include modelling of value optimisation strategies against real market data; analysis of future market opportunities and current trends; updated control parameters.

- Work Package 4 - Project Consumer Engagement and Design: Delta EE will develop a suitable “customer touch point plan” on engagement with potential consumers. City University will be closely involved and will be involved in a number of workshops with potential consumers. The main outputs of this work package will be to design and develop a “customer touch point” map for hybrid heat pumps and consumer technology.

- Work Package 5 - Customer Recruitment and Pilot Installations: The process involves the recruitment and survey of homes for the trial, design and software development for system installation and commissioning, production of installation documentation and user guide. The installation and commissioning of hybrid heat pumps into 4 pilot homes. The output will be the production of documentation to support installs; data analysis report from the pilot homes; a report on the status of the recruitment process and the findings of the pilot installation activities.

- Work Package 6 - Measurement specification: The main objective of this work package is to measure the hybrid heat pump behaviour in each home. Imperial College will develop the metrics to be measured together with their measurement regime (frequency, accuracy, reporting formats etc.). The desired output of this work package is to design a metrics and measurement regime.

- Work Package 7 - Metering and Data Processing: The main output of this work package is to develop a tested code to integrate PassivSystems hub with metering equipment.

  Innovations – capture of electricity and gas metering data by HEMS to integrate with heating control interface; capture of domestic metering data to measure demand shifting outcomes.

- Work Package 8 - Consumer Engagement/ Consumer Interface/ Heat Pump Interfaces: At this stage research into consumer trust and associated interface adaptations, delivery of heating budget data to consumers will be the key focus; user can specify set point or budget to determine thermostat settings. The expected output is to develop a tested code for hybrid heat pump control.

  Innovations – Research into consumer trust and associated interface adaptations, delivery of heating budget data to consumers; user can specify set point or budget to determine thermostat settings
- Work Package 9 - System testing and evaluation: The lab based system testing of hybrid control and smart meter integration with simulated inputs to model different energy market and home heating demand scenarios. The main output from this work package is to develop System test logs.

4.6.2 Phase 2

Phase 2 ran over the 2017-2018 heating season and utilised 75 trial homes installed with hybrid heating systems in a mixture of private (including off-gas grid) and social housing. Phase 2 includes work packages 10-14, which are explained below:

- Work Package 10 - Installations and Support: The main activity in this work package is to carry out process design and software development for system installation and commissioning including the production of installation documentation and user guide. The key output from this work package is to develop documentation to support installs as well as the installed hybrid heat pumps and controls.

- Work Package 11 - Control Development and Testing: The detailed design, development and unit testing of individual home hub demand forecasts, demand response planning and demand response execution. The key output is to develop a tested code for hybrid heat pump aggregation.

Innovations – 15 minute demand forecasting by fuel type by home; fuel and load shift to market signals with guaranteed service levels

- Work Package 12 - Aggregation and Market Optimisation: The detailed design, development and unit testing of PassivSystems server level aggregation of individual home hub demand forecasts, demand response planning and demand response execution. The key output from this work package is to develop a tested code for hybrid heat pump aggregation.

  Innovations – Portfolio level demand forecast and intelligent load shifting dependent on market requirement

- Work Package 13 - Analysis Reporting: Review of collected data and final consumer feedback, assessment of commercial opportunities based on the findings and updating of the original business plan, reporting to WPD, creation of presentations and report for wider dissemination of findings. The key outputs of this work package is to report the findings of the project, press release; academic research publication; presentation material for academic and industry conferences; social media dissemination of results.

- Work Package 14 - Project Shutdown: Agreement of post-project terms and conditions with consumers for any ongoing services, removal of equipment as required, reconfiguring of the hybrid heat pump as required, data cleansing and WEEE compliant disposal of redundant equipment.

4.7 Project Delivery

The scheme involved installation of Hybrid Heat Pump hardware in 75 housing units, on-site commissioning, technology adoption and measurement of field trial outcomes.

4.7.1 Outline Project Plan

Phase	Description	Start Date	End Date
Milestone	**Milestone description**	**Start Date**	**Finish date**
M1	WP1: System Modelling & Controls	01/08/16	31/12/16
M2	WP2: High Level Design	01/08/16	01/10/16
M3	WP3: Market Integration Strategies	15/08/16	31/12/16
M4	WP4: Consumer Engagement & Design	01/09/16	31/12/16
M5	WP5: Customer Recruitment and Pilot Installations	01/09/16	31/01/17
M6	WP6: Measurement Specification	01/10/16	31/12/16
M7	WP7: Metering and Data Processing	01/10/16	31/12/16
M8	WP8: Consumer Engagement/HHP Interface	01/10/16	31/12/16
M9	WP9: System testing and evaluation	01/12/16	31/01/17
M10	WP10: Supply & Installation	01/02/17	30/09/17
M11	WP11: Control Development and Testing	01/02/17	31/12/17
M12	WP12: Aggregation & Market Optimisation Consumer Interface	01/10/17	30/04/17
M13	WP13: Analysis & Reporting	02/10/17	31/05/18
M13	WP14: Project Shutdown	01/04/18	31/04/18

Table 3: Project Milestones

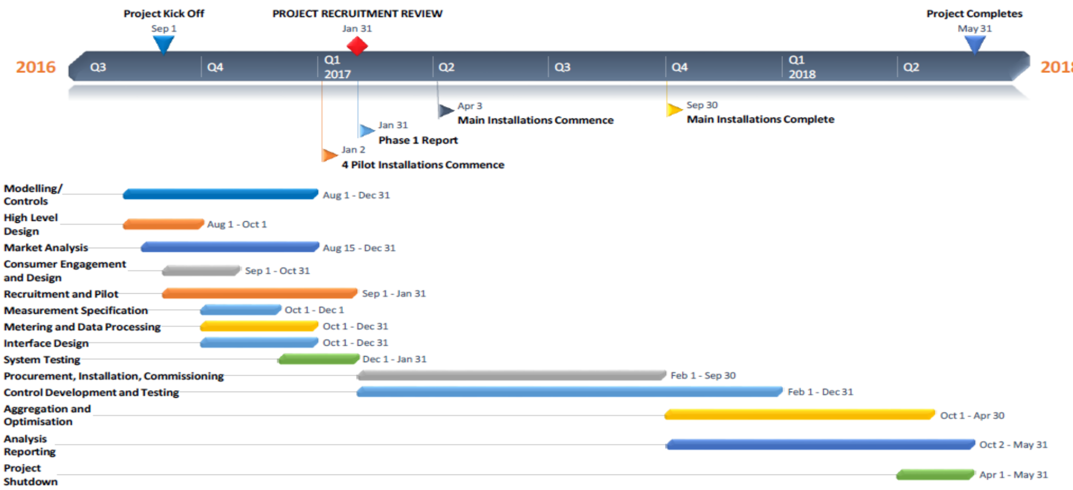

Figure 2: Project Plan

4.8 Defining Use-Cases and System Architecture

The hybrid heating solution was made up of several entities or actors. The high level use-cases that define the main features of the solution and the key actors are described below.

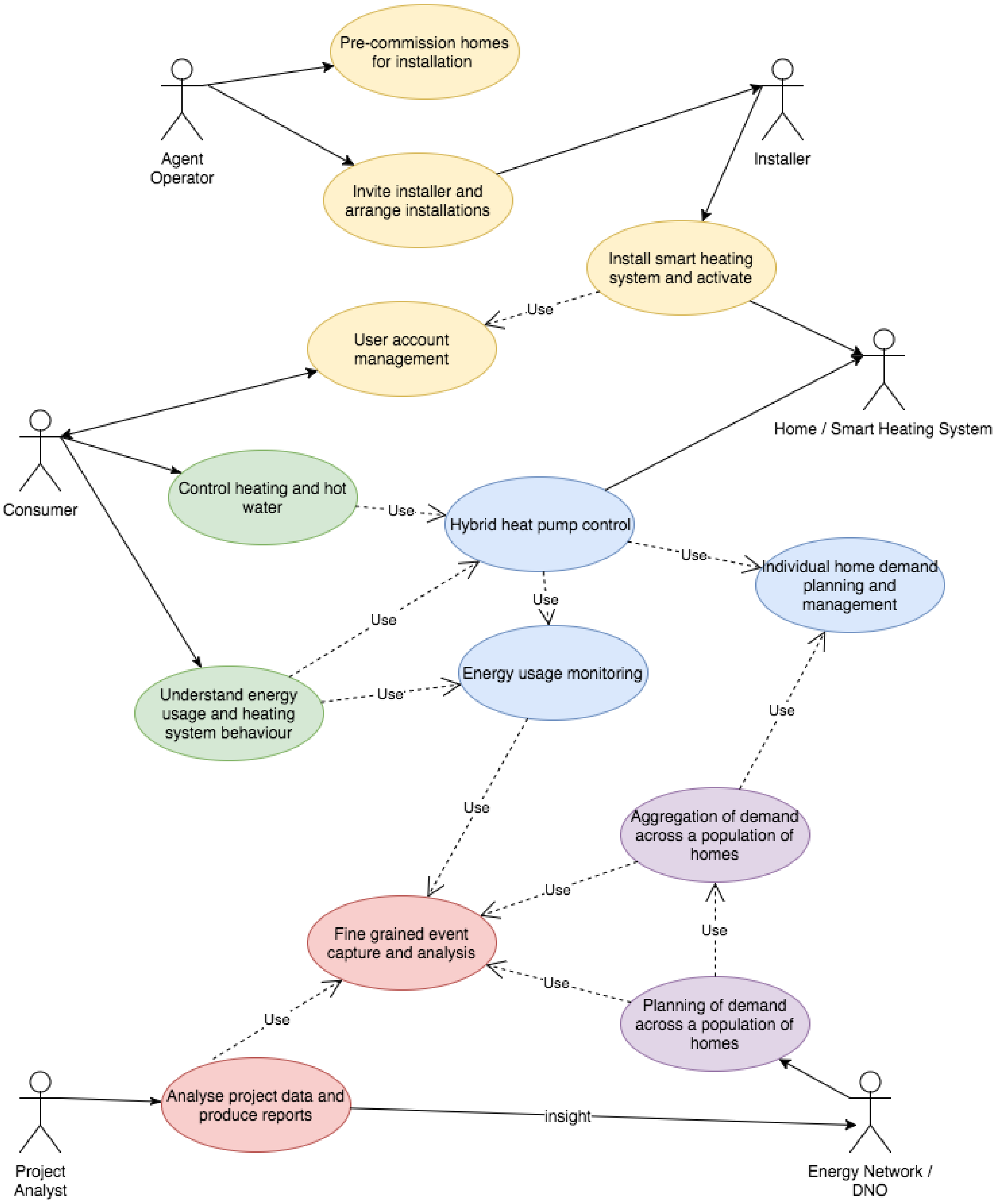

Figure 3: Actions

- Consumer: This is the home owner or tenant using the PassivLiving heat product. They would interact with the hybrid heating system to configure and control their heating and hot water requirements. One of the key goals of the project was to explore how energy usage and heating system behaviour was communicated to the Consumer, especially when demand management scenarios were taking place. The consumer would interface with the system via the PassivLiving heat Portal and App.

- Home / Smart Heating System: The Home is the location where the hybrid heat pump, Passiv Hub and other heating and monitoring controls were installed. A Consumer controls the heating in their home. All data is collected on a per-home basis.

- Agent Operator: A protocol within the PassivSystems architecture, called the Agent Operator, was the central administrator for the system. This had the responsibility for creating and managing installer accounts, commissioning homes and managing the Consumers.

- Installer: The Installer was the person who visited the home to install and configure the heat pump and PassivLiving components. They would use a dedicated Install App that allowed them to join devices, configure the system and verify its status. Three different installers were used in the project.ie. WDS Green Energy, Master Therm and Spire Renewables.

- Energy Network: The Energy Network (DNO or GDN) is the provider of energy being used by the homes. They would be interested in being able to effectively manage their network by understanding the expected demand on their network and being able to plan that demand for purchasing or balancing purposes. In this case WPD and WWU.

- Project Analyst: The Project Analyst, within PassivSystems, would use all of the data collected during the project to build models of behaviour and produce reports. These will be used to tune behaviour and to determine any follow-up work across the wider network.

4.9 Project Resource

Western Power Distribution (WPD) and Wales & West Utilities formed a partnership with PassivSystems to deliver the Freedom Project under the NIA funding mechanism.
PassivSystems appointed the following project partners to aid with the provision of specific tasks of the project:

- Imperial College,
- Delta-ee and
- City University.

A project working group consisting of personnel from all project partners was formed at the start of the project.

Project Partner	Resource	Detail
Western Power Distribution	Faithful Chanda	Project Manager, WPD
Wales & West Utilities	Oliver Lancaster	Project Manager, WWU
	Lucy Mason	Innovation Manager , WWU
PassivSystems	Ian Rose	Professional Services Director, Project Lead
	Tom Veli	Professional Services Manager, Project Manager
Delta - EE	Andrew Turton	Principal Analyst: Customer proposition and development of engagement framework
	Phillipa Hardy/Jennifer Arran	Senior Analyst: Customer proposition and development of engagement framework
City University	Simone Stumpf	HCI Design Lead
Imperial College	Goran Strbac, Dimitrios Papadaskalopoulos, Meysam Qadrdan, Predrag Djapic, Marko Aunedi	Network Modelling Team led by Prof Goran Strbac

Table 4: Project Resource

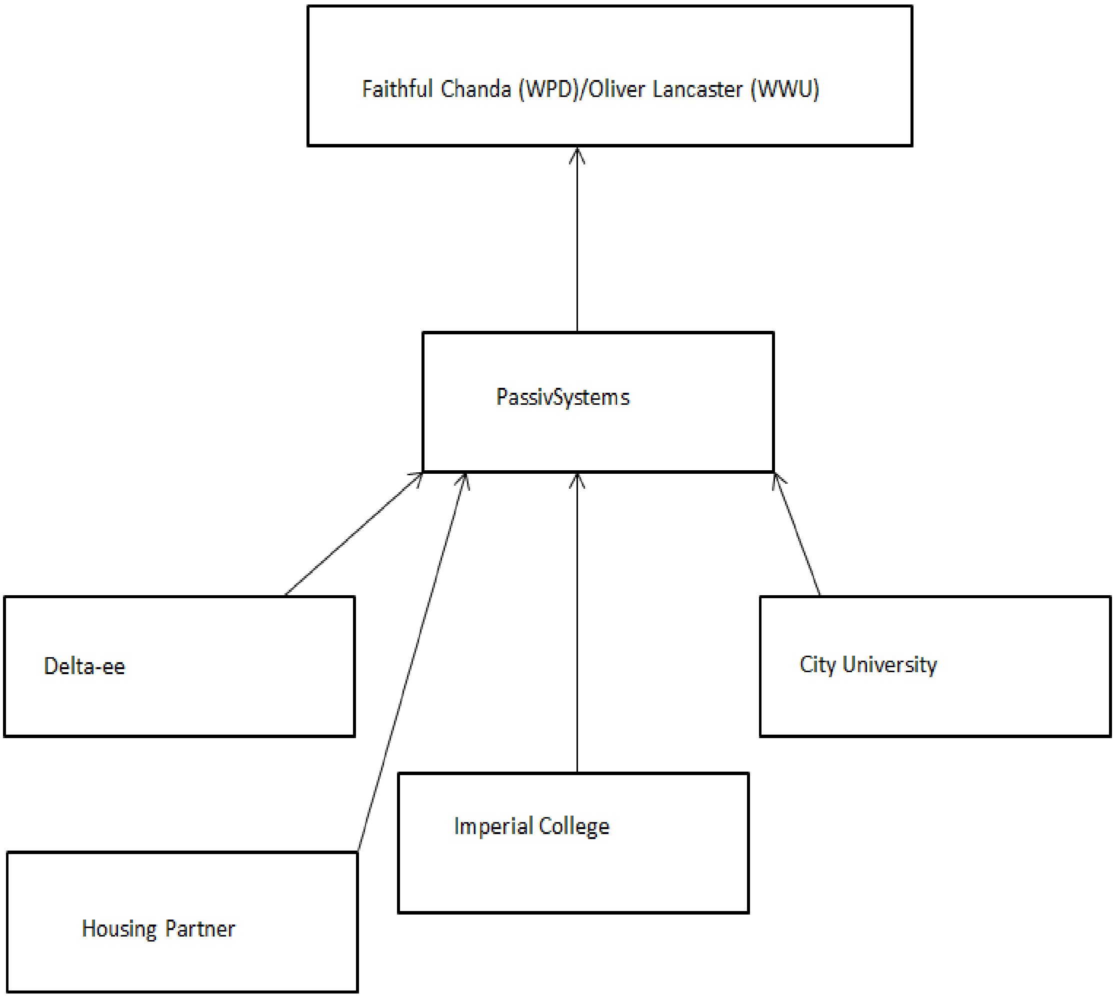

Figure 4: Project Structure

4.9.1 Project Partners and Roles

1. PassivSystems: PassivSystems is a provider of domestic energy services and has invested in excess of £25m in developing a connected homes services platform (PassivEnergy) that is providing energy monitoring and control solutions into existing domestic heating and rooftop solar generation markets. The Project Manager from PassivSystems had the authority to run the project on a day-to-day basis on behalf of the Project Board within the constraints and tolerances laid down by the project board. The Project Manager's prime responsibility was to ensure that the project produced the required deliverables, to the required standard of quality and within the specified constraints of time and cost. The Project Manager was also responsible for the project producing a result that is capable of achieving the benefits defined in the Business Case.

Major tasks included:

- Ensure project objectives were clearly defined and articulated.
- Define deliverables necessary to achieve project outcomes.
- Manage the production of the required deliverables.
- Plan and monitor the project.
- Manage the risks, including the development of contingency plans.
- Take responsibility for overall progress and use of resources and initiate corrective action where necessary.
- Liaise with the Project Board or its appointed Project Assurance roles to assure the overall direction and integrity of the project.
- Agree technical and quality strategy with appropriate members of the Project Board.
- Identify and obtain any support and advice required for the management, planning and control of the project.
- Responsible for project administration.
- Appoint a hybrid supplier.
- Appoint a hybrid installation contractor.
- Commission specialist consultants, surveys and investigations for hybrid installations.

2. Delta EE: Delta-ee led the consumer engagement programme over the duration of the field trials. They designed an engagement framework and programme followed by conducting the engagement process. They also led the recruitment and selection of customers and coordinated the selection of the hybrid heat pump technologies so that the technology was compatible with the customer's house types. Delta EE's expertise provided an understanding of existing and future models of hybrid heat pump operation in different customer and housing types and how these impact on energy demands and operation economics from the customer perspective.

3. Imperial College: Imperial College led the field trial design and analysed data outcomes in order to understand the future network implications and the broader energy system impacts.

This work would be of direct value to guiding policy makers on the future value of demand flexibility.

4. City University: City University assisted with the design of user interfaces that clearly communicate and explained the automated decisions and actions taken by the predictive load control system in order to build and increase consumer trust. This involved the evaluation of the existing control app, to determine usability violations with a view to improving the control UI design. City University conducted a series of individual interviews with 20 potential users of the service to identify their needs and wants. The background information was used to target users and the design to provide optimal fit. City University also conducted stakeholder interviews to investigate business and technical constraints, as well as desk research to provide an overview of the state-of-the-art of control interfaces for automated system, and their effects on trust, intelligibility and perceived control.

Contextual interviews were conducted between 22nd August and 2nd September 2016 with the aim to:

- Get an understanding of the relative importance of control versus intelligibility for users
- Explore design trade-offs in control user interfaces
- Explore importance of feedback in hybrid heat pump systems.
- Key findings were:
- Automation and autonomous system actions are desirable and in some cases required. However, this means that the system takes control away from the user and as such the system has to communicate its actions clearly so that users trust it.
- Text explanations and visual graphics support users in understanding systems' actions. Participants consistently agreed that the explanation was useful. Explanations should be detailed, precise and accurate in order to gain users trust. Graphics were useful to explain the wider context of how the actual system works and gave participants more credibility about its actions.
- It is important that system explanations describe the benefit for the user of taking an action instead of stressing the possibly negative impact of not taking an action. For example, instead of saying '*the heating was delayed due to a peak demand in energy market',* the system could communicate cost savings, e.g. '*to save you money during the peak hours, the system was preheated during the off peak times*'.
- As long as users understand what the system is doing and what action users can take at any given time, users will be happy to rely on intelligent system decision.
- Participants' mental model is based around traditional gas boiler central heating system and it is important to shift it towards a hybrid heat pump model. For example, participants struggled with scheduling using temperature set point.
- Many participants did not understand demand response and preheating. Information about both needs to be integral to early customer communication and engagement.

5. Innovation Project Managers: WPD and WWU: Overall responsibility, leadership and authority for the project were assigned to the Innovation Project Managers.

Major tasks included:

- 'Owning' the vision for the project.
- To run the project and realise the benefits.
- Managing the interfaces and communication with the project's stakeholders.
- Ensuring the linkages are maintained between the project and the organisation's strategic direction.
- Ensuring that the aims of the project continue to be aligned with evolving project needs.
- Compiling Progress Reports that formally assess the achievements of the project and the benefits realised from the NIA investment.
- Overall control of the project implementation, with personal responsibility for the project's achievement.

In addition, the Project Innovation Manager would have:

- The strength to make decisions that are often strategic in nature.
- Access to and understanding of the business information necessary to make the right decisions.
- Access to and liaise with key stakeholders.
- The ability to communicate the aims and objectives of the project, and visibly to lead its execution.

4.10 Project Risks

The project was managed using proven project management methodology previously used in other projects. The associated risk management processes ensured that risks were recorded, clearly defined, responsibility assigned and mitigating actions identified. The risk register was reviewed at regular project meetings and significant risks were escalated to relevant members of the team. The Project Managers had responsibility for managing the risks on a day to day basis.

4.10.1 Reporting and Communications Cycle

The successful delivery of the Freedom Project was ensured through the implementation of best practice project management, governance and effective controls. Central to this was:

- A detailed baseline project schedule (down to the level of daily activities) used to track progress.
- Live Risk Register and Issues Log that were updated and reviewed monthly.
- Clear roles and responsibilities, including ownership of activities, risks and deliverables.
- An agreed meeting schedule that included monthly progress reviews with WPD/WWU and PassivSystems.
- A Project Review Group (that had a senior representative from partner organisations) that met every 6months to review progress, budget, risks and issues.

4.10.2 Reporting Cycle

The project team met on a monthly basis and this was to ensure progress, risks and issues to be reported and identified in a timely and accurate manner. This meeting will also review the Risk Register and Issues Log and cover any resourcing issues. Two days in advance of this meeting PassivSystems will circulate a concise report that sets out the following in a standard format:

- Overall progress – Red, Amber, Green (RAG) status
- Key activities in last reporting period
- By Task – progress vs project plan
- Deliverables
- Top five Risks and Issues
- Key dependencies
- Costs / budget / invoicing
- Change control
- Decisions required
- Key activities planned for next period.

4.11 Project Review Group

To aid with the delivery of the project, a Freedom Project Review Group was established and met on a bi-annual basis. The role of the Project Review Group was to:

- Ensure the project was aligned with organisational strategy;
- Ensure the project made good use of assets;
- Assist with resolving strategic level issues and risks;
- Approve or reject changes to the project with a high impact on timelines and budget;
- Assess project progress and report on project to senior management and higher authorities;
- Provide advice and guidance on business issues facing the project;
- Use influence and authority to assist the project in achieving its outcomes;
- Review and approve final project deliverables; and
- Perform reviews at agreed stage boundaries.

4.12 Procurement

4.12.1 Hybrid Heat Pump Selection

For the Freedom project we needed to select a suitable hybrid heat pump. To provide the benefits promised in the project of efficient operation and demand flexibility services, it was necessary that we selected the right technology and maintained the ability to control the heat pump accurately. We needed to understand our requirements, both in terms of the high level control interface and the physical connection. PassivSystems had worked in the past with a number of heat pump manufacturers and had some prior knowledge of the market.

4.12.2 Manufacturer Experience

Over the last few years PassivSystems has worked with a number of heat pump manufacturers to greater or lesser extents.

- Daikin: PassivSystems have integrated with Daikin heat pumps using a Modbus connection to their “RTD” (Real Time Daikin) interface adaptors, and achieved successful control using internal registers, e.g. to specify space heating flow temperature (about 20 installs). However, the RTD interface was unlikely to be satisfactory in this project. The devices are expensive, and different RTDs are required for different heat pump models, and some have severe limitations in practice (although mainly to do with hot water control). Daikin also have a tendency to update firmware on their heat pump such that they are incompatible with RTDs, and for this reason Daikin are withdrawing support for the RTDs. Daikin have also developed their own remote control solution for heat pumps, which means Passiv remote control solution was less attractive. Daikin had been keen on promoting their hybrid heat pumps so it was plausible they would give special support for the project.

- Samsung: PassivSystems have had some discussions with Samsung in 2014 (via UK distributor Freedom Heat Pumps) and believe that sufficient control was possible via their own RS-485 interface.

- Kensa: PassivSystems have successfully controlled Kensa ground source heat pumps with single-speed compressors using an on/off relay interface (about 20 installs). However these were not suitable for the project.

- Hitachi: PassivSystems had integrated with Hitachi heat pumps via a “Modbus gateway ATW-MBS-001”, which they were involved in specifying in the NEDO Project. There are 10 installs to date (NEDO project).

- Panasonic: PassivSystems had successfully integrated with Panasonic heat pumps using an “IntesisBox PA-AW-MBS-1” Modbus adaptor (2 installs). However, PassivSystems had not fully validated hot water control but were able to effectively control space heating via target flow temperature.

- Nibe: PassivSystems did believe that a Modbus-RTU RS-485 interface existed but had not used it. They would not be confident that Nibe would have made a good partner.

- Neura: PassivSystems have had discussions in the past and they produced a quote for developing a TCP/IP control interface, which has a considerable development budget. They would not be confident that Neura would have made a good partner, as they have developed their own remote controls, and their units are quite large.

- Itho Daalderop: PassivSystems had spoken to this Dutch manufacturer to partner and it sounded feasible to integrate. They make an exhaust air hybrid heat pump which although is a neat solution as it is a single unit, it requires a ventilation system which was believed to be relatively rare in the UK.

- Mitsubishi: PassivSystems have had discussions with Mitsubishi but had not yet found a feasible way of controlling it (the UK office would have needed cooperation from their head office). They had also developed their own remote monitoring and control facility.

4.12.3 Heat Pumps used for the Project

The following table gives details of heat pump procured for the project.

Provider	Services/goods	Area of project applicable to	Delivery Dates
Samsung	Samsung heat pump system	Main Freedom installations in Bridgend , South Wales	February 2017: 15 Samsung heat pumps
ThermalEarth	MasterTherm heat Pump system	Main Freedom installations in Bridgend , South Wales	February 2017: 40 MasterTherm heat pumps
Daikin	Daikin heat pump system	Main Freedom installations in Bridgend , South Wales	February 2017: 16 Daikin heat pumps

Table 5: Procurement Details

4.13 Control Interface Considerations

4.13.1 Type of Heat Pump

Understanding the rate of flow (or return) temperature to the heating system was a crucial consideration in the selection process. This enables the Passiv control system to take care of the thermal requirements of the house (meeting the comfort requirements of the householder in the optimal way), while the heat pump manages the best way of producing water at the specified temperature (internal valve control, refrigerant temperature etc.).

- If the heat pump has a single speed compressor, a single on/off (relay) interface is sufficient, as together with temperature sensors this allows the Passiv equipment to control flow temperature.
- If the heat pump has a modulating (inverter) compressor, a single on/off (relay) interface would not be sufficient. It is important to be able to tell the heat pump to run at a lower power level, as otherwise there is unnecessary cycling at part load and it is not possible to control flow temperature. In this case our requirement is either direct control of compressor power level or a specification of target flow temperature (or

return temperature). It is necessary to have the on/off (relay) interface as well, to ensure the unit is fully powered down when not required.

Other control requirements:

- Zone control (if zone valve fitted and operated by heat pump)
- Backup/auxiliary heater control (on/off/level)
- Defrost status. For an air source heat pump, it is important to be notified when the heat pump is doing a defrost cycle.

Optional monitoring requirements:

- Flow and return temperature. At least one of these is required, but they may be supplied via a heat meter or pipe temperature sensors rather than via the heat pump.
- Compressor level. This would provide an alternative to power metering.

4.13.2 Gas Boiler / Switching

The requirement is different depending on whether the gas boiler is provided as an integrated unit with the heat pump, or whether it is supplied completely separately.

- For an integrated solution, it is necessary to be able to tell the hybrid heat pump which hybrid mode to run in (gas boiler or heat pump). For systems like Daikin's where they can run simultaneously we needed to understand what the control possibilities were; our minimum requirement is absolute control of 100% electric or 100% gas.
- For separate systems, we need to be able to turn the gas boiler on or off via a usual central heating relay.
- Optional: In either case, it is advantageous to be able to specify the return temperature (or flow temperature) for the gas boiler, as this will enable small efficiency gains (e.g. due to condensing).

4.13.3 Domestic Hot Water

There are a number of possibilities for domestic hot water that were needed to be explored during phase 1, for example:

- Gas combi boiler
- Stored hot water, gas heated only
- Stored hot water, heated by either gas or heat pump
- with or without a controlled immersion heater

The other consideration was having the ability to control hot water via the heat pump. This increases the potential for demand flexibility as a turn-up, but the most important application is probably demand limitation, therefore not an essential feature for the project.

Our requirements depend on the system configuration:

- Gas combi boiler: ideally we would know when it is producing hot water (not essential)
- Gas stored hot water production: we would need to control hot water production via an on/off relay command

- Hybrid stored hot water production: we would prefer to have full control over which system produces hot water (e.g. direct valve control).
- Optional: it is advantageous to have control over hot water temperature (setpoint) and also over flow temperature (or return temperature) during hot water production.
- Optional: immersion heater on/off control.

4.14 Physical Interface

The Passiv hub communicates with its HAN (home area network) via Z-Wave protocol, and with the remote server via a wired Ethernet IP connection. It has a USB port which can be connected to various serial ports using an adaptor. PassivSystems have the ability to switch mains or volt-free using a wireless Z-Wave HVAC. Various makes of heat pump have in the past been controlled using Modbus-RTU protocol over a serial connection for controlling heat pumps, and this is usually the preferred protocol.

It is also necessary to consider physical installation limitations. The Passiv hub needs to have a hard-wired Ethernet cable for its internet connection. This puts some constraints on a wired heat pump interface, as the customer broadband router is unlikely to be next to the heat pump. Workarounds are available such as powerline adaptors or a Wi-Fi access point for the hub but it is always important to consider complexity.

The following possibilities for communicating with the heat pump were considered:

- Z-Wave wireless (heat pump incorporates a Z-Wave module)
- Modbus-RTU (wired serial)
- Ethernet or IP connection (heat pump is also connected to the home LAN, and exposes perhaps a REST API).
- Other protocol via serial (possibly via adaptor)
- Other protocol via USB (possibly via adaptor)

4.15 Branding

The branding logo for the project was designed as shown below. Synergy produced the branding logo.

Figure 5: Branding

4.16 Deployment

The project required the design, build and testing of a new system that allowed the customer and networks to utilise, as required, the hybrid heat pumps for mutual benefit. 75 homes with hybrid heating systems were deployed. The 75 hybrid heating system installation work package commenced in June 2017 and was completed in early October 2017. Typically, a hybrid heating system installation was completed in 2 to 3 days and an additional day was allocated for the installation of the meter and monitoring equipment.

4.16.1 Commissioning and Installation

The process for installation and commission began with adding new homes to the PassivSystems portfolio and the creation of a user management account. Adding a home includes details of its address and location. Additionally the product for that home is selected at this time. This product determines which monitoring and control services will be enabled for the home and which kit needs to be installed to satisfy the service requirement. New services covering energy and products monitoring, hybrid heat pump control and demand management were created for the project.

Three heat pump manufacturers were used (MasterTherm, Samsung and Daikin), sized as small as possible (5kW, except MasterTherm units at 8kW). The final split of customer types was 40 social tenants and 35 private homeowners. We had 16 Daikin Altherma hybrid systems, 43 MasterTherm/Vaillant hybrid systems and 16 Samsung/Worcester hybrid systems. Almost all of the installations involved fitting new gas combi boilers and air source heat pumps, with no radiator upgrades or additional insulation fitted. A few houses had slightly different installations – one with a retrofitted heat pump to their existing gas boiler and three with a system boiler (i.e. with a hot water cylinder). The performance was measured under a number of different operating scenarios. The gas boiler was generally a new highly efficient combination boiler (providing instantaneous hot water), but the trial also encompassed three system boilers with a hot water tank configuration, and a heat pump retrofitted to an existing boiler configuration. To ensure that all the installations were compliant, independent assessments of all hybrid installations were carried out by Gas Assessment and Training Ltd.

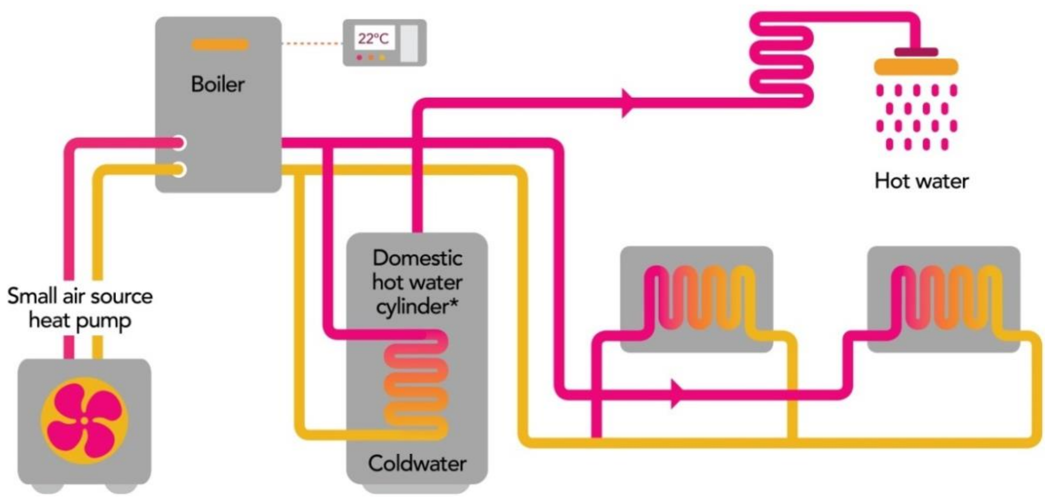

Figure 6: Configuration of a Hybrid Heating System

Below are some of the installations from the trial:

Figure 7: Daikin Units Installation

The Daikin Combined units were all installed by WDS Green Energy.

- MasterTherm Heat pumps - 8kW

The MasterTherm and the Vaillant boiler were installed by Thermal Earth.

Figure 8: MasterTherm Installation

Figure 9: Samsung Installation

The Samsung heat pumps and the associated Worcester Bosch boiler were installed by Spire Renewables.

4.16.2 Measurement Points Included:

- Low-resolution whole-home gas and electricity metering (where possible, only a minority of homes)
- High-resolution measurement of electricity consumption and heat production of the heat pump
- Pipe temperature sensors to measure heat delivery temperature (e.g. radiators)
- Room temperature sensors in main living area and bedroom, and bedroom humidity

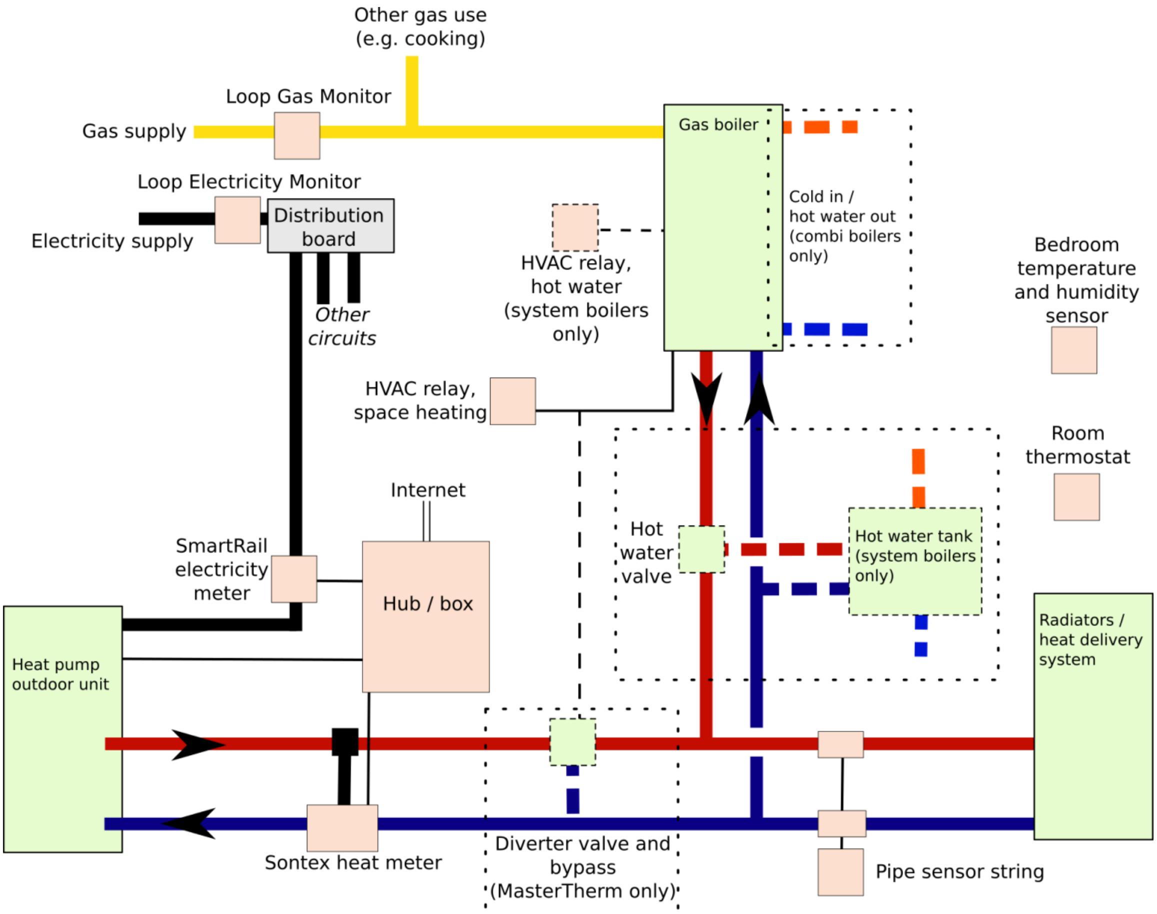

Figure 10: Schematic diagram of physical equipment deployed in a Freedom installation.
Note: that the Daikin configuration is different as the boiler and heat pump have a "series" plumbing arrangement within the integrated unit.

4.16.3 Control Configuration

All triallists were provided with the PassivLiving smartphone app which enabled them to choose how warm they wanted to be and at what time of day (heating schedule); they could also adjust settings live via the app or a physical room thermostat. The app also provided feedback on whether the system was running, which fuel was in use, context sensitive questions and answers, budgeting tools and graphical explanations of past and future operation (looking 12 hours back and 12 hours ahead).

The system used PassivSystems' optimised control strategy which ran the hybrid heating system at least cost to the householder (determining fuel choice and temperature of heat pump operation). Constraints were imposed during interventions, but the system always sought the lowest cost strategy to meet specified comfort levels. All homes were controlled in a manner that assumed the absence of RHI (Renewable Heat Incentive) payments.

4.17 Planned Interventions

Over the course of the Freedom Project main field trial, a number of interventions were planned by PassivSystems R&D team, where the control strategy of the heat pump was adapted to explore various scenarios and meet the research objectives of the project:

- Different fuel cost ratios (i.e. lower electricity price relative to gas) to explore future price scenarios;
- Fixed patterns of time-varying electricity tariffs and restricted-consumption periods as a simple proxy of the smart grid;
- "Impulse" experiments to look at the effects of highly simultaneous fuel switching on both electricity and gas networks;
- Aggregated demand management to simulate avoiding the capacity limit of an electricity subnetwork.

4.18 Data Analysis

Obtaining good quality data was a key factor of success for Freedom. The design phase was predicated on the achievement of a robust, but viable, design that could deliver the requirement in the timescales. We believe that this was a considerable achievement given the complexity of the requirement. Therefore to get good data we see as a particularly strong message for Freedom.

The analysis of the data has been another challenge because of the volume of data and the amount of analysis required in order to test the hypothesis. However, this has been completed and the full results are detailed within the Final Report, a link to which is provided within Section 10. Most of the data analysis was based on data interpolated to half-hourly intervals. Aggregate data sets averaged all of the homes that were available for the period in question and not experiencing any faults, so were presented in units similar to "kW per home"; the number of homes that contributed varied with time.

Heat output data was not straightforward to acquire: there was no heat meter on the boiler, and the heat pump heat meter could be affected by boiler operation. Heat meter data presented in this report was pre-processed to give meaningful results:

- Heat output for the heat pump was the heat meter reading during periods when we knew the boiler was off.
- Heat output for the boiler was inferred by using a "virtual heat meter" that utilises the pipe temperature sensors on the radiator pipes. The flow rate was either measured directly (Daikin), or assumed to be the same as during heat pump operation (MasterTherm/Samsung). Either way, the boiler heat figure was an approximation but had been validated against loop gas meter reads where available or there was a good match given likely boiler efficiency of 90%.
- For COP/SPF calculations, data was only included when both electricity and heat readings were available for that half hour, and both above zero. This means examples for defrost cycles when the heat pump wasn't otherwise running may not have been fully accounted for.

4.19 Customer Engagement

Freedom was a long project and throughout, it was important to maintain a consistent dialogue with the customers. This in itself was a considerable lesson for WPD, WWU and all the partners in that the amount of effort required was considerably more than we had anticipated. However the main outcome that others including DNOs can take from the project in this regard were:

- Customers were generally positive about the project.
- There were some significant lessons for the industry we feel about engaging with customers in innovation projects.
- It is extremely time consuming to engage with customers and maintain the level of engagement required for this type of initiative and whilst we have gained valuable insights, we have to consider the wider value for money aspects of these solutions. Throughout the Freedom Project a combination of in-depth interviews, focus groups and surveys were utilised at various stages of the trial in order to assess customer experiences and perceptions of smart hybrid heating systems. Delta-ee also completed one GB representative survey with its own customer panel.

4.20 Decommissioning

Following the Freedom Project expiry letter that was issued in May 2018, 8 homes wished to have either their controls removed or revert back to a standard combi-boiler.

- 3 WWHA homes with MasterTherm had requested the removal of their hybrid and to be reverted back to a combi-boiler,
- 3 Samsung homes had requested the removal of their hybrid and to be reverted back to a combi-boiler
- 1 Samsung home asked to keep the Passiv controls but with improvements - PassivSystems installed a 500 series z-wave thermostat.
- 1 Daikin home requested to revert back to standard Daikin controls.

5 Performance Compared to Original Aims, Objectives and Success Criteria

The project has addressed all aspects of the energy trilemma, with specific focus on heat and the potential for hybrid heating systems to be transformational in delivering solutions that will shape future energy market dynamics. As a result of the Freedom Project, smart hybrid heating systems have demonstrated that they are the enabling technology in the BEIS long-term strategic heat pathways, providing the opportunity for partial electrification combined with decarbonised gas in hybrid heating systems, as well as identifying the opportunity for hybrid heat networks.

The findings of the project will contribute to the challenge of reducing carbon emissions at the lowest cost impact for domestic consumers by delivering increased heating system efficiencies, and a reduced unit cost from the energy supplier for energy consumed by the hybrid heating system. The project has completed a comprehensive range of demand response events to demonstrate the ability to deliver electrified heat while protecting energy network security and optimise fuel vectors on carbon intensity. Algorithms have evolved and been refined based on actual field and market data over the duration of 2017-2018 winter season.

The project found that at today's prices, it is rarely cost-effective to operate the heat pump; and even in the scenario that gas prices increase by 50%, it is only worthwhile for the heat pump to take 40–50% of the heat load.
For all homes, a 5kW heat pump capacity was sufficient to deliver this heat load – and having a bigger unit could compromise efficiency. The situation was different for off-gas-grid homes on much more expensive LPG (Calor gas), where the heat pump could offer the householder significant running cost savings and took 78% of the heat load. Here the fuel switch to gas happened for appliance capacity (rather than economic) reasons, and automated switching to the boiler when the heat pump was unable to keep the house warm was demonstrated, without any noticeable thermal comfort on the householders.

The hybrid fuel-switching strategy that is most cost effective for the typical household is continuously varying, gentle heat pump operation with bursts of gas boiler use as required – very different from a conventional hybrid system switching fuel based on external temperature (a relatively poor strategy). Energy consumption patterns were hugely diverse between homes, but in aggregate the electricity demand profile is quite flat, with small peaks in demand occurring at around 04:30 and 14:00, and minimum consumption around 22:00. This is a very different shape from conventional assumptions, where peak demand coincides with other electrical demand – illustrating that for a smart hybrid, the best operating pattern for a householder also benefits the electricity grid. Gas demand patterns varied more strongly but there was no evidence of sudden changes that could cause problems for the gas distribution network.

6 Required Modifications to the Planned Approach during the Course of the Project

The delivery methodology at the outset was envisaged as a traditional waterfall one with a series of dependent phases.

Freedom did not require any changes to its approach. It did however require two separate phases during its lifecycle to review the milestone on recruitment and the success of the pilot trial. No change in Methodology (it remained a waterfall delivery) was required throughout the project

7 Project Costs

Activity	Budget (£)	Actual (£)	Variance
WPD Project Management	70,000	86,325	-23%
Passiv Systems Contract	1,562,447	1,569,949	0.5%
Wales & West Utilities	1,762,709	1,762,709	0%
PassivSystems Contribution	182,550	182,550	0%
Branding Fees	4,000	3,495	0%
Dissemination	8,000	8,470	-0.1%
Total	3,589,706	3,613,498	0.7%

Table 6: Project Costs

The total project was successfully delivered approximately 30% below the project budget of £5,182,380 despite above expected interest in the project from stakeholders and the number of events we attended and disseminated at.

8 Lessons Learnt for Future Projects

- Personnel and Coordination: Working on a large multi discipline project requires coordination among the people with very different responsibilities. It is vitally important that these roles are clearly defined at the start of the project. While there are a variety of tasks being undertaken to complete the project, it is inherently useful if all project members are aware of the roles of others to minimise misunderstandings around tasks. It is also important that sub-contractors do not rely on a single person as this can cause unexpected delays. Coordination between installation teams is always vital to prevent making multiple visits to the property: Once the hybrid system installation and the meter and monitoring equipment had been installed, PassivSystems would enter the home and connect these items to the Passiv hub. Between the homeowner, the installation contractor and PassivSystems we had to arrange availability to do this and it took more effort/coordination than expected. In future, the installation contractor will connect the hybrid system, meters and monitoring equipment straight after the hybrid system has been installed – this will provide a fluid process and minimal visits to the home.

- Customer engagement: During the earlier part of the trial we learnt that consumers needed to know about the project to a comfortable level of detail. We had continued to engage with them throughout the trial period to ensure that sufficient information was made available to them.

- Incompatibility with equipment during installation: Sontex heat meter used was not compatible with the Daikin unit. The installation contractor attempted to fit the Sontex heat meter to the Daikin unit, however, could not fit the final temperature sensor probe as it was too big to integrate with the unit. A Danfoss heat meter was eventually used and this required a second visit for the installer to fit the unit and a second visit for PassivSystems to connect to the hub, which was an inconvenience for the homeowner.

- Main installation work: Following the installations from initial phase, we ensured that lessons learnt during this period were implemented in the second phase of the project. As installation can be challenging we sought feedback from the installers. This is discussed below:

- How easy was it to install a hybrid heating system?
  The connection style that was used to connect the heat pump to a new combi boiler made the installations extremely simple and resulted in negligible down-time for the consumer. Cutting two isolators onto the feeds to the heat pump meant we could get the new boiler up and running on the first day onsite (providing the boiler replacement was straightforward), whilst simply connecting and powering on the heat pump once the electrical modifications had been done.

We left the consumer not aware of any drop-off in hot water/heating production throughout the install process.

- What were the challenges of installing a hybrid heating system?
  Initially it was finding properties with sufficient indoor space to connect the heat pump into the boiler – we countered this as the project progressed by designing a weatherproof enclosure so they could be fitted externally. The main retrofit challenges we faced were in modifying the electrical supply and running new feeds for the heat pump, in some cases through the cables around the building, which could pose a challenge. This was especially the case in some properties with 600mm stone walls and issues with coring and the wireless communication elements, but as the installations progressed we became better and better at overcoming these issues once we learnt the realistic range of the components we were working with.

- How did we find installing the PassivSystems controls?
  Using a centralised box which housed all of the PassivSystems control equipment made the connections nice and easy – the use of wireless pairing between the thermostat and the Internet via power connections made connecting all of the components extremely simple.

- How did we find educating the customer on the hybrid heating system?
  The process was well documented - as the winter progressed we learnt a lot about the location of the thermostat in the property being key to customer satisfaction. Educating the customer on the fact that they would have the heat pump running at a time where they hadn't necessarily asked it to run (where it was pre-heating prior to an in-period on the thermostat) was initially a challenge but we learnt as the winter progressed and we resolved a couple of issues and re-educated customers which fully resolved the issues.

- How did you find educating the customer on the PassivSystems controls?
  The app control and access was well-received by our customers.

- What customer challenges did we have?
  Getting the customers used to the heating running well in advance of their requested time and thermostat location being key to customer satisfaction, were the two main issues we discovered.

- What can be done to make it easier to install hybrids?
  The physical installation of the hybrid system was actually extremely simple, especially when compared to the "heat pump only" retrofit installs we normally work on. System boilers posed an added complication (we primarily worked with combis for our installs) – it would be interesting to see a solution for these as they represent a substantial portion of the off-gas network.

- What can be done to make it easier to install PassivSystems controls?
  Some of the data recording requirements of the Freedom Project made the physical size of the box quite tricky to manage. The box had a number of wireless pairing elements with different sources in different locations, which made siting the box occasionally fairly complicated. A lot of these elements would be unnecessary on a commercial roll-out of the hybrid systems which would actually result in a smaller box with fewer wireless pairing elements. A longer range thermostat would have helped in a couple of the properties but to be frank, any wireless thermostat would have struggled to pair given the dense construction of some of the target homes.

- How could we sell/install more hybrid heating systems? What would be the challenges?
  As the technology is not that well-known yet, it can be tricky to sell the benefits of such a system.

- Early adopters often require more detailed cases to persuade them to uptake new technologies but there are substantial benefits (redundancy, managing future fluctuations in energy supply prices and demand) hybrid systems offer. By getting the energy providers onside to offer flexible electricity and gas tariffs that add a substantial incentive to the home-owner would be a major step forward in hybrid heat pump uptake.

- If there was a large nationwide scale deployment what challenges would we face?
  Scaling up and educating nonexperienced tradesmen would be absolutely key as we would be building a consumer model that provides sufficient benefit to those on the mains gas grid to buy into the new technologies.

- Loss of Communication: Seven of the Samsung heat pumps went offline. Working with Samsung we installed an additional piece of hardware, SNET module, to the Samsung heat pumps.

- Complaints: We received a complaint from one of the triallists on the 9th of March 2018. The triallist expressed dissatisfaction with the electrical wiring in his home due to the installations we carried out. He also complained about the expected savings he was promised over a 7 year period by our installers. WPD offered him a compensation package to cover for all the repairs to his property and inconvenience caused. However, the triallist declined the offer and indicated that he was taking the issue to the next level. We received an email from the Bridgend Member of Parliament asking for clarification on the matter which we have since responded to. No further contact with WPD at the time of this report. WPD have closed the complaint.

- Demand Flexibility: The key flexibility offered by PassivSystems hybrid heating system is the ability to turn off electricity consumption immediately and indefinitely, without impact on householders, as heating can be provided by the gas boiler instead. For a heating control technology to succeed, it is crucial that householders get the thermal comfort they need and perceive that heating systems are running cost-effectively. Freedom trial homes were successfully maintained at the comfort levels specified by the occupants for the vast majority of the time. Significant project effort went into developing app features targeting at building trust and understanding, and most users responded positively to app-based control. Some triallists struggled with the transition from very direct control of their heating (turning a boiler on and off) to indirect control where they specified desired comfort levels – even though the latter should in principle lead to better outcomes for them (cost savings and better comfort). Some people perceived that the system was wasting energy by running when it didn't need to (e.g. overnight), whereas in fact the most efficient way to run a heat pump is constantly and gently. This challenge is fundamental to the transition of households to low carbon home heating that incorporates a heat pump, and there is an important role to play for PassivSystems smart app-based systems that can help people understand the changes and easily accomplish the adjustments to comfort levels that they need.

- Economics: Current consumer gas and electricity prices are hugely unrepresentative of their relative carbon emissions, and "green taxes" have significantly increased electricity prices, having the perverse effect of pushing consumers away from using renewably-generated electricity for low carbon heating. There is little economic basis for most householders to switch to a hybrid heating system (although the Renewable Heat Incentive provides some contribution), with the exception of off-gas-grid homes where there is a huge and immediate opportunity.

- Technology readiness: The benefits of hybrid heating systems can only be fully realised if PassivSystems' smart control system is in place that can coordinate the needs of individual households (affordable comfort) with network-level requirements (peak demand or carbon limitation). The biggest technological barrier is that most hybrid-ready heat pumps are not ready for smart digital control: it is recommended that manufacturers are required to provide open interfaces with an appropriate level of third-party control. Likewise, although not tested in the Freedom Project, open interfaces for third party control of boilers is required to maximise Boiler Plus benefits, such as load-compensation modulating control and range-rating boilers to the specific space heating requirements for each home, combined with flue heat recovery where appropriate.

- Policy: Current policies, such as RHI, have no requirement for smart controls for hybrid heating systems (or for indeed any heat pumps). The Freedom Project learning has shown that this is a major error, as inflexible electric heating is a risk to national infrastructure, compromises carbon reductions and does not give best value to end consumers (conventional hybrid heating controls are quite poor and revenue opportunities are lost). It is essential that the national whole-energy system evolves such that the inherent storage available in the gas distribution network can be utilised to balance the grid: this is entirely contingent on smart controls that enable quantitative aggregate demand management.

- Consumer acceptance: The transition to efficient, low-carbon heating with heat pumps in a hybrid system requires a change in the way homes are heated, and for this to be successful any approach needs to be consumer-focussed. A change to full-electric heating would be much more significant. More work is needed on how to best communicate with the diverse range of end-users, to ensure they feel fully in control of their thermal comfort and have confidence that complex hybrid systems are working in their best interest. Smart systems (such as the one demonstrated in the Freedom Project) are required to properly balance consumers' requirements with national and network requirements. Alternative home heating from a heat pump alone requires in-home retrofitted insulation measures and changeover to low-temperature radiators that brings significant cost and disruption – the avoidance of this issue provided by smart hybrids is a much more appealing proposition to consumers.

8.1 Dissemination Events

Learning has been a fundamental part of the success of Freedom. It has been a very informative exercise for WPD and its partners and helped shape how knowledge on innovation projects should be managed in the future.

Throughout Freedom project there has been a series of stakeholder events, including the report launch in the House of Commons, Site workshops, and LCNI events for broader consultation. WPD and its project partners have engaged extensively with various stakeholders and other participants involved in DSR and heating across as wide a spectrum as possible and this can be seen in the next section where various events took place during the project. More detailed information about the process and findings can be found in the final report in this area, various links to which can be found in Section 10. Also worth mentioning that at the 2017 & 2018 LCNI Conference in Telford we have had a Freedom model on exhibition and shared knowledge through the events with other DNOs and Stakeholders.

Listed below are some of the dissemination events on the project.

Event	Date	Location
Future of Gas, IGEM South West	09/11/16	Bristol
Welsh Baccalaureate – Global Futures	01/12/16	Newport
Cardiff University	30/01/17	Newport
Carbon Connect	08/02/17	London
Low-carbon Heating Technical Innovation Workshop	14/02/17	BEIS, London
Calor Gas	09/03/17	Newport
Welsh Government Smart Living Dinner & Workshop	13/03/17 – 14/03/17	Cardiff
IGEM Event	21/03/17	Newport
Alternative Gas Workshop	27/03/17	Bristol
Welsh Government Energy Futures Event	30/03/17	Cardiff
BEIS Freedom Meeting	04/04/17	BEIS, London
BCBC & Welsh Gov't	05/04/17	Bridgend
Welsh Gov't Hydrogen Event	27/04/17	Port Talbot
BEIS Heat Team Delegation Visit	04/05/17	Newport
Policy UK Heat Event	09/05/17	Westminster
Utility Week – Wales Energy Conference	16/05/17	Cardiff
IEA Heat Pump Conference	15/05/17 – 18/05/17	Rotterdam, The Netherlands
BEIS Hybrid Consultation	23/05/17	Virtual
Welsh Government	25/05/17	Cardiff
Constructing Excellence in Wales	26/05/17	Newport
PassivSystems All-Staff Dissemination	30/05/17	Newbury
Panasonic Manufacturing UK	31/05/17	Cardiff
Welsh Gov't Smart & Low Carbon Workshop	29/06/17	Neath
Wardell Armstrong Energy Team	30/06/17	Cardiff
IGEM Road to 2050	04/07/17	London
Energy Systems Catapult	06/07/17	Birmingham
UKCCC & WG	07/07/17	Cardiff
BEIS Freedom Meeting	13/07/17	BEIS, London
IGEM Event	15/06/17	Birmingham
ERP Heat Workshop	18/07/17	BEIS, London
UKPN Innovation Meeting	24/07/18	Newport
Neath Port Talbot Local Authority Energy Manager	28/07/17	Neath

Panasonic Manufacturing UK	02/08/17	Cardiff
UKCCC Delegation Visit	10/08/17	Newport
Centrica Energy Futures	21/08/17	Newport
FLEXIS Global Launch – with Welsh Gov't	21/08/17	Cardiff
BEIS Hybrid Consultation Workshop	22/08/17	BEIS, London
CKI Freedom Meeting	11/09/17	Virtual (UK-Hong Kong)
Element Energy – Hybrids	19/09/17	Virtual
Welsh Government – Networking for Innovation	21/09/18	Cardiff
IEA Heat Pump Conference	26/09/17	BEIS, London
IEA Annex45	05/10/17	Utrecht, The Netherlands
WPD Balancing Act	05/10/17	Westminster
ERP Low Carbon Heat	11/10/17	London
UKOPA	17/10/17	Edinburgh
BEIS Freedom Meeting	19/10/17	Newport
Energy Systems Catapult	25/10/17	Newport
Kensa	09/11/17	Newport
Welsh Gov't Onshore Renewable Energy Team	10/11/17	Cardiff
APPG Intelligent Energy	22/11/17	House of Commons
Regen Renewable Futures	28/11/17	Bath
LCNI	06/12/17 – 07/12/17	Telford
BEIS Heat Workshop with DNOs, GDNs & TSOs	11/12/17	BEIS, London
BEIS Clean Growth Event	11/12/17	House of Lords
UKCCC-Welsh Gov't Carbon Budgets Event	19/12/17	Cardiff
BCBC Local Area Energy Strategy	20/12/17	Bridgend
ESC – Philp New meeting	29/01/18	Newport
BEIS Freedom Meeting	31/01/18	BEIS, London
Welsh Gov't Senior Civil Servants	01/02/18	Cardiff
Freedom Interim Report Launch	07/02/18 – 08/02/18	Cardiff
EUA Event	13/02/18	Kenilworth
Institute of Welsh Affairs Energy Event	12/02/18	Bangor, North Wales
NEA	20/02/18	Newport
UKCCC Meeting	15/03/18	Newbury
BEIS Heat Workshop with DNOs, GDNs & TSOs	24/04/18	ENA, London
British Embassy Heat Event by BEIS	26/04/18	Berlin
Ynni Glan	02/05/18	Newport
BEIS Visit	02/05/18	Newport
CKI Future Technology Conference	07/05/18 – 08/05/18	Hong Kong
Utility Week – Wales Energy Conference	16/05/18	Cardiff

Utility Week Live	22/05/18 – 23/05/18	NEC, Birmingham
Delta-ee Webinar	23/05/18	Web
Welsh Gov't Milford Haven Zero Carbon Area	08/06/18	Cardiff
Amber Energy	11/06/18	Cardiff
SWECO Energy Team	13/06/18	Bristol
Welsh Gov't Decarbonisation of Housing	11/06/18 & 8x more since so far	Cardiff & Swansea
Regen Smart Energy Marketplace	19/06/18	Exeter
WPD Balancing Act	20/06/17	Westminster, Great George Street
Policy Exchange	21/06/18	Westminster
APPG Energy Studies (Claire Perry)	26/06/18	House of Commons
Cardiff City Region Event	27/06/18	Cardiff
UKCCC Event	28/06/18	Portcullis House
BEIS Data Meeting	03/07/18	Newbury
Smart Energy Wales	04/07/18	Cardiff
Westminster Forum	05/07/18	Belgravia, London
Carbon Connect	10/07/18	House of Commons
Welsh Gov't Cabinet Secretary Meeting (Lesley Griffiths)	12/07/18	The Senedd, Cardiff
Northern Gas Networks	18/07/18	Leeds
Bright Blue (Think Tank) Heat Consultation	23/07/18	Virtual
Exeter University	22/08/18	Newport
Alan Whitehead MP Meeting	03/09/18	Port Talbot
Welsh Gov't – Freedom Customer Proposition Meeting	07/09/18	Cardiff
UKCCC Meeting	20/09/18	Virtual
BEIS & IEA Heat Pump Event	25/09/18	BEIS, London
IEA Annex45	27/09/18	BEIS, London
Worcester Bosch	06/08/18 & other dates	Worcester
Eisteddfod	08/08/18	Cardiff
Freedom Report Launch Event	09/10/18	House of Commons
Welsh Gov't Cabinet Secretary Meeting (Lesley Griffiths & Huw Irranca-Davies)	11/10/18	Bridgend
LCNI	16/10/18 – 17/10/18	Telford
Claire Perry Meeting	18/10/18	Cardiff
Welsh Gov't Cabinet Secretary Meeting (Vaughan Gething)	19/10/18	Cardiff
Welsh Gov't – Freedom Next Steps	13/11/18	Cardiff
Westminster Forum	15/11/18	Belgravia, London
Hy4Heat (BEIS/ARUP)	15/11/18	Marylebone, London
Imperial Heat Event	15/11/18	Kensington, London
Imperial Private Dinner	15/11/18	Kensington, London

UKCCC Committee & Secretariat Meeting	22/11/18	Cardiff
UKCCC & Welsh Gov't Private Dinner	22/11/18	Cardiff
UKCCC-Welsh Gov't Event	23/11/18	Cardiff
Regen Renewable Futures	27/11/18	Bath
APPG Energy Studies	04/12/18	House of Commons
Welsh Gov't Milford Haven Zero Carbon Area	11/12/19	Cardiff
Welsh Gov't – Freedom Next Steps	21/12/18	Cardiff

Table 7: Dissemination Events

8.2 Awards and project recognition

Event	Date	Attended by	Category	Location
Regen Green Energy	27/11/18	WPD, WWU & PassivSystems	Green Energy System Disruptor	Bath
Business Green Awards	07/12/18	WPD & PassivSystems	R & D Technology of the Year	London

Table 8: Award Events

9 The Outcomes of the Project

9.1 Key Learnings from the Project

Whole energy systems modelling has demonstrated that smart hybrid systems can deliver a no-regrets transition to low carbon heat, which offers a significant financial saving compared to a full electrification scenario. Indeed, the carbon outcome improves with hybridisation, as during cold weather and periods of low renewable power generation natural gas is burned at higher efficiency in domestic boilers than if it were burned in peaking gas generation plants with the associated network losses during transmission to the home.

As the gas demand on the system is reduced by hybridisation, so the opportunity for green gas is presented to further reduce carbon emissions. Green gas technology, such as biomethane, BioSNG and hydrogen blends combined with smart hybrid systems provides a long-term solution for low carbon heat.

Off gas grid homes within the trial using LPG provided insight into a future energy system with a fuel price ratio representative of future renewable gas prices. One of these homes was an exposed stone-built miner’s hillside cottage where the heat pump carried 78% of heat demand over the winter, significantly reducing gas consumption and saving the customer £736 on their winter heating bill without any requirement to improve the thermal efficiency of the building or replace any radiators. The customer said…
“We would be reluctant to use our heating before the hybrid heating system was installed, I was conscious of cost but now we are seeing huge savings and we did not need to top up LPG this winter. I feel more in control of my heating system and the home is always warm when we require heat.”

The project successfully demonstrated that hybrid heating systems were able to maintain consumer comfort across a broad range of housing types, ages and sizes representative of existing housing stock, with consumers from a range of socio-economic groups (private and social housing). The smart control switched between appliances driven by cost – supporting the decarbonisation of heat in an affordable way and with limited behaviour change.

Systems met warmth and comfort demands in all homes over the winter without making any changes to the existing wet heating system or installing any thermal improvements to the property. This is in sharp contrast to a pure heat pump solution, which requires a thermally efficient building and larger radiators to deliver required set points using lower flow temperatures than a boiler.

The heating controls used predictive optimisation of running costs to enable the heat pump to pre-heat the building ahead of an occupancy period, thereby spreading the heating load and operating the ASHP at a low flow temperature to optimise efficiency. The aggregated load of all homes was predicted by half hour for the 24 hour period ahead using weather forecast data, learned building thermal properties and comfort schedules for each home. Constraint instructions were then added, for example to minimise carbon emissions or to limit power demand in each home or at portfolio level, resulting in a responsive change to the heating strategy from any signals received.

When there is insufficient renewable electricity generation, when it is very cold and/or when there are capacity constraints in the national or local electricity network, the heat load can shift across to the gas network, and vice-versa, to provide uncompromised heat, flexibly using the vast energy storage within the gas system (210TWh seasonally).

Freedom Project hybrid systems provide a potential solution to deliver mass market decarbonisation of domestic heating whilst providing comfort and value to consumers, avoiding demand peaks on the electricity system that would require large additional investments in electricity transmission and distribution networks and a substantial reserve of generation capacity.

The energy system benefits demonstrated in the field trial were modelled at a whole system level by Imperial College. In a low-flexible system, the Freedom smart controlled hybrid heating controls, combined with flexibility and balancing services, indicated savings of up to £15.2 b/year compared to heat pumps alone, with the greatest savings delivered in a system with stricter carbon intensity targets for electricity supply.

Project partner PassivSystems have identified an emerging proposition for heat as a service which can be deployed now, which benefits from third party assignment of rights to the RHI and avoids the initial household conversion costs falling upon the consumer. PassivSystems believe that the combined value of fuel arbitrage and flexible energy system services could replace the RHI; however a bridging incentive would still need to be in place post March 2021 until market changes have been effected and economies of scale have been achieved.

Freedom installations with new boilers, ASHPs and controls equipment are estimated to typically cost ~£7.5-9.5k per home with a ~50:50 split between hardware and installation costs. Initial dense roll-out could achieve a significant saving on this with reduced risk and early benefits from economies of scale, reducing to ~£4k with large-scale proliferation and an established market. Cost improvements could clearly be made where the existing boiler is able to be retained. The up-front cost to consumers could be overcome with provision of heat as a service.

9.1.2 Market, Regulatory & Policy Recommendations

The outcomes achieved by the Freedom Project demonstrate that hybrid heating is a viable, cost effective, consumer friendly, energy system supporting solution to decarbonise UK domestic heating. A lot of the benefits can be achieved quite simply, but according to analysis done by Imperial College the full power could be unleashed through a number of policy changes to enable and amplify a wide scale market for smart hybrid heating, including:

- The value of flexibility should be recognised across short, medium and long timescales to recognise frequency, intermittency and capacity benefits.
- Demand side access to the markets should be available to distributed forms of flexibility with respect to size of the demand and the length of service contracts.

- More dynamic market price signals and locational pricing and emissions could incentivise availability of flexibility when and where it is most needed by the energy system.
- Incentives should be tailored towards smart, optimised low carbon solutions that unlock benefits with the broader, integrated, whole energy system.
- Decarbonisation policy costs are added to electricity bills – removing these would improve the electricity: gas price ratio to support cost-optimised use of ASHPs in smart hybrids.

9.1.3 Customer Engagement

- Installation feedback: Overall the majority of installations were problem free (76% of respondents) and there was a high level of trust of the installer (85% stated they trust them). However, where problems with installation arose, less than 20% of respondents were satisfied with how this problem was resolved. This suggests that post-installation customer service requires improvement.

- Initial customer experience of the hybrid heating system was positive. At the mid-way point, hybrid heating systems had a high approval rating with over 60% of respondents stating that their initial trial experience had matched their expectation. A majority of respondents also stated that they would recommend a hybrid heating system to their friend. The hybrid heating system environmental friendliness, ease of use and provision of heat/comfort are the aspects of the system most valued, and the results indicated that the looks of the system, running cost and maintenance are potential customer concerns

- Running cost savings are a concern for participant: Running-cost savings were never included as part of the trial aims – but throughout customers has fixated on them. As a result, this has been the most unsatisfactory part of the trial for customers. Challenging customer perceptions on the running costs, and ensuring the right incentives and prices are in place for success, will be critical to long-term hybrid heating system success outside of the trial. The high running costs reported by some customers have not been substantiated and also indicate confusion about how customers may understand and interpret their bills.

- Customer attitudes and appeal towards the hybrid heating system: Economic factors are key criteria for mass market success and business models will be needed in the near term to ensure that hybrid heating systems can offer cost-comparable solutions to existing heating systems. The reliability of the system is critically important, providing more data on how the system is working may ensure that confidence on this point is improved. Including a smart app in any bundle when a heating system is purchased would improve customer confidence, both in terms of convenience (and making it more existing for them) and in reassurance (so they can see the system is working as it should).

Involving customers in the siting of the system is important for gaining acceptance of the outside unit and should be standard procedure at installation to improve satisfaction.

- Shifting customers away from gas boilers being their sole source of space heating will be a challenge – customers are overwhelmingly positive about their existing heating system. Ease of use, comfort, reliability and up-front and running costs are the primary aspects of a heating system that customers value. The hybrid heating system performs well with respect to ease of use and comfort provided but the up-front costs and operating costs of hybrid heating systems today are likely too high for many customers. In order for customers to engage with smart hybrid heating the systems must be able to compete on the priority areas of running costs, reliability and comfort. When combined with low hybrid system awareness, the scale of the challenge is clear. There is a real need for education among customers, as well as installers (who largely hold the customer relationship). A near-term option could be to target off-gas homeowners, who are more likely to be dissatisfied with their system (and where the economic case is stronger) as a basis for building expertise and customer momentum.

9.2 Next Steps

The Freedom Project partners are now considering new projects that may seek to affirm and extend the work done to date. Projects include the application of hybrid heating in non-domestic buildings, exploring new heat-as-a-service business models, integrating other flexible home appliances to further develop 'Smart Living' within the hybrid energy management system and identifying opportunities for technology innovations to support supply chain cost optimisation.
The Freedom Project team is exploring the potential for valuable follow-on projects:

The FreeNonDom Project is a feasibility study that is currently underway and looking at the potential to apply Freedom smart hybrid controls in nondomestic buildings, such as offices, schools and care homes. This project is looking into, amongst other aspects, heat demand profiles, current controls, current appliances and the range of appliances that could be employed in a potential demonstrator trial, such as gas heat pumps.

Freedom smart controls and all the learning is being taken up to the north east of England to the No Regrets Heating Project, which is a hybrid heating project aiming to use a hybrid tariff to access aggregated demand-side response value.

The Offset Project with Samsung and supported by Freedom partners is due to commence soon. It will investigate smart living homes where the hybrid heating controls integrate and manage the whole energy consumption of the home with controllable appliances.

A detailed, further exploration of the pathway to market and consumer proposition for comfort-as-a-service called Freedom2Choose is currently seeking funding. The Freedom team is supporting the FlexiCell Project that is looking at the benefits of a novel hybrid arrangement using gas-fed hydrogen fuel cells to power ASHPs in a small number of homes. A high-rise building project (HyRise Project), whereby multioccupancy or high-rise building could be converted from individual home gas heating with gas risers to a retrofitted district heating system and heat interface units, supplied from a plant room with a fully optimised and flexible hybrid heat centre running on very similar control algorithms to those developed for the Freedom Project.

A multi-flex home project that combines PassivSystems' smart hybrid heating system, an ultra-low emission vehicle (ULEV) and a smart appliance with different usage patterns and users from different socioeconomic groups. PassivSystems will take its current aggregation platform to provide benefits to the grid directly from PassivSystems' smart hybrid heating system and Vehicle to Grid (V2G) services by balancing domestic heat and local ULEV charge demand to local embedded generation. Consumers will benefit by being able to access service packages that include the smart hybrid heating system, ULEV, rooftop solar PV and grid electricity. Service providers will add value by optimising PassivSystems' hybrid heating system, the charge times to maximise the use of PV generation, lowering electricity costs, and selling the ULEV battery flexibility to the grid. By quantifying the cost and value of different service components through an extensive field trial, partners will build confidence to invest further in innovative new business models.

The potential is being explored to introduce hybrid controls to hybridise a heat network with similar controls developed for the Freedom Project (FreeNet Project), either as central hybrid heat production, or with hybrid top-up from preheated water in the home.

Opportunities are also presented to apply the new energy market, framework and policies required to deliver the full value of multi-service value streams from hybrids and wider flexibility in a transformation town or region, with the South Wales corridor offering a representative blueprint to test the potential for proliferating smart solutions that can be replicated elsewhere.

10 Data Access Details

The scale and timeframe of the project has remained consistent with the registration document, a copy of which can be found here: www.westernpowerinnovation.co.uk/Document-library/2016/Registration-Forms/NIA_WPD_023_5128_Project-Registeration.aspx

https://www.westernpower.co.uk/news-and-events/latest-events/wpd-balancing-act-conference - Balancing Act Presentation slides in the link as PDF document.

https://www.westernpower.co.uk/news-and-events/latest-events/low-carbon-networks-innovation-conference-lcni - LCNI presentation slides in the link as PDF document.

https://www.westernpower.co.uk/innovation/projects/freedom - Freedom progress reports can be found under the documents tab.

Final Freedom report: https://www.westernpower.co.uk/downloads/12221
Summary: https://www.westernpower.co.uk/downloads/12218

11 Foreground IPR

The Freedom final report has discussed how the various IP has been produced during the course of the project. In addition, at the start of the project, the project partners did bring with them some background IP to aid with new developments and processes including Wireframes from City University and hybrid control codes from PassivSystems as well as a range of modelling scenarios by Imperial College.

12 Planned Implementation

It is not our intention at the present time to rollout the hybrid heating system as conditions are not wholly conducive to effectively deploy such a system.

13 Contact

Further details on replicating the project can be made available from the following points of contact:

Future Networks Team
Western Power Distribution,
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