Freedom Project

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Final Report

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Project Partner Foreword

Freedom Project findings point to a breakthrough for home comfort

The Freedom Project is a joint Western Power Distribution and Wales & West Utilities £5m innovation initiative in the Bridgend 'living heat laboratory' in South Wales. Using an air source heat pump and high-efficiency gas boiler hybrid system in 75 residential properties, the project has demonstrated the significant benefits that an integrated whole energy systems approach to deploying smart dual-fuel technologies can deliver.

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The project has shown that using existing utility infrastructure assets, a hybrid approach to heating that harnesses growing contributions of renewable electricity and green gas could deliver the total decarbonisation of domestic heat.

The decarbonisation agenda has already resulted in significant change in the production of energy. The system is changing from one of controllable thermal generation to uncertain renewable generation with high levels of variability.
It is well understood that maintaining security of supply in a decarbonised energy system presents many challenges.
The project findings have shown that smart, flexibly controllable hybrid heating technology can always fall back onto the gas network and present a range of opportunities which maintains high levels of security of supply in an electricity system with intermittent, distributed and weather dependent inputs.

The cost of ensuring continued security of supply with intermittent low carbon power runs into £billions per year if demand flexibility is not part of the solution. The Freedom Project has shown that by using smart control to manage flexible demand, it is possible to significantly reduce energy systems costs by as much as £15billion per year compared to full electrification – with our analysis indicating that hybrids could be the lowest cost pathway to decarbonise home heating.

The biggest challenge in decarbonising heat is how to fund low carbon customer equipment that is more costly than current market solutions, in the case of domestic heating, the gas boiler. Freedom research, carried out by Imperial College, proposes that the energy system benefits of demand flexibility are directed to the consumer to be used to fund low carbon heating assets – providing an attractive proposition which is affordable for customers on and off the gas grid, with off-gas grid homes presenting an immediate opportunity to adopt the technology.

One of the most practical challenges of implementing low carbon heat solutions in homes is the changeover to low temperature systems, such as heat pumps, which can involve costly and disruptive in-home retrofitted insulation measures and replacement of radiators. Hybrid heating avoids these problems and delivers an appealing smart technology solution to decarbonise heat that offers lowest disruption to the householder.

To turn this vision into reality Imperial College academics suggest that a number of market reforms may be required. The future cost of delivering power will be determined by how and when customers consume, not how much they consume. Markets need to be consumer centric, must promote a wider range of consumer choices and must give clear price signals. Those that embrace demand flexibility could expect bills to be half those of inflexible peers consuming that same amount. Energy markets and the objectives of the low carbon agenda need to be aligned, for example aligning the capacity market and Renewable Obligations scheme, demand side response and generation should operate on a level playing field and market prices need to be cost reflective.

By creating these conditions, heating solutions such as that demonstrated in Freedom could thrive, customers would benefit from lower bills and the transition to an affordable low carbon digital energy market will commence.

The UK is a world leader in the technologies that could enable this transformation and our island status with limited interconnection makes the requirement to solve the energy system challenge all the more pressing. The Freedom Project has signposted a way forward to maximise the benefits for consumers and as partners we will continue to build on Freedom's success.

1. Executive summary

The UK has made great strides in decarbonising the power sector and new technologies are starting to drive low carbon transitions in the gas and transport sectors. The decarbonisation of heating remains stubbornly resistant to incentive schemes aimed at promoting low carbon alternatives to the ubiquitous condensing gas boiler.

Solving the heating challenge is complex. Solutions need to reduce carbon emissions whilst providing comfort and value to consumers, avoiding high capital costs and delivering heat without creating capacity peaks on the electricity system that would require large additional investments in network and generation capacity. The Freedom Project sought to develop and test new hybrid control technologies that could deliver low carbon heating solutions in homes that satisfied these criteria and had the potential to deliver the mass market decarbonisation of domestic heating.

The project developed an advanced control platform for hybrid heating systems *(see Figure 1)*, managing heat delivery from both a gas boiler and an air source heat pump (ASHP). The consumer was able to use convenient and intuitive app-based controls to manage their comfort requirements, whilst the aggregated demand from the heat pumps was managed against different grid constraint scenarios.

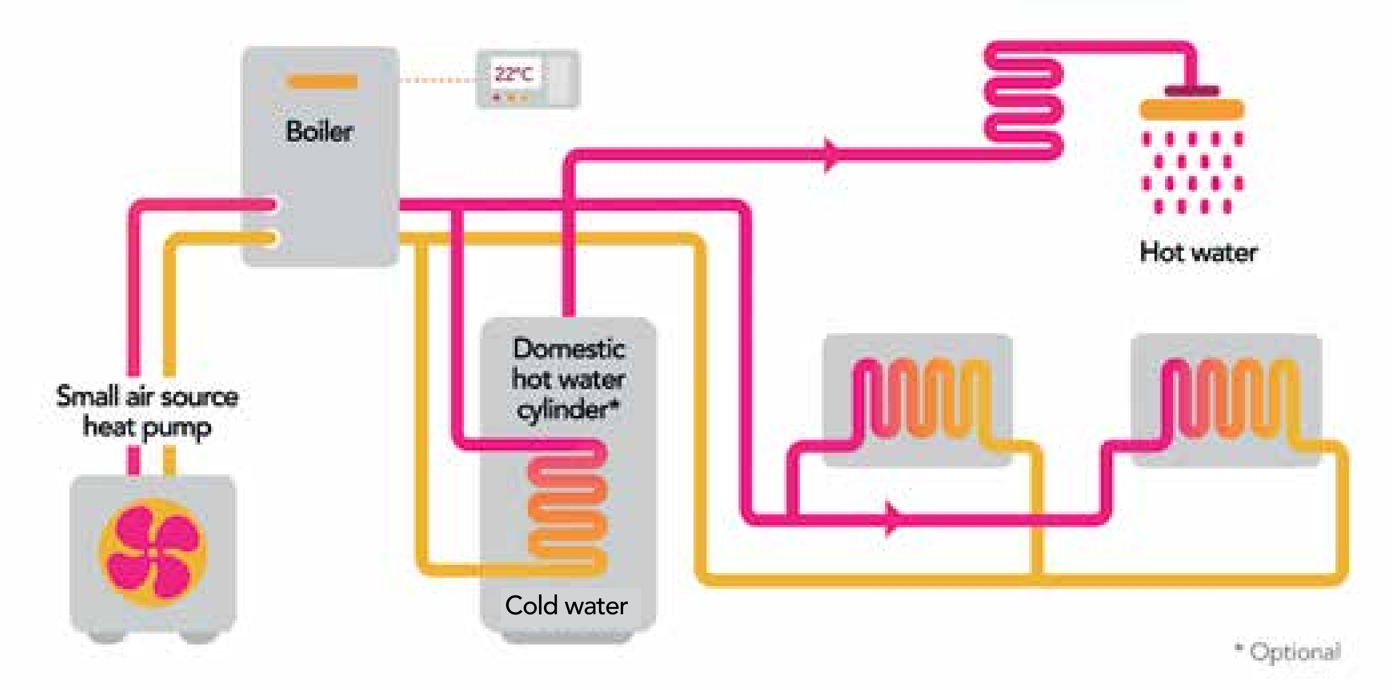


Figure 1: The hybrid heating system

The project successfully demonstrated that hybrid heating systems were able to maintain consumer comfort across a broad range of housing types, ages and sizes, with consumers from a range of socio-economic groups (in both private and social housing). This was achieved without making any changes to the existing wet heating system that was being used for the gas boiler and with no 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.

Hybrid heating systems are viable across all homes on and off the gas grid.

Comfort can be maintained even when using a small ASHP without making any changes to the extant heating system and building insulation.

The systems were operated in a range of different fuel price scenarios, including different ranges of gas pricing and with both fixed and variable rate electricity tariffs. When optimising for consumer cost with today's energy prices, the systems strongly favour gas boiler usage due to the very low cost of gas compared with electricity. However, homes running on Liquefied Petroleum Gas (LPG) boilers achieved large cost savings by **switching around 80% of their heating load onto the ASHP.** When the gas grid connected systems were given artificially inflated gas prices ASHP usage increased, with around **50% heat pump** usage being achieved with a **50% increase in gas costs.** In all scenarios, the control system delivered good coefficients of performance from the heat pumps, despite heat pumps operating at times in **temperatures below -6°C.** These findings show that hybrid heating systems can shift a large percentage of heat demand to renewable power sources whilst delivering good system efficiency using only a small ASHP. Under an appropriate fuel pricing regime, the system has the potential to save consumers money through smart switching of the fuel source.

- Consumer comfort was always maintained regardless of system constraints
- Off-gas grid consumers made significant savings on their heating bills

In a scenario in which **heat pumps deliver 80% of heating demand,** the switch of demand from the gas to the electricity network would create significant electricity network capacity issues.

The project sought to manage this by two different strategies. 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, timing the demand ahead of current system peaks, and operating the ASHP at a low flow temperature to optimise efficiency. This is in stark contrast with traditional hybrid systems that simply switch fuel based on external temperature. In addition, the aggregated load of all homes was forecast by the half hour for the coming 24 hour period. The demand forecast used weather forecast data, learned building thermal properties and schedules for each home to predict the expected demand shape. This shape was then modified by providing constraint instructions, for example to limit power demand in each home or limit power demand at portfolio level.

The field trial demonstrated that hybrids can provide fully flexible loads with the ability to: constrain peak whole-home demand below the existing Elexon Profile Class 1 peak whilst still delivering 50% of the heat demand through the heat pump; enforce a capacity cap across a population, including a cap of zero ASHP demand; increase ASHP demand at times of plentiful low-cost renewable electricity; for the first time ever live carbon forecasts were used so that the ASHP could track grid carbon intensity and avoid times of high carbon peaking plant generation.

The field data has shown that hybrid heating systems can provide fully flexible demand that is able to respond dynamically to network, price and carbon signals and constraints.

- ASHP demand was proved to be fully flexible and able to respond to a broad range of energy system conditions
- Demand can be accurately predicted and capacity constraints can be imposed at both home and aggregated levels and centrally managed

The energy system benefits demonstrated in the field trial were modelled at a whole system level by Imperial College. Their modelling identified energy system cost savings for the responsive hybrid heating system case over the pure ASHP case of £9.3 bn/year in the 100g CO_2/kWh case and £7.4 bn/year in the 25g CO_2/kWh case (where there was limited value from other forms of flexibility). The majority of these savings come from avoided investment in new generation capacity (primarily wind and nuclear) and avoided investment in electricity distribution network capacity. The benefits of enabling system balancing services from responsive hybrid heating systems are an additional £0.9 bn/year in the 100g case increasing to £13 bn/year in the 25g case. The value of different smart pre-heating strategies was also assessed, with the model predicting increases from £2.8 – £3.7 bn/year in the 100g cases to £10.3 – £13.5 bn/year in the 25g cases. **In a low flexible system, the system value of PassivSystems smart controlled hybrid heating combined with flexibility and balancing services is £5.3 bn/year in the 100g case, increasing to £15.2 bn/year in the 25g case.**

The modelling demonstrates that **hybrid heating systems can deliver a no-regrets transition to low carbon heat at a lower cost than the equivalent full electrification scenario. Indeed, the carbon outcome improves with hybridisation,** as during cold weather and periods of low renewable power generation gas is burned at higher efficiency in domestic boilers than if it were burned in peaking gas generation plant 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 to further enhance carbon outcomes increases. **Green gas technology combined with smart hybrid systems provides a long-term solution for low carbon heat provision.**

- Smart hybrid heating systems can save billions in avoided generation and electricity network capacity reinforcement costs when compared to a pure electrification scenario.
- Hybrids can deliver the UK's long-term decarbonisation targets for heating.

The outcomes achieved by the project demonstrate that hybrid heating is a viable, low cost, consumer friendly, energy system-supporting solution to decarbonising UK domestic heating. These findings lead to a number of policy implications should the UK government wish to see the emergence of a viable market for these solutions. **A new energy market design is required across multiple timescales, ranging from capacity markets with a horizon of multiple years to balancing markets operating very close to real-time, in order to recognise the full system value of smart hybrid heating.** In particular, the market should recognise Demand Side Response (DSR) value delivered over days and weeks when weather systems curtail wind generation and DSR from hybrids can provide a more cost-effective solution than the current approach of building sufficient thermal generation capacity to cover the shortfall.

The limits imposed by market rules regarding the minimum size and the minimum temporal availability of participants in energy, balancing and capacity markets need reform to enable distributed forms of flexibility, such as hybrids, accessing value streams in certain markets. More dynamic market price signals can potentially incentivise availability of flexibility from hybrids during periods when it is most needed by the system. **Location-specific value in new market arrangements,** through the introduction of locational marginal pricing and emissions, will encourage deployment in areas where system flexibility has greatest value. New **mechanisms for remunerating avoided investments in low-carbon generation should be established** and potentially linked with reforms to the capacity market to link capacity procurement with the low carbon agenda. **Capacity market reform should also create a level playing field for DSR.** The current policy of adding decarbonisation policy costs to the electricity bill needs to be reconsidered to stop the current dynamic of high electricity costs and low gas costs pushing consumers away from low carbon heating technologies towards higher carbon gas boilers.

Finally, current incentives promote non-smart low carbon heating solutions for both hybrids and heat pumps. This policy ignores the huge benefits that can be achieved through integration of optimisation of heating systems with the broader energy system, adding to the capacity challenge rather than helping to resolve it.

- Energy market reform can create a viable market for hybrid heating systems and can address the challenge of the additional capital cost placed on consumers to decarbonise their heating system
- Low carbon incentives must recognise the value of smart controls to avoid unnecessary energy system costs

The implementation of these policy changes would stimulate the creation of new consumer focused business models that pass energy system value to the consumer that cover the additional cost of moving to low carbon heating assets. With companies such as PassivSystems leading the world in new energy management technologies, **the UK has an opportunity to transform the domestic heating market to deliver carbon reduction obligations whilst creating jobs and export opportunities in markets targeted by the UK's Industrial Strategy.**

Hybridisation exploits existing investments in gas and electricity network assets, uses proven mass market boiler and ASHP technologies, and provides a no-regrets option in the short term whilst the UK Government's ongoing investigations into other potential heating technologies are concluded.

- The Freedom Project has identified a viable mass market solution to heat decarbonisation
- The UK is well positioned to benefit from job creation and export opportunities by being an early adopter

The project partners who delivered the Freedom Project are now pursuing new projects that seek to affirm and extend the work done to date. Projects include extension of hybrid concepts into non-domestic buildings, exploring new comfort-as-a-service business models, integrating other flexible home appliances with the hybrid energy management system and identifying opportunities for technology innovations to support supply chain cost optimisation.

2. Introduction

2.1 Project overview

The Freedom Project has investigated the network, consumer and broader energy system implications of high volume deployments of hybrid heating systems. The technology, which combines a conventional gas boiler and an air source heat pump (ASHP) with PassivSystems optimised smart controls, can be used as fully flexible loads capable of providing significant energy system value.

Freedom = Flexible Residential Energy Efficiency, Demand Optimisation & Management

As an industry first, Distribution Network Operator (DNO), Western Power Distribution (WPD) and Gas Distribution Network (GDN), Wales & West Utilities formed a partnership and accessed their respective Network Innovation Allowances (NIA) and invested in PassivSystems to deliver the Freedom Project. To support the delivery of this two-phased project, PassivSystems appointed project partners; Imperial College, Delta-ee and City University (see *Figure 2*).

Figure 2: The project partners

Phase 1

Phase 1 of the project produced forensic models from which hypotheses of system performance, detailed market assessments and consumer research were derived.

In addition, it delivered a four-home pilot installation to assess the selected hardware, installation contractors and project customer engagement.

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 (see *Figure 3*). 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.

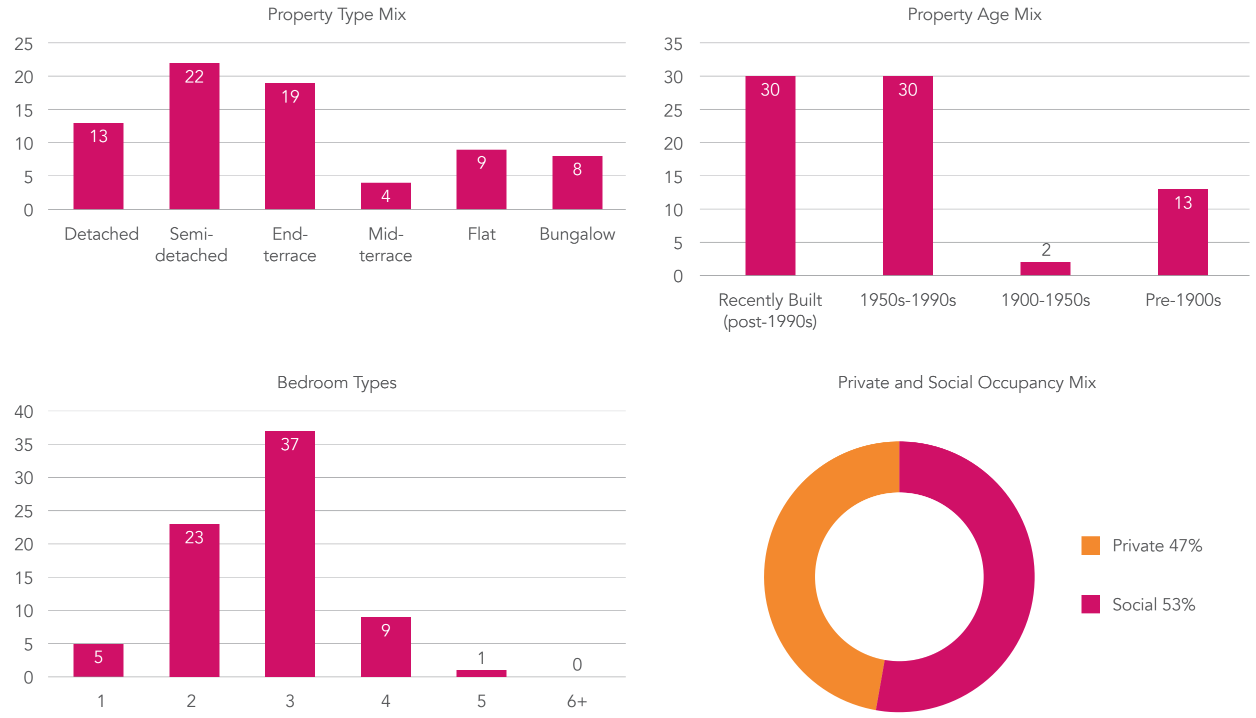


Figure 3: The Freedom Project property mix

The project partners are all experts in their fields and the project utilises the market-leading controls technology developed by PassivSystems. The project has provided, for both electricity and gas network operators, meaningful insights into the future evolution of the domestic heat sector, the impact on networks in the short and long term and steps that can be taken to best manage future network risks and opportunities arising from a proliferation of the hybridisation of heat.

For the first time, this NIA-funded project has brought together gas and electricity network operators in the field trial region and has provided both parties with robust, field-tested data which has made a meaningful contribution to their 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)[1].

[1] *Energy UK's Pathways for the GB Electricity Sector to 2030 (February 2016): www.energy-uk.org.uk/publication.html?task=file.download&id=5722*

2.2 Project objectives

1. **Use the ability of the hybrid heating system and PassivSystems smart controls to switch between gas and electric load to provide fuel arbitrage and highly flexible demand response services.**

2. **Demonstrate the consumer, network, carbon and energy system benefits of large-scale deployment of hybrid heating systems with aggregated demand response controls.**

3. **Gain insights into the means of balancing the interests of the consumer, supplier, and network operators when seeking to derive value from the demand flexibility.**

4. **Address all elements of the energy trilemma *(see Figure 4)*:**

Figure 4: The energy trilemma

The project has addressed all aspects of the energy trilemma, with a 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.

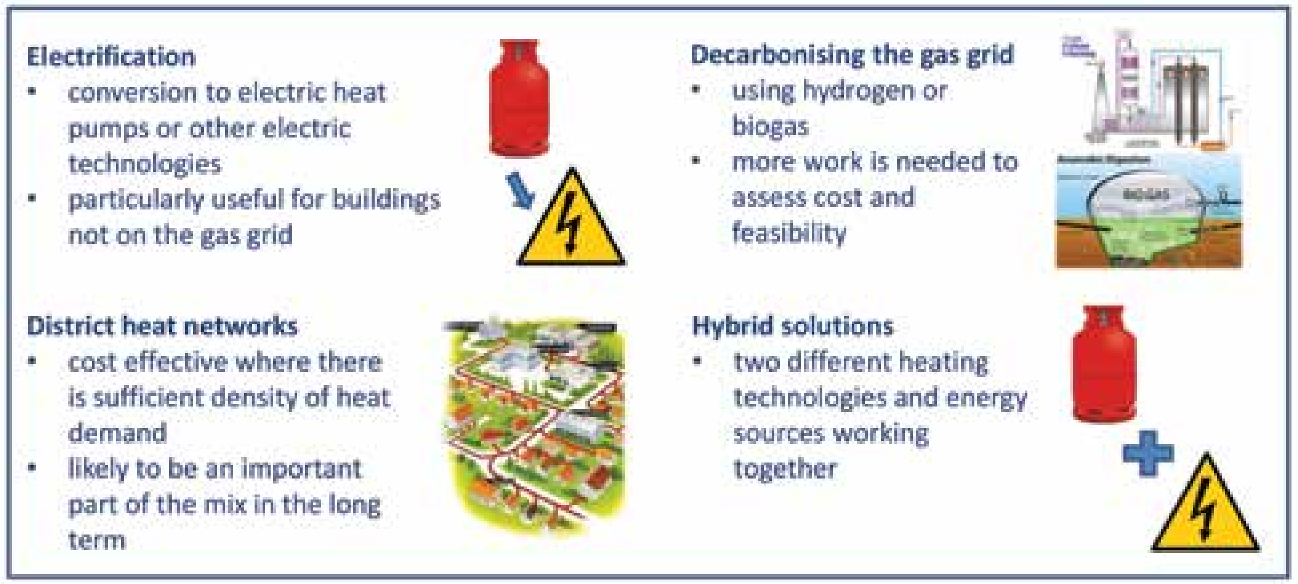


Figure 5: BEIS long-term strategic heat pathways (December 2017)

3. Freedom hybrid heating systems field trial results analysis

3.1 Introduction

PassivSystems' findings from the main field trial of the Freedom Project (winter 2017-2018) are described in this section and the technical analysis directly derived from field trial data.

The original aims of the project, which were set out for the field trial, the installations and the interventions are provided below. The results from the field trial for each type of intervention that was carried out, including baseline performance at different fuel price ratios, demand flexibility from tariff signals, demand constraints and aggregate demand management, are also presented below.

3.2 Deployment summary

- 75 homes with hybrid heating systems deployed *(see Figure 6)*
- Three heat pump manufacturers used (MasterTherm, Samsung and Daikin), sized as small as possible (5kW, except MasterTherm units at 8kW)
- 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)

3.3 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

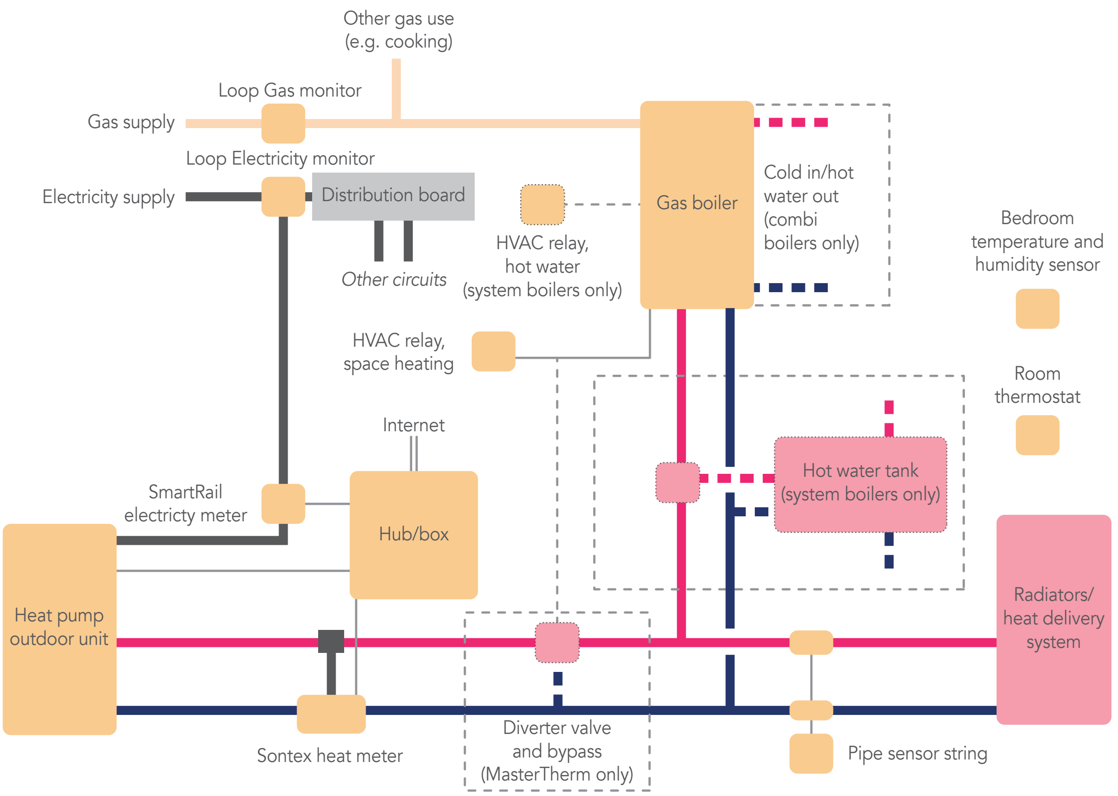


Figure 6: Schematic diagram of physical equipment deployed in a Freedom installation. Note that the Daikin configuration is different as the boiler and heat pump have a 'series' plumbing arrangement within the integrated unit

3.4 Control configuration

All triallists were provided with the PassivLiving **smartphone app** which enables them to choose how warm they want to be and at what time of day (heating schedule); they can also adjust settings live via the app or a physical room thermostat.

The app also provides **feedback** on whether the system is running, which fuel is 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 uses PassivSystems **optimised control** strategy which runs 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 Renewable Heat Incentive (RHI) payments.

3.5 Planned interventions

Over the course of the Freedom Project main field trial, a number of interventions were planned 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.

Forecast average and marginal electricity carbon intensity.

Aggregated demand management to simulate avoiding the capacity limit of an electricity subnetwork.

The project timeline (at the outset of the field trial) is shown in *Figure 7*:

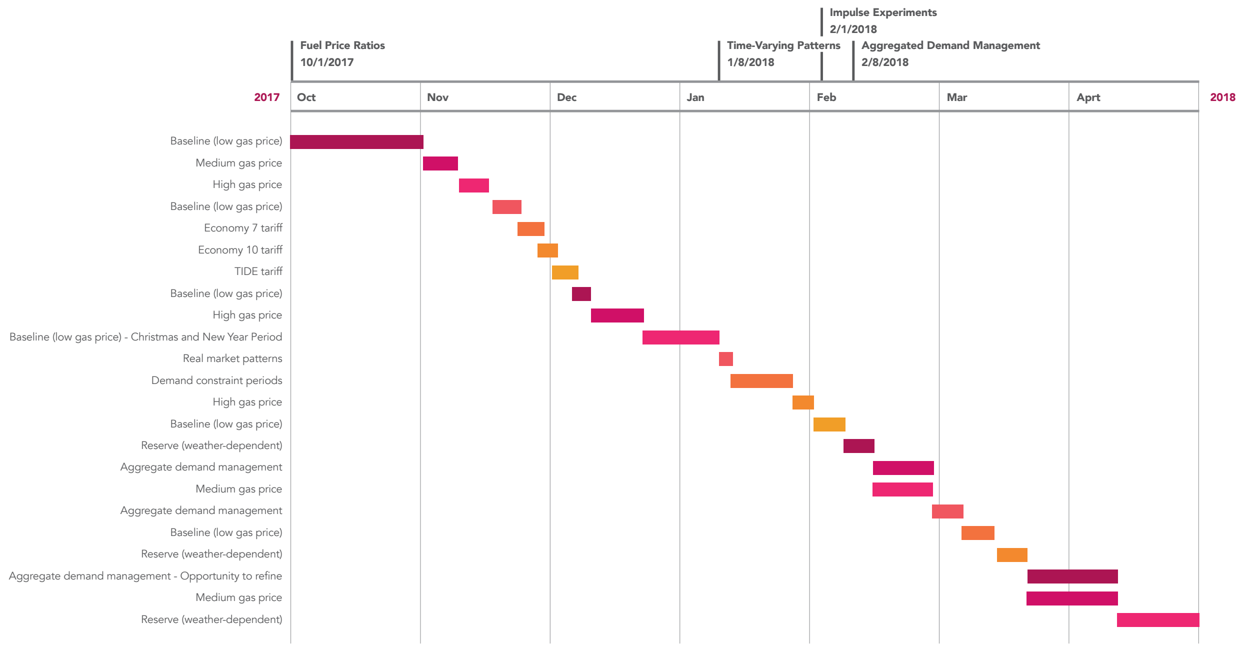


Figure 7: Outline of planned interventions throughout the Freedom Project field trial.

3.6 Data analysis

Most of the data analysis is based on data interpolated to half-hourly intervals. Aggregate data sets average all of the homes that were available for the period in question and not experiencing any faults, so are presented in units similar to 'kW per home'; the number of homes that contribute will vary with time. Heat output data was not straightforward to acquire: there was no heat meter on the boiler and the heat pump heat meter can 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 is the heat meter reading during periods when the boiler was known to be 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 is either measured directly (Daikin), or assumed to be the same as during heat pump operation (MasterTherm/ Samsung). Either way, the boiler heat figure is an approximation but has been validated against Loop gas meter reads where available or there is a good match given likely boiler efficiency of 90%
- **For Coefficient of Performance** (COP)/Seasonal Performance Factor (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.

3.7 Freedom field trial results:
Data analysis and review of findings

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.**

The project investigated how these energy-demand patterns could be changed through a time-varying electricity tariff. Operation was optimised to achieve comfort levels for minimum running costs under the tariff, thus quantifying the flexibility of hybrid heating systems with the needs of the householder prioritised. These experiments were highly innovative as live, real-world forecasts were used to influence heating system operation.

- Pricing was also applied from **live day-ahead electricity auction prices,** simulating a scenario where the user is directly charged time-varying market prices. Similar tariffs have very recently become available to householders with smart meters, and have the potential to benefit both the consumer and the grid, as demand is shifted to times when electricity is cheap and plentiful.
- Pricing was applied that directly reflected average carbon intensity, using **live carbon forecasts** from the National Grid for electricity, and also pricing gas by carbon: so system operation is optimised for total minimum carbon emissions. At today's average carbon factors, the heat pump is hugely prioritised over the boiler, but in future scenarios where renewable gas is introduced to the grid, we saw the system switch to gas to reduce carbon emissions, and a similar thing happens if the system, more accurately, considers the **'marginal' carbon intensity** of electricity from flexible generation sources (coal or open cycle gas turbines) when heat demand can't be met by intermittent renewable generation.

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. The ability to switch to gas simultaneously across the portfolio of Freedom homes **within 1-2 minutes** has been demonstrated, and no significant sudden impact of gas consumption was observed. The potential to use heat pumps for balancing services, such as Firm Frequency Response (FFR), was investigated and concluded that they **could be used for fast turn-down** (as systems could be turned off in less than 14 seconds), but turn-on is too slow to be useful.

This **flexibility can be utilised to enable decarbonisation of heating without any increase in electricity peak demand.** PassivSystems successfully demonstrated its sophisticated aggregate demand management system to achieve this. A profile of existing (non-heat-pump) electricity load was assumed, and then the heat pump demand managed so that the total load (in aggregate across the portfolio) was kept within a specified demand cap. So at the time of non-heat-pump peak demand, the heat pumps are largely off – and at other times they are using the **"spare" electricity grid capacity** to decarbonise heating if renewable generation is performing well. Householders are not impacted as comfort levels are maintained by the gas boiler, and heat pump efficiency (COP) is not compromised (but in fact slightly improved) by the demand management.

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 targetted 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 smart app-based systems that can help people understand the changes and easily accomplish the adjustments to comfort levels that they need.

PassivSystems hybrid heating technology is ready for wide-scale deployment and well-placed to contribute to decarbonising heating in the UK, but only with an increased deployment of renewable electricity generation and if it is combined with PassivSystems smart controls that can coordinate operation so that the inherent energy storage in the gas distribution network is made available to balance the electricity grid.

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 electricity generated from renewable sources for low carbon heating. There is little economic basis for most households 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 large and immediate opportunity.

POLICY

Current policies, such as RHI, have no requirement for smart controls for hybrid heating systems (or, indeed, for any heat pumps). The Freedom Project learning has shown that this is a shortfall, 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.

TECHNOLOGY READINESS

The benefits of hybrid heating systems can only be fully realised if smart controls are in place to 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.

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. 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.

3.8 Aggregate demand management

The aggregation interventions made full use of PassivSystems' aggregated demand management technology, and addresses the central challenge of the Freedom Project: the scenario where many homes have moved over to heat pumps in order to decarbonise home heating, but the electricity network does not have enough capacity to meet the load. The project's proposed solution to this problem is the hybrid heating system: when the electricity network nears its capacity, heating load can be intelligently switched over to gas.

The project used the field trial homes to emulate a future scenario as follows:

- **Assumed an average profile for non-heat-pump electricity baseload** consumption (using the standard Elexon profile that is used for settlement purposes)
- **Set a load cap at 0.75kW per home,** slightly above the peak baseload value, to simulate a scenario where the heat pump avoids affecting peak electricity consumption over the course of a day
- Added the heat pump power consumption to the baseload profile to simulate total power demand. This emulates **100% penetration of hybrid heating systems:** for each heat pump there is a corresponding baseload
- **Simulated 50% penetration of hybrid heating systems** by adding the heat pump power consumption multiplied by 0.5 to the baseload profile: for each heat pump there are two contributing baseloads. The load cap remains the same on a per home basis, relative to the baseload peak demand. This scenario requires weaker demand constraints
- Experiments were carried out in **low, mid and high gas price scenarios.** A distribution use of system (DuOS) pricing scenario was also utilised simultaneously

Evaluating aggregated power levels on a 'per home' basis enables the available data to be fully utilised, even when the number of homes varies. In a real situation, these per home values would be multiplied by the number of homes and compared to an absolute power rating of a substation.

Generally, PassivSystems' aggregated demand management calculations would run every half hour and determine the best way of keeping the homes within the aggregate demand cap while meeting the comfort requirements for each house at lowest cost to the occupant. Constraint signals would then be pushed to the individual houses, and the hubs at each site then autonomously control the heating consistently with these constraints.

The actual electricity demand of these homes (in aggregate) when operating in these demand management scenarios are displayed below. It was not possible to separate the portfolio into two cohorts with and without the demand management in place, so instead predictions of power consumption were used to compare had the constraints not been applied to the systems.

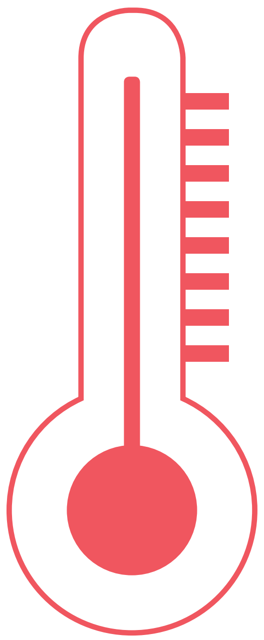


Figure 8 presents an aggregate electricity and heat demand over time during max load demand management operation, in a high gas price or **Gas Cost Ratio (GCR) scenario (GCR=0.33),** involving **54 homes on average.** This was a testing period and the demand management software was not operating the whole time. A DuOS avoidance signal (high electricity prices between 17:00 and 19:30) was applied in addition on two days. The top graph shows heat pump power consumption added on top of simulated electrical baseload, which should be managed to stay beneath a demand cap of **0.75kW/home.** The green dashed line shows PassivSystems' predictions of what the total power demand would have been if the demand cap had not been applied, and for completeness the blue dashed line shows PassivSystems' predictions of total power demand with constraints in place (which would match true demand with perfect predictions). The middle graph shows external temperature during the period for comparison, and the bottom graph shows heat production by the heat pump and boiler separately (not stacked).

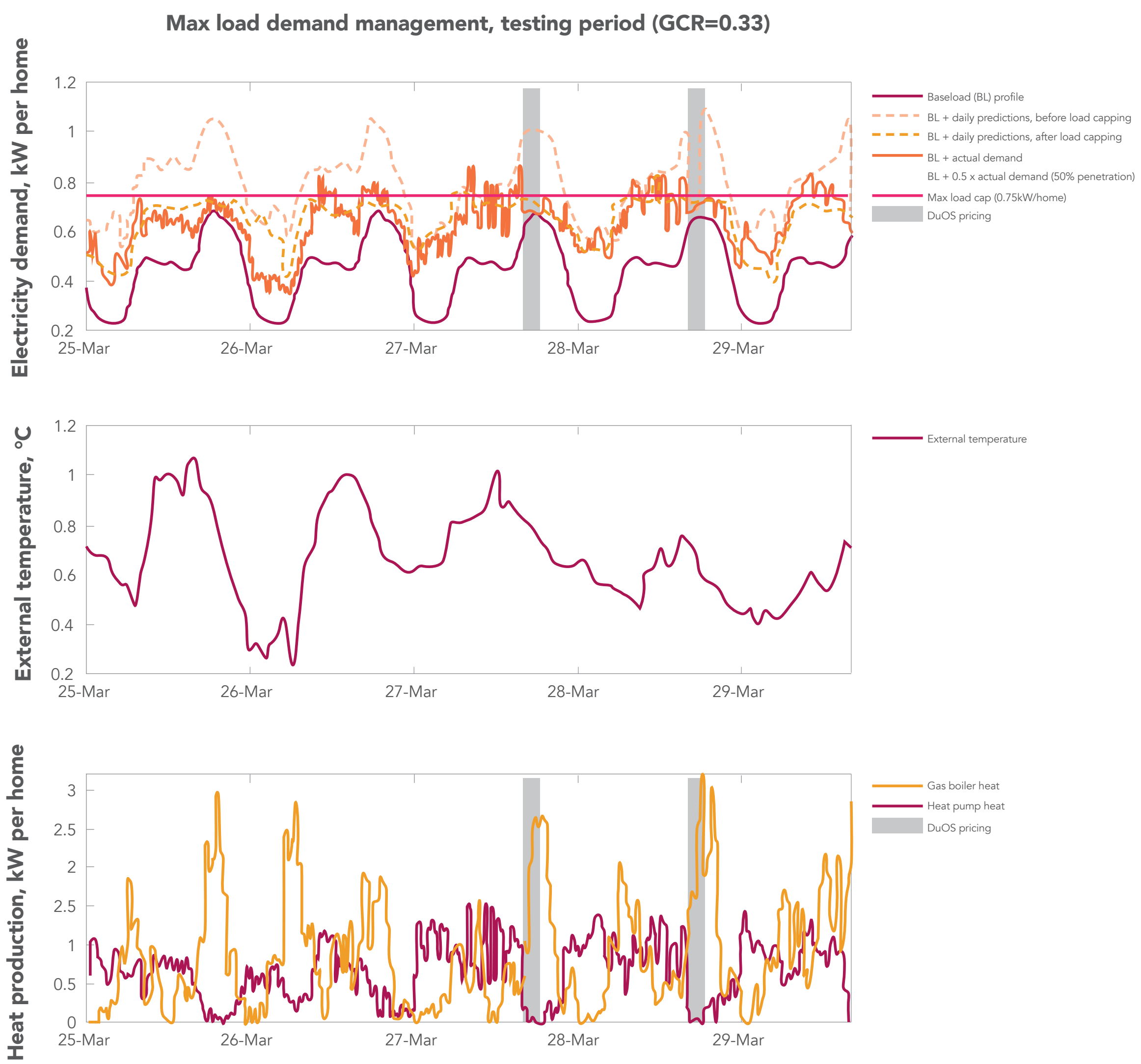


Figure 8: Aggregate electricity and heat demand over time during max load demand management operation, in a high gas price (GCR=0.33) scenario, involving 54 homes on average

Figure 8 shows a successful extended period of sophisticated aggregate demand management on a portfolio of 54 homes, with heat pump power consumption being significantly reduced (and replaced with gas boiler heating) at peak times without impacting householders. At other times, the aggregate power consumption of heat pumps is managed beneath the cap most of the time, although there is an error margin of about 0.1 to 0.2 kW/home.

3.9 Aggregation summary

PassivSystems has successfully demonstrated sophisticated aggregate demand management capability on a portfolio of about 50 hybrid heating systems.

During peak periods, heat pump electricity demand can be reduced to a very low level and replaced with gas boiler heating without impacting householders, and at other times heat pump electricity demand can be managed to avoid increasing overall peak demand, to an accuracy of about **0.1 to 0.2 kW/home.**

3.10 Carbon intensity forecasting

The project considered what happens to demand patterns if electricity costs reflected more directly the time-varying cost in its production and distribution: considering carbon pricing and electricity day-ahead auction prices. These signals were applied to half of the homes, leaving the remainder on a flat electricity tariff and a medium gas price (GCR=0.26) as a baseline comparison; the results are shown in *Figure 9* through to *Figure 11*.

Figure 9 shows the aggregate electricity and heat demand over time in response to carbon intensity price signals (involving on average 15 live priced homes and 18 other homes). **The signals were derived from live carbon forecasts from National Grid APIs** (coloured lines in top plot with circles at the time the forecast was received); for reference, the true carbon intensity post-hoc is shown as a dashed line. The carbon intensities include distribution losses (i.e. per kWh electricity delivered to the home). The middle plot shows aggregate electricity demand over time, with the control group on a flat tariff as a dashed line. The bottom flow shows heat production from the boiler and the heat pump (not stacked), likewise with the control group as dashed lines. **Three experiments were carried out over time to match different carbon intensities of gas: natural gas at 184g CO_2/kWh; a future green gas scenario at 60g CO_2/kWh; a future super green gas scenario of 40g CO_2/kWh.**

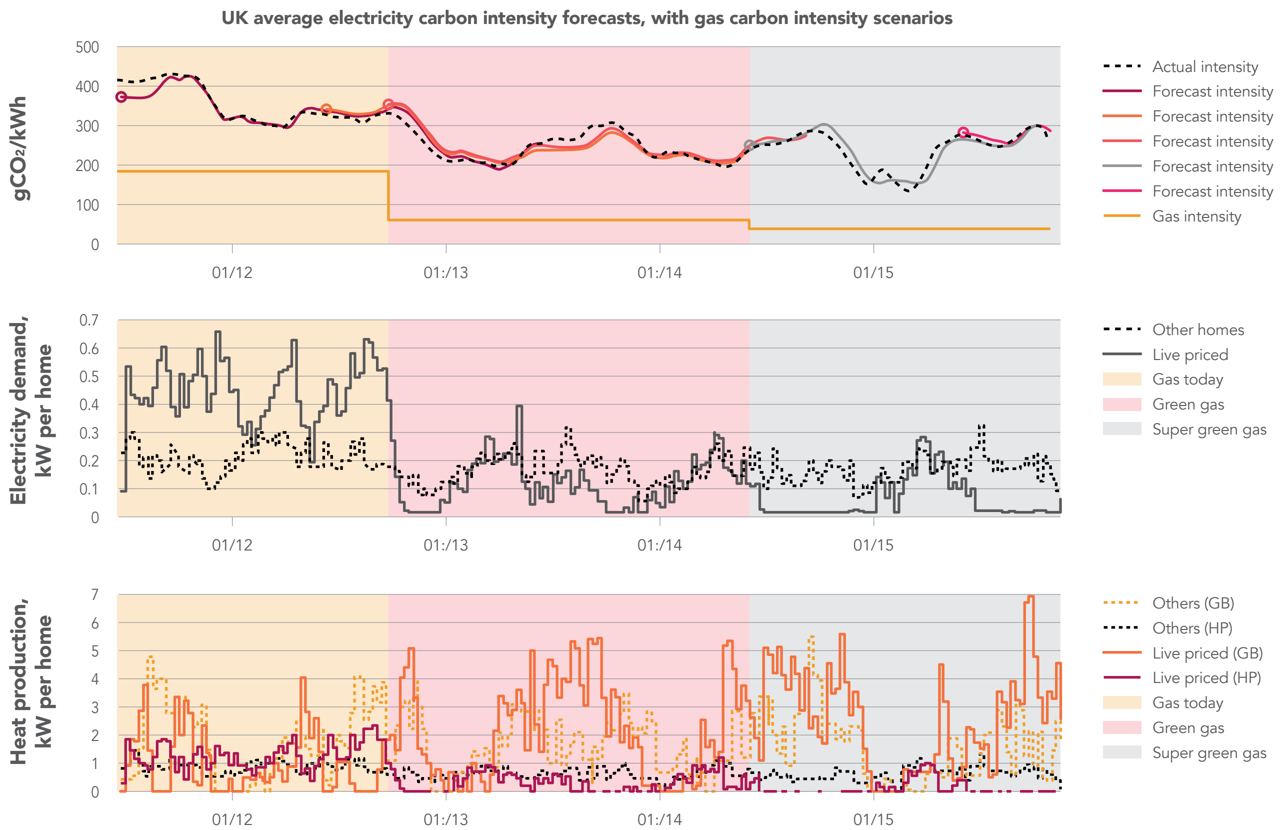


Figure 9: Aggregate electricity and heat demand over time in response to carbon intensity price signals (involving on average 15 live priced homes and 18 other homes)

Figure 10 shows an aggregate electricity and heat demand over time in response to **electricity day-ahead auction price signals** on 16 and 17 January 2018 (involving on average 14 live priced homes and 19 other homes). The top line shows the market prices taken from NordPool[2] ; these prices were subsequently doubled to **replicate a future green gas scenario** (i.e. gas at 200% of today's prices), as the system is controlling based on the relative gas:electricity price. The middle plot shows aggregate electricity demand over time, with the control group on a flat tariff as a dashed line. The bottom flow shows heat production from the boiler and the heat pump (not stacked), likewise with the control group as dashed lines.

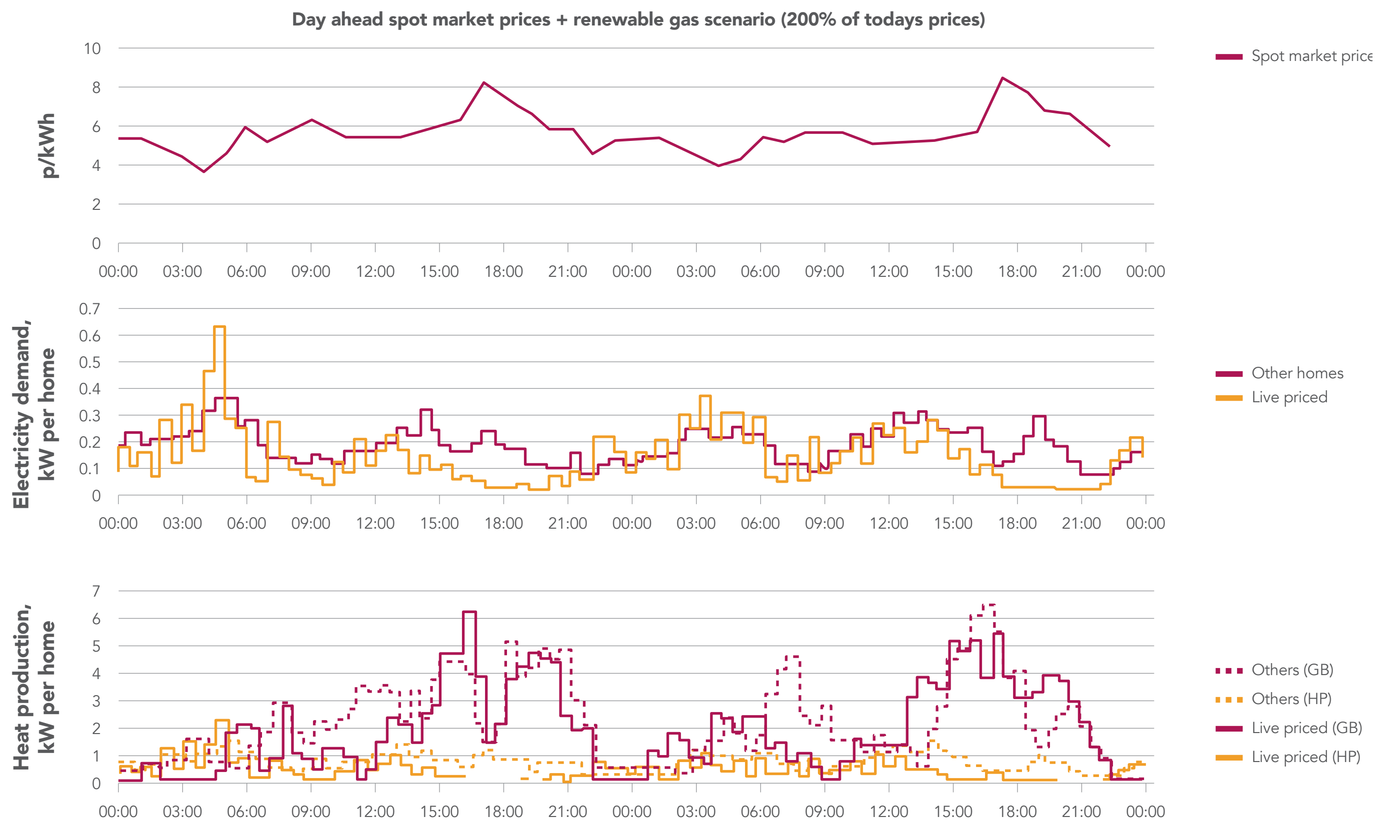


Figure 10: Aggregate electricity and heat demand over time in response to electricity day-ahead auction prices signals on 16 and 17 January 2018 (involving on average 14 live priced homes and 19 other homes)

[2] www.nordpoolgroup.com/Market-data1/GB/Auction-prices/UK/Hourly/?view=table

Figure 11 presents aggregate electricity and heat demand over time in response to **'marginal' carbon intensity price signals,** on 22 to 24 January 2018 (involving on average 13 live priced homes and 19 other homes). Carbon intensity forecasts are not available live as anything other than an average, so 2017 carbon intensity data was utilised; the marginal intensity was constructed by identifying times when coal generation exceeded 9,000MW, and allocating the carbon intensity of coal-generated electricity at these times (937g CO_2/kWh). At other times the electricity was allocated the carbon intensity of the next-worst generator (combined cycle gas turbines or CCGTs, assumed to be 394g CO_2/kWh). These settings are **indicative of future marginal carbon switching,** albeit from 2025 much of the peaking flexible generation is likely to come from local open cycle gas turbines (OCGTs) (651g CO_2/kWh). The resulting signal is shown in the top graph; homes were given the true carbon intensity of natural gas as the price for gas boiler operation. The middle plot shows aggregate electricity demand over time, with the control group on a flat tariff as a dashed line. The bottom flow shows heat production from the boiler and the heat pump (not stacked), likewise with the control group as dashed lines.

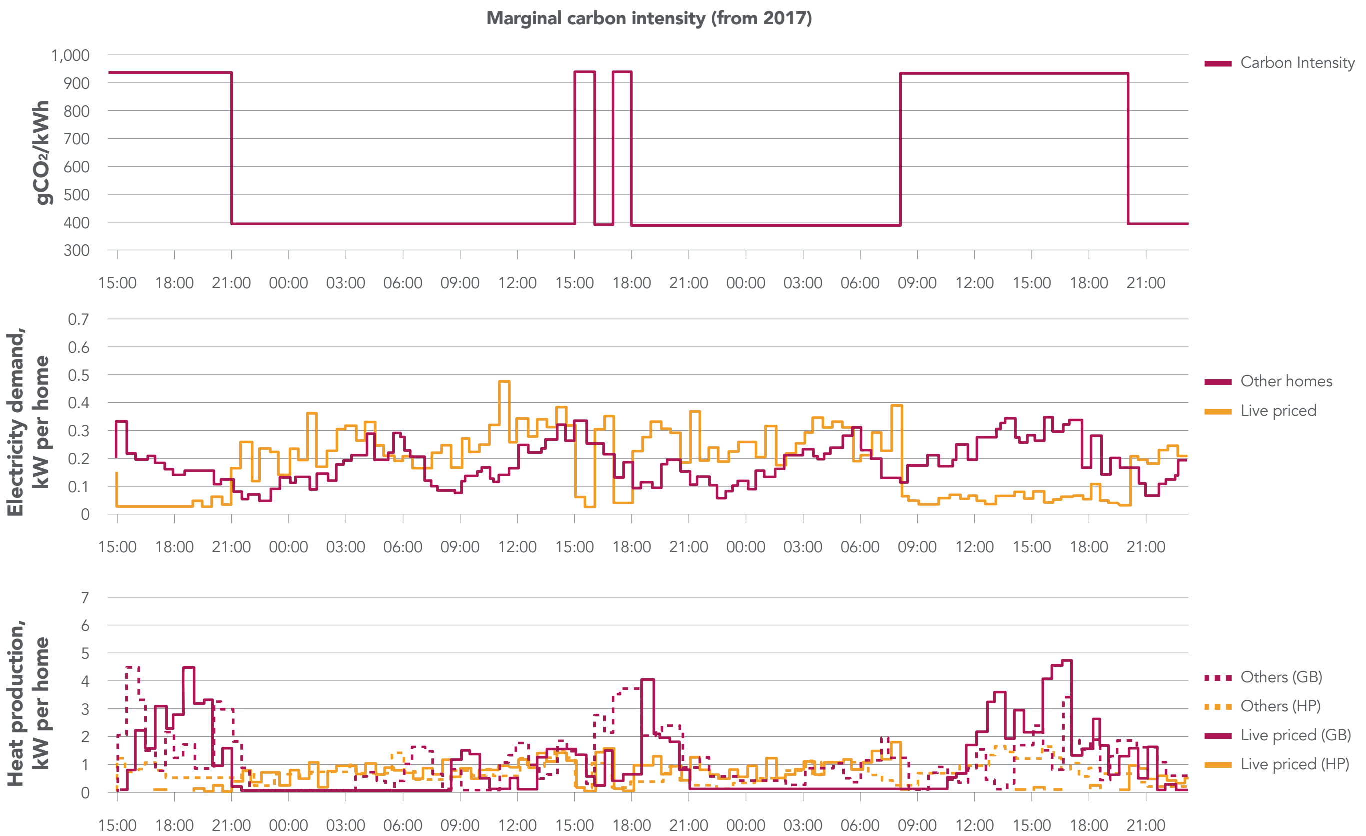


Figure 11: Aggregate electricity and heat demand over time in response to "marginal" carbon intensity price signals, on 22nd to 24th January 2018 (involving on average 13 live priced homes and 19 other homes).

All of the different decarbonisation strategies will be reliant on the consumer getting appropriate price signals to drive them towards low carbon heating options. Hybridisation is no different. Certainly the control system needs to be more sophisticated in how it manages the heat sources to deliver best cost outcomes when compared to traditional heating controls, but there is no reason for this complexity to fall on the consumer. Analogous to driving a hybrid vehicle, the consumer can rely on the technology to make decisions about system optimisation, and cost outcomes should encourage consumers to install smart systems that provide the best returns.

3.11 Carbon intensity forecasting conclusion

PassivSystems carbon pricing

This intervention *(Figures 9, 10 and 11)* is highly innovative as actual live (average) carbon intensity forecasts were used to influence the operation of the hybrid systems. For low carbon operation, the heat pump is highly favoured (and the system also tries to charge the home during lower carbon periods in advance of higher carbon periods, although this is not very obvious from the data). The contrast with the current price regime in the UK is huge: prices currently massively encourage the use of higher carbon fuel. As gas becomes lower carbon (future scenarios of renewable/green gas), the heat pump is used less, until it becomes completely suppressed during periods of higher carbon electricity.

The day-ahead market

This intervention demonstrates the system is successfully shifting heat pump consumption away from high market prices (18:00) and increasing it at lower prices (04:00). There is no noticeable impact on gas consumption however. It is worth noting that it was necessary to double gas prices to get a sensible experiment, as otherwise the heat pump would have been used flat out. This is a huge contrast to the consumer price scenario, under which gas is the cheapest fuel; between wholesale prices and consumer prices, electricity gets a vastly bigger price increase than gas. So when comparing heat pump heating with boiler heating, 'green taxes' that support renewable electricity generation are having the effect of pushing householders towards higher carbon heating.

PassivSystems 'marginal' carbon pricing

This demonstrates pricing electricity according to the most carbon-intensive generator has a much more dramatic effect on the fuel choice – compared to coal-generated electricity powering the heat pump, the gas boiler is now significantly preferred on a carbon basis. Big reductions in heat pump usage are evident during these times, and gas boiler usage increases significantly during the daytime. The 'marginal pricing' scenario is targeted at cold, windless winter days when the extra load of heat pumps means that coal generation, or likely open cycle gas turbines (OCGT) generation in the future, is turned up when it would not otherwise be required. The experiments have successfully demonstrated that hybrid systems could switch to gas in these circumstances to genuinely minimise real-world carbon emissions.

3.12 Field trial analysis

High gas cost ratio, cold weather: 'Beast from the East'

Below is a 'Beast from the East' case study showing the time-series of a hybrid heating system during cold weather, on a high GCR.

The top graph displays room temperature and the user's requested set-point; note that the householder frequently changes their mind about the temperature wanted in the evening. The second graph shows external temperatures; **-6C on 1 March was the coldest temperature in Bridgend this winter.** The third shows heat provided to the house from each fuel source and the fourth shows radiator temperatures. The heat pump is running almost all the time providing a baseload of heat input, but it is not economic to run it above 40°C, and much higher radiator temperatures are required to heat the house up again *(see Figure 12).*

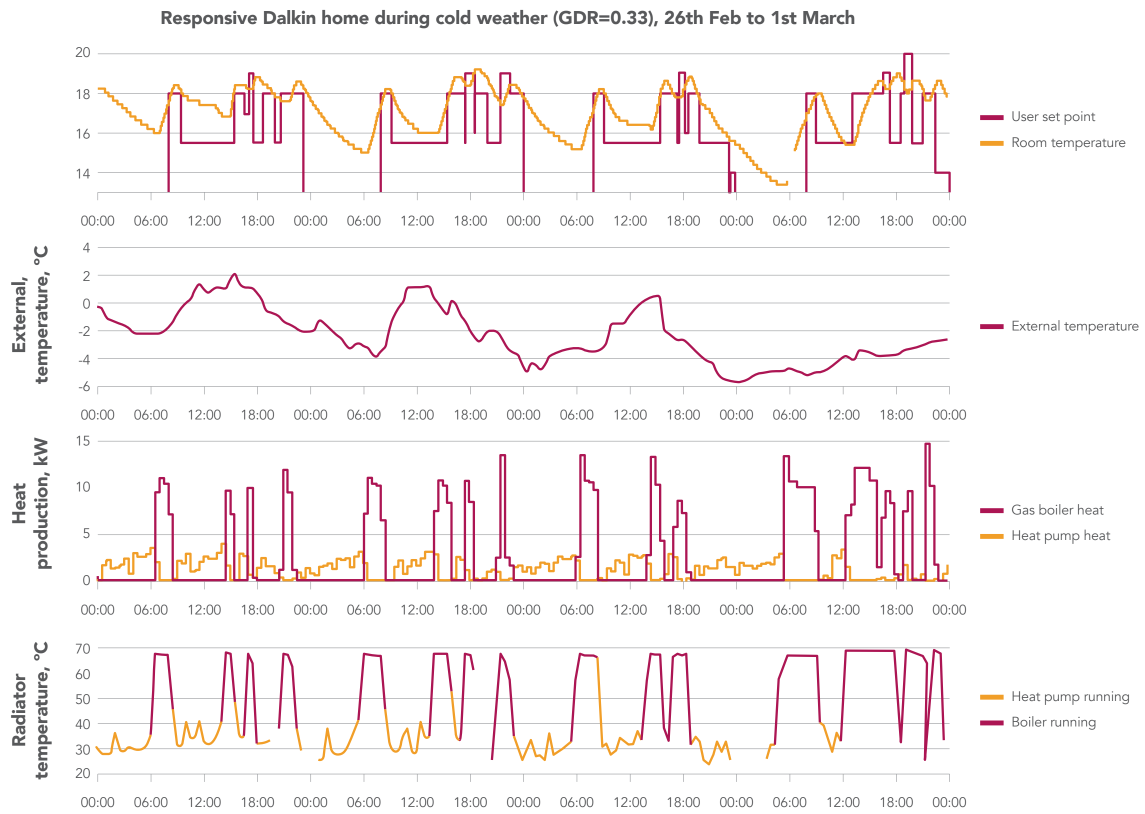


Figure 12: Case study showing time-series of a hybrid heating system during cold weather, on a high gas cost ratio

3.13 Field trial analysis

High gas cost ratio, cold weather, poorly insulated home: 'Beast from the East'

Below is a 'Beast from the East' case study showing the time-series of a hybrid heating system during cold weather and on a high GCR, but this time in a home that struggles to heat, presumably due to poor insulation or similar.

The top graph displays room temperature and the user's requested set-point; note that on 1 March the boiler fires all night but cannot get the house above 19C until around 06:00. During 1st March, there are frequent drops in temperature, perhaps doors being opened during the snowy day. The second graph shows external temperatures. The third graph shows heat provided to the house from each fuel source, and the fourth shows radiator temperatures. **The boiler runs a high proportion of the time, but it is still worthwhile using the heat pump sometimes even in sub-zero weather** *(see Figure 13).*

Figure 13: Case study showing time-series of a hybrid heating system during cold weather, on a high gas cost ratio, in a home that struggles to heat, presumably due to poor insulation or similar

Typical behaviour is similar to a gas boiler on its own, with heating off when not required and then reheated for occupied periods, except that the **heat pump is used to pre-warm the radiators to 30-40°C before switching over to the gas boiler.**

The transition point is dependent on the gas:electricity price ratio and the thermal properties of the home; for some homes it is worthwhile running the heat pump gently all night in colder weather if the gas price is high enough.

A heat pump running in this way enables decarbonisation to some extent if renewable generation is performing well, although it is limited by the cost impact of expensive electricity: the fuel transition is always determined on an economic basis.

3.14 Field trial analysis
Off-gas grid properties

It is always advantageous to use the heat pump in LPG (Calor gas) homes from a cost perspective, and so the transition is determined on an appliance capacity basis. It has been successfully demonstrated how the LPG gas boiler is switched on automatically in the coldest weather, when the heat pump is unable to keep up with demand, without noticeable impact on the occupants' comfort. The smart controls maximise both decarbonisation (when heat pumps are fed with low carbon power) and cost savings for the consumer compared to conventional controls, where they would switch to gas much more often, as the installer is likely to have set up quite a conservative transition temperature.

The technology proved especially cost effective in homes off the gas grid. A Freedom Project participant and her family live in a former miner's cottage in a rural location in the South Wales Valleys *(see Figure 14).* Her home achieved a heating bill **saving of £736 over the 2017-2018 winter season** without any requirement to improve the thermal efficiency of the building or replace any radiators.

Figure 14. LPG case study home

This hybrid heating system delivered **19,887kWh heat** from the heat pump and **5,587kWh from the LPG boiler.** This cost the homeowner £657 in electricity and £391 in LPG, **totalling £1,047.** Producing the same amount of heat with LPG would have cost **£1,783.**

The heat pump took 78% of the heat load and its SPF averaged at 3.9 – with the overall system **outperforming the Microgeneration Certification Scheme (MCS) by 25%.** As well as an excellent cost outcome, a future generation mix with greater renewable capacity could achieve **100% decarbonisation** using BioLPG to balance and provide flexibility.

"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 FREEDOM PROJECT TRIAL PARTICIPANT

3.15 Field trial analysis
LPG home, mild weather

Below is a case study showing the time-series of a hybrid heating system with LPG, configured with a very high GCR matching real pricing, during typical winter weather.

The top graph displays room temperature and the user's chosen set-point; requested comfort levels are met and the house is maintained at a warm temperature during the day to maximise the heat pump efficiency. The second shows external temperatures which are fairly average winter temperatures. The third shows heat provided to the house from each fuel source, and the fourth shows radiator temperatures. **The heat pump is running almost all the time and the house can be kept warm with only 40°C radiators,** but the temperature is modulated down slightly overnight to reduce thermal losses *(see Figure 15).*

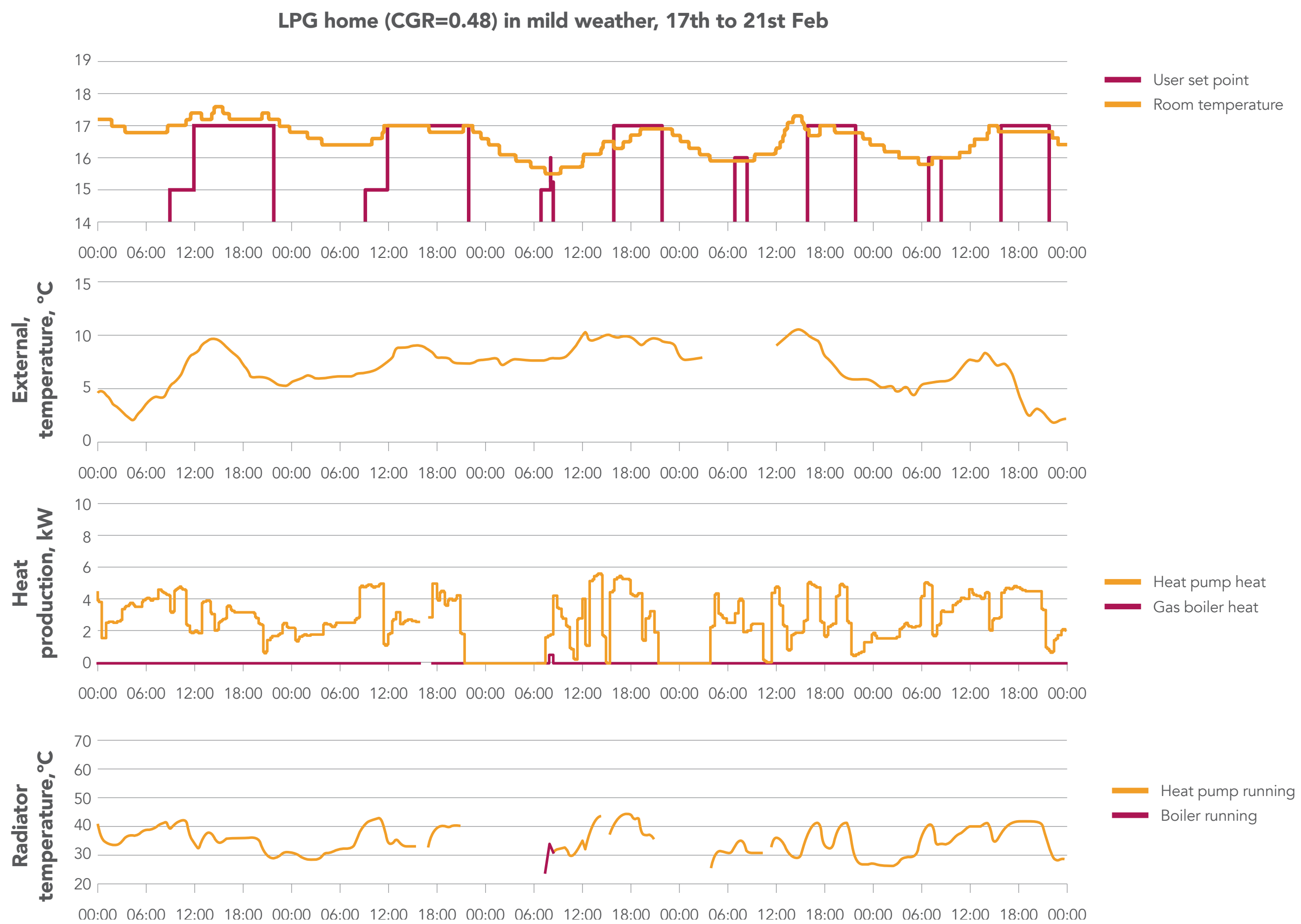


Figure 15: Case study showing time-series of a hybrid heating system with LPG, configured with a very high gas cost ratio matching real pricing, during typical winter weather

3.16 Field trial analysis
LPG home, cold weather

Below is a case study showing the time-series of a hybrid heating system with LPG, configured with a very high GCR matching real pricing in cold weather.

The top graph displays room temperature and the users' requested set-point; requested comfort levels are largely met although sometimes the system struggles to keep the house warm. The second graph shows external temperatures, the third shows heat provided to the house from each fuel source and the fourth shows radiator temperatures. The heat pump is running all the time in mild weather, but **the system automatically switches to gas during the periods when the heat pump is unable to keep the house warm** (switching for appliance capacity rather than cost reasons); nevertheless it is still worthwhile running the heat pump during the coldest weather, enabling carbon savings over a pure gas system if enough renewable generation can be available for heat load *(see Figure 16).*

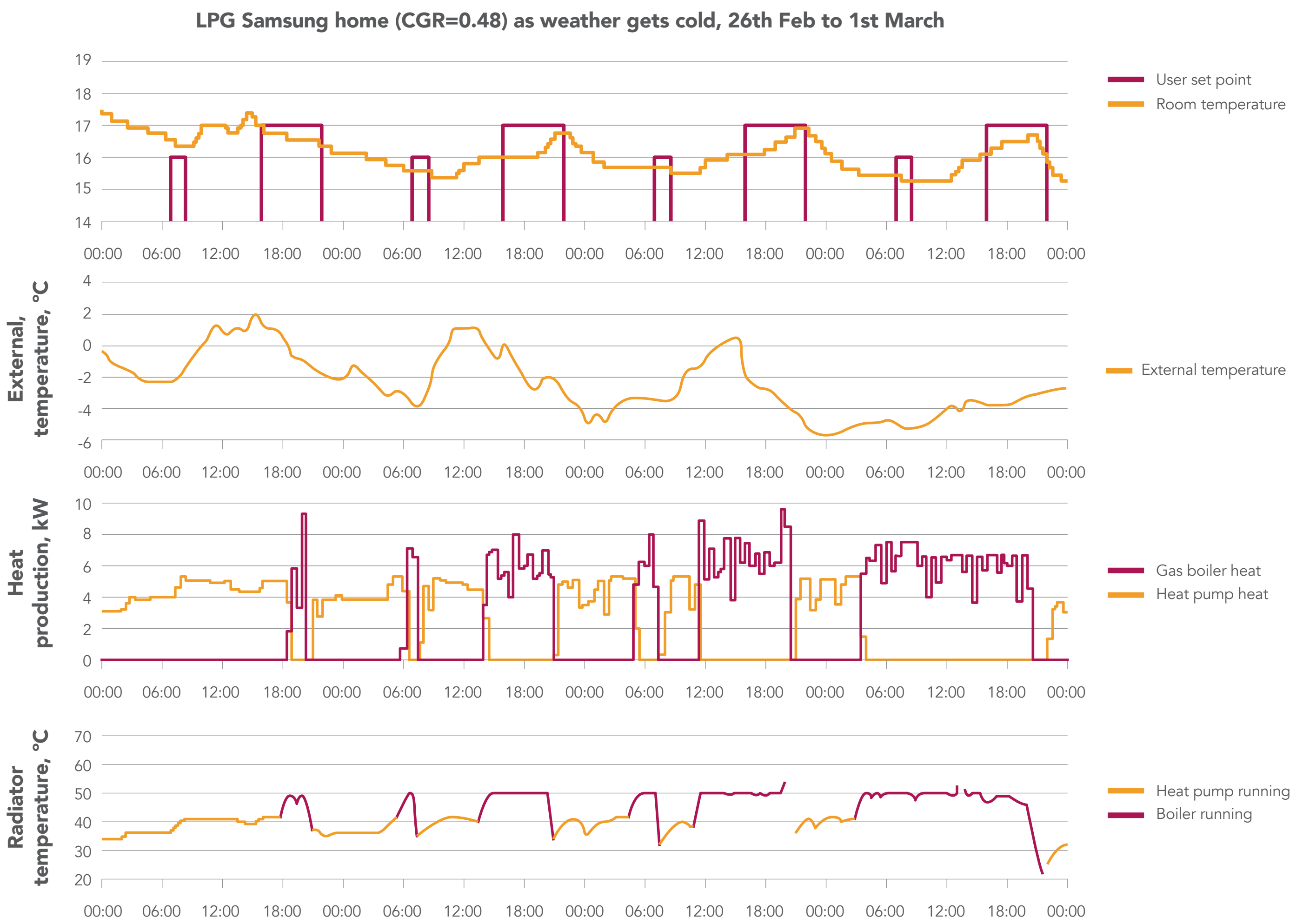


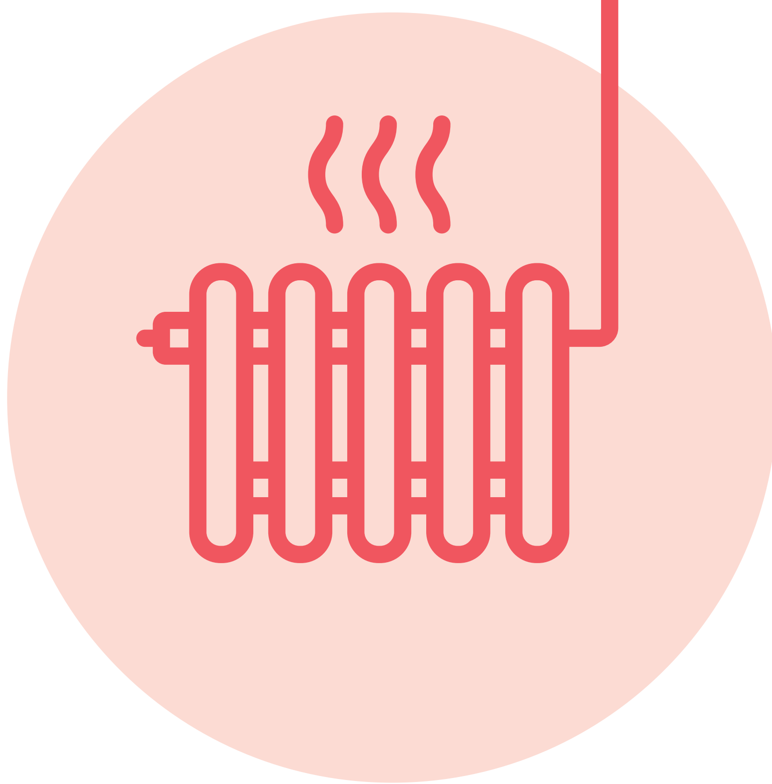
Figure 16: Case study showing time-series of a hybrid heating system with LPG, configured with a very high gas cost ratio matching real pricing in cold weather

The below case study showing the time-series of a hybrid heating system, optimised for LPG (GCR=0.49), but with **two periods of DuOS pricing applied.** The top figure displays room temperature and the user's requested setpoint; it is evident there was no direct impact from the DuOS periods (third graph in pink), although the user has been changing the setpoint around the times in question. The second graph shows external temperatures which were fairly mild. The third graph shows heat provided to the house from each fuel source, and the fourth shows radiator temperatures.

Figure 17: Case study showing time-series of a hybrid heating system, optimised for LPG (GCR=0.49), but with two periods of DuOS pricing applied

3.17 Field trial analysis
Summary and conclusion

The findings from the Freedom Project field trial experiments and interventions are provided in this section. Some next steps and general project conclusions from these activities are also drawn.



3.18 Installation and physical configuration

Hybrid heating systems were installed in detached, semi-detached, end-of-terrace and mid-terrace houses, flats and bungalows. No housing types were encountered where it was not possible to install a hybrid. In an apartment currently heated by a combi-boiler, it is possible to externally wall mount a small ASHP and plumb into the existing wet heating system with no loss of internal space.

The trial included **Daikin, MasterTherm** and **Samsung** heat pumps, each with a different plumbing configuration. All had initial issues relative to their communication interface, and there were varying levels of performance between the models, but by the end of the trial all three types functioned well and would be suitable for future deployment. We were unable to test the unique Daikin simultaneous operation mode due to limitations of the control interface provided by Daikin, but this is expected to be of limited value overall with smart controls rendering weather-compensated control obsolete. Simultaneous appliance operation should be tested in future trials.

Fossil fuel boilers can be hybridised relatively easily in retrofit by simply connecting a heat pump to the space heating pipework ('T'd-in'). Monitoring heat and gas consumption of a hybrid heating system can be difficult to achieve reliably and cost effectively.

3.19 Baseline performance

Optimised for consumer cost and comfort

PassivSystems smart fuel switching that provides comfort at minimum cost to trial participants has been demonstrated across a variety of future scenarios (e.g. from today's cheap gas prices to as high as natural gas is likely to go, as well as potential renewable gas prices). For all homes on mains gas, fuel switching was determined economically (i.e. the boiler becomes a cheaper way of heating the house after a certain point), rather than because the heat pump no longer had enough heating capacity, thus meaning that 5kW heat pumps were sufficient for most homes (in the absence of RHI).

The PassivSystems control strategy for hybrid heating systems that is most cost-effective is to use the heat pump for extended pre-warming at low temperatures (or running all the time as a baseload, depending on conditions), rather than the conventional strategy of fuel-switching based on current external temperature (although the field trial did not test this hypothesis).

Automated fuel switching for capacity reasons was also demonstrated on LPG homes where the gas price was much higher (i.e. the heat pump is still the cheapest way to heat the house, but the higher power output of the boiler is required to keep the house warm in cold weather); the smart controls maximised the heat pump operation, even in the coldest weather, while automatically guaranteeing occupant comfort by using the boiler when necessary.

PassivSystems hybridised heat pumps achieved significantly better SPFs (median 3.60 when optimised for current gas prices) than those of monovalent heat pumps in other trials, largely because the **smart controls will only use the heat pump when the SPF is good enough.** It is essential that policymakers use the right efficiency figures when assessing the potential for hybrid heating systems.

Peak electricity demand for hybrid heating systems (optimised for least consumer cost) occurs at 04:30 and 14:00, several hours earlier than previously assumed, and means that there is less conflict than previously believed with other load on the electricity grid (which peaks at 17:00—19:00). For the LPG homes (and likely future renewable gas scenarios) load is very flat. Previous studies have assumed electricity demand was similar to gas boiler heat demand profiles, which would be grossly misleading for an optimised hybrid heating system.

Prices need to be radically different from current rates to incentivise heat pump usage. When control is optimised for least consumer cost, the gas boiler still provides most of the house's heat load: **at today's prices, the heat pump provides between 1% and 20% of the heat (depending on weather), and in the future high-price scenario the heat pump provides 38% to 48% of the heat. In the LPG homes, which is most representative of future renewable gas prices, the heat pump carried 78% of heat demand over the winter.**

3.20 Demand flexibility

PassivSystems hybrid heating systems have ultimate demand flexibility for turn-down, and gas networks can fill the gap: heat pump electricity demand can be reliably reduced to less than 20W per home within a few minutes if required, lasting indefinitely, without impacting occupant comfort. Gas demand increases as a result but there has been no evidence that would result in pressure drops: the huge energy storage in the gas networks can be exploited.

The project demonstrated that variable electricity tariffs can incentivise shifts in electricity demand, providing insight into the cost and value of demand flexibility.

Possibly for the first time ever, PassivSystems has optimised a hybrid heating system using (a) live (average) carbon forecasts and (b) live electricity market day-ahead auction prices. These scenarios resulted in the heating being run for **(a) real net minimum carbon emissions and (b) real net wholesale electricity costs.**

Much more accurately, 'marginal carbon pricing' has been used to demonstrate how **a gas boiler operating on natural gas can be used to avoid high carbon intensity and low efficiency (coal and gas peaking) electricity generation,** and thus how PassivSystems smart hybrid systems avoid the 'backfiring' of increased carbon emissions from additional generation to produce the extra electricity required by heat pumps.

The project has established that heat pumps can be used for frequency response services in the turn-down direction: **although some heat pumps took up to 14 seconds in the trial, it is possible to turn them off remotely within 10 seconds.** Heat pumps cannot be used for fast turn-up services as they take approximately 5 minutes to ramp up power consumption.

PassivSystems sophisticated aggregate demand management capability has been successfully demonstrated on a portfolio of about 50 hybrid heating systems. It showed that **PassivSystems hybrid heating systems can operate without increasing the existing peak in electricity demand:** aggregate load is actively managed so that the sum of heat pump demand and all other demand stays within a specified demand cap. So at the time of peak demand, the heat pumps are largely off, and at other times they are using spare electricity grid capacity to decarbonise heating (when marginal sources of electricity are low carbon). Householders are not impacted as comfort levels are maintained by the gas boiler; and heat pump efficiency is not compromised by the demand management. **The current Freedom system can control aggregate demand within an accuracy of about 0.1 to 0.2 kW/home** (with potential for future improvement).

3.21 Consumer acceptability

Freedom trial homes were maintained at the desired comfort levels for the vast majority of the time (within the constraints of the physical heating systems), and this comfort was provided at minimum running cost to the participants (evaluated for the scenario in operation) for the vast majority of the time.

There was a largely positive response to PassivSystems' PassivLiving app-based heating control, but some consumers struggled with the transition from having direct control (of turning their heating on and off) to specifying desired comfort levels – even though the latter should in principle lead to better outcomes for them (both cost saving and better comfort). In some cases this was due to a lack of understanding (e.g. why the heat pump is running outside the times they expected), and in others due to not having set up the comfort specification (heating schedule) correctly.

It is crucial that householders feel in control of their heating, otherwise they lose trust in the system early on and do not engage if they have already made up their minds.

These challenges are fundamental parts of the transition to cost-effective low carbon heating that incorporates heat pumps.

A few households had a strong preference for 'burst heating' which is incompatible with decarbonisation using heat pumps. In future this needs to be seen as an extravagance (perhaps served by renewable gas) rather than an energy saving measure; it is challenging to convince people with heat pumps that they can save money by running their heating for longer.

Consumers perceived that the heat pumps were using much more electricity than actual usage, and were overconfident in how changes in energy consumption could be determined from billing and meter reads. It is crucial that householders perceive they are making savings.

ON

3.22 Next steps for PassivSystems

PassivSystems has identified the following areas which would merit further attention or enhancement in future work:

Improvements to the PassivLiving heating control app that make it easier for householders to control heating in the way they want to, understand how to achieve particular goals, and have confidence that the system is working correctly and delivering savings. This could be combined with a project which includes a strong component of householder training and education.

Improved modelling of the electricity consumption of heat pumps, to provide more accurate forecasts and manage demand more precisely.

Improved aggregate load management that addresses some of the anomalies observed in this trial, and refined so that it can actively react to changes and keep demand robustly within the specified cap.

Long-term testing of 'RHI-optimised' operation and automatic management to maximise revenue within the demand cap, and understand the impact on the grid and demand flexibility in this scenario.

Exploration of finer-tuned control of heat pumps, such as specifying inverter frequency or modulation levels, and the possible benefits of simultaneous heat pump and boiler running. In addition, the **exploration of finer-tuned control of boilers,** including load-compensation modulation and range-rating the boiler for the space heating demand of the home.

3.23 Conclusions by PassivSystems

One of the main aims of the Freedom Project was to demonstrate the potential for hybrid heating systems to decarbonise domestic heating in the UK. Heat pumps are generally lower carbon heat sources than gas boilers, but the impact they have on the electricity grid during times of peak demand is a huge barrier to their wide-scale deployment.

PassivSystems' smart hybrid heating systems solve this problem, as they can bring into play the huge energy storage in the gas network, by switching to gas boilers at times of peak demand, or at times when the electricity network has high carbon intensity. This capability is completely reliant on having a smart control system in place, which can coordinate operation in individual homes with the network-level requirements, at the same time as ensuring that householders are provided with the levels of thermal comfort they need, at least financial cost.

Current gas and electricity prices are hugely unrepresentative of their relative carbon emissions. Using PassivSystems' optimised hybrid heating systems to minimise carbon will currently result in the heat pump hardly being used until winter coal-fired plants are removed and renewable generation sources grow significantly to decarbonise beyond existing load requirements. Also, optimising the hybrid heating system according to current fuel prices will hardly use the heat pump, except for some top-up in milder conditions. The exception is off-gas-grid homes (on oil or LPG) where a hybrid heating system can offer immediate and significant savings in running costs and be ready to decarbonise substantially with a greener power grid. Injecting more renewable gas into the network has similar outcomes, as costs start to better reflect carbon intensity. The Renewable Heat Incentive goes some way towards addressing the price imbalance, but contains no requirement for heat pumps to have smart controls, which means that the true benefits of hybrid heating systems will not currently be realised.

PassivSystems' hybrid heating technology is ready for wide-scale deployment and this project has shown that only small (5kW) heat pumps are likely to be required, and retrofitting them to existing boiler systems is more straightforward than one might expect. PassivSystems smart, optimised control of hybrid heating systems works well, and can deliver reliable comfort, cheaper running costs and better outcomes for the electricity grid. The weakest link in the chain are the heat pumps themselves, which are not generally ready for smart digital control: manufacturers need to be incentivised to provide open interfaces with the appropriate level of control; similar can be said of boilers too so that they can also be smart hybrid-ready for third-party optimised control. Finally, for a new technology to succeed, it is crucial that consumers are fully on board: they need to feel in control of their thermal comfort, and trust the system to run their heating in their best interests; this can be a challenge when behaviour patterns need to change and consequences are counter-intuitive.

4. PassivSystems optimised hybrid heating system controls

4.1 PassivSystems optimised controls

PassivSystems has developed Predictive Demand Control (PDC) technology; the system learns the detailed thermal response of a property, and builds a physics model of the house and heating system. Using this model, it can optimise the performance of the heating system over the upcoming day, and predict the control strategy that is required to minimise energy consumption while meeting the comfort demands of the occupiers at the lowest possible cost.

For example, when applied to heat pumps, PDC enables the right 'overnight setback' strategy to be chosen. Conventionally, heat pumps are controlled in one of two very different ways:

1. **On a time-switch/programmer,** which often results in the heat pump running for hours at an inefficiently high heating water temperature (e.g. in order to heat a house back up again in the morning)

2. **On a constant weather-compensated heating water temperature,** which results in unnecessary overnight heat loss (and is compounded by installers frequently choosing unnecessarily high settings)

PDC chooses exactly the right compromise between these two extremes: keeping the heat pump running gently, but ramping up slowly throughout the night using a dynamically controlled flow temperature. This allows the house to cool slightly, reducing thermal losses, while keeping the heat pump running at the lowest possible temperature. Critically, the strategy is automatically tuned to the house so, for example, the system would choose continuous heating for a slow responding system such as underfloor heating, or turn off for some of the night if the house appears to lose heat quickly.

PassivSystems PDC can also essentially self-diagnose cost-efficient demand reduction measures that could be applied to the home to increase fabric storage and thus available flexibility and further reduce the cost of heat to customers.

4.2 Demand response with predictive control

As well as being able to optimise the performance of heat pumps, predictive control enables comprehensive functionality for demand management and varying energy prices: building thermal inertia can be exploited to store energy. Demand is automatically shifted in order to take advantage of the lowest prices, while fitting within demand constraints and ensuring that the comfort requirements of occupants is met. Decisions are made on the basis of quantitative trade-offs between storing heat in the fabric of the building, the additional heat losses incurred and any discomfort for the occupants.

4.3 PassivSystems optimised control of hybrid heating systems

Conventional control systems for hybrid heating systems usually simply transition between electricity and gas on the basis of the current external temperature, sometimes with a temperature range of simultaneous operation.

The systems calculate the external temperature at which the heat pump produces heat at the same price as the gas boiler, due to the coefficient-of-performance (COP) dropping at lower external temperatures. This is a natural extension of weather-compensated control, which assumes a static heat load.

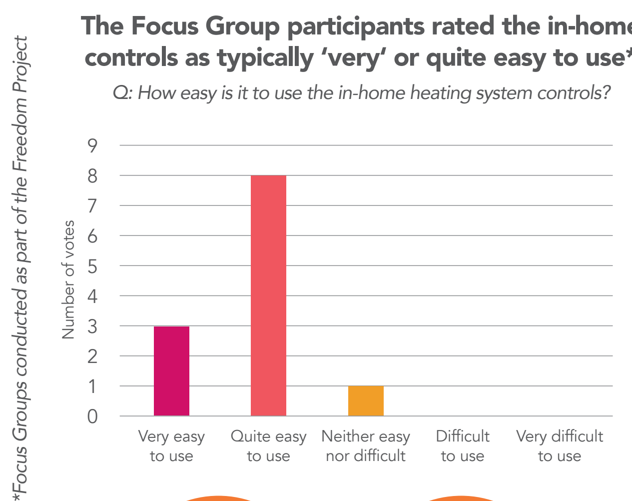
The Freedom Project used a dynamic control approach for hybrid heating systems that works better than the conventional 'external transition temperature' approach: the heating water temperature affects COP as much as the external temperature.

4.4 Customer feedback on PassivSystems optimised controls

The controls and (in particular) the PassivLiving app were a key success of the trial. Customers engaged with them readily and easily and the remote control aspect had high appeal. The app provided data and guidance to give consumers reassurance and help them understand when and how different parts of their hybrid heating system are working. There is scope to extend this work to minimise concerns over future billing and maintenance call outs (e.g. by reassuring consumers over the responsiveness to temperature changes).

The vast majority of respondents used the PassivLiving app to manage their heating system rather than the in-home controls. This is not unexpected, given the convenience and ubiquitous nature of the smartphone.

Nevertheless both the PassivLiving app and the in-home controls were rated highly and the user experience for those that did use the in-home control was positive *(see Figure 18)*. Very few customers used the website, but it was useful to those that did use it and so it should continue to be available to ensure customers have plenty of choice on how to view their data.



"They're just there and they do their job"

"The thermostat is very easy to control"

Figure 18: PassivSystems optimised control feedback

The in-home controls were mainly used as a back-up to the app or to override the current heating system setting – thus providing customers with peace of mind.

In particular they are needed for customer peace of mind, in case the system needs to be over-ridden or the app fails.

Therefore, whilst they may be used infrequently, it is recommended that the in-home controls still form part of the heating system set-up.

Only two Focus Group participants used the website

Thus, while it may be a useful medium to convey information it has not been heavily used by the trial participants.

4.5 PassivSystems optimised control improvements

The primary concern relating to the heating controls was the responsiveness or accuracy of the system to set temperature levels. This may be due to an operational problem with the system, or a lack of participant understanding of how the system works and how the levels and ranges are set, indicating the need for further up-front provision of information and ongoing access to support on the system operation.

Respondents stated they understood how to use the controls at the point of installation

90% said the controls were explained to them

87% understood this explanation

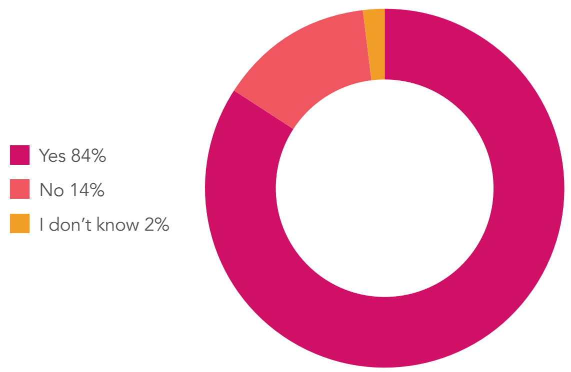
However as the trial continued, there was some feedback that more information would be useful, in order for participants to refer back to it. This is particularly important if the in-home control is used infrequently. This could be relatively basic, and the **Focus Group participants stated that a simple instruction booklet would have been a useful addition.** This could reduce the number of customer enquiries and potentially minimise calls for assistance for simple operational / control problems.

There are some simple improvements that could be made to the controls, and the set-point temperature might require further exploration:

- More information displayed to the customer on fuel type and temperature. More specifically: (1) symbols, readily seen and understood 'at a glance' should be added to indicate what fuel is being used, and (2) a display of what the room temperature is, in addition to what it is set at. During the trial there was some confusion over the set-point temperature and when the ASHP element was working (some customers went outside to check as they thought this was the only way to tell).
- Tighter temperature control. It was the perception of a number of trial participants that the controls were not responsive enough. In particular around the temperature setpoint (e.g. if the temperature was set at 18, the internal room temperature would fluctuate between 16 and 20). This could be due, in some cases, to the siting of the thermostat in a cooler or warmer room in the house (resulting in overheating or underheating) or due to misuse by the participant. Some customers also queried why their setpoint was not being achieved when the room temperature was within 0.5 degrees of their setpoint, which shows that the provision of data is giving a perceived dissatisfaction from heating system performance
- Improved reception and Wi-Fi connectivity. There were some issues on the trial with participants claiming that they could not sustain connection between the heating system, the thermostat and the controls. It is unclear here whether this is a real or perceived issue.

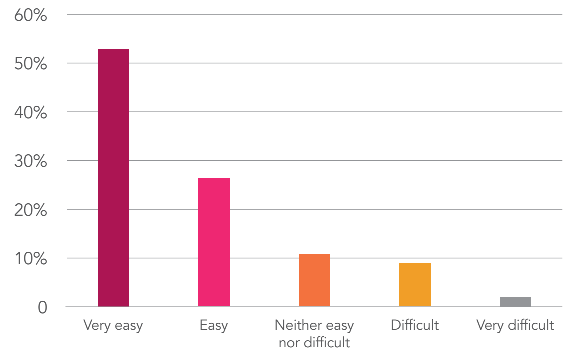
The vast majority of trial participants use the app for temperature control

Q: Do you use the app to control the temperature in your home?



More than three-quarters or the trial participants found the app 'easy' or 'very easy' to use

Q: Do you use the app to control the temperature in your home?



"We might decide to stay overnight, something like that, so I could just go (indicates pressing the app) and override it, which is brilliant..."

"It's pretty simple to use. You get a visual of the temperature in the middle so you know what you're doing. You can't really make a mistake."

These were two primary drivers for high customer satisfaction:

Remote control of one's heating systems

Simple and intuitive to use

"The fact that you can remotely control it if you intend going home a bit earlier...you can override it, even boost it..."

"Since they've updated the app you can now see the source of the heat which is so useful."

Figure 19: PassivSystems' smart hybrid control feedback

4.6 PassivSystems optimised control key findings

- **The in-home controls and app were consistently rated highly by customers;** both were considered easy to use *(see Figure 19).*
- **The in-home controls were not used as frequently as the app.** Their main purpose is a secondary control if the app is unavailable. However, due to potential infrequent use, the controls need to be simple and easy to understand – customers forgot the instruction they received at install.
- **The app has been one of the customer's favourite features of the whole hybrid heating system.** In particular remote control has high appeal.
- **Both the controls and the app can play a role in improving customer confidence.** They need to provide enough data that reassures customers their system is working correctly without being overly complex.

4.7 PassivSystems optimised control recommendations

- **As previously mentioned – a 'smart' app should be included in any bundle sale for a hybrid heating system** as it may support increased uptake.
- The inclusion of the PassivLiving app can also **reassure customers their system is working,** especially if it includes information on the fuel being used or when the heat pump is operating.
- **Consider introducing different 'levels' of control.** Some customers are really engaged and want a lot of information, and so it might be possible to have different 'levels' of control for different types of user. This could include a basic control where those less engaged are confident that they won't somehow 'break the system', which might appeal to Registered Social Landlords (RSLs).

Sometimes **simple is best** – in particular for the in-home control, customers would like an instruction booklet. A single-sided user-guide would be sufficient and could be attached to the control itself.

5. Electricity and gas network impact

The increased roll-out of hybrid heating systems in the domestic heat sector is expected to lead to significant variability and unpredictability in electricity and gas demand. This could potentially present challenges for the operation and design of electricity and gas networks.

Imperial College quantified potential savings in electricity distribution networks in South Wales resulting from switching from electric-only to hybrid heating systems, as well as to assess the capability of the existing gas distribution networks to deal with large and sudden increases in gas demand due to switching from electricity to gas as the fuel for hybrid heating systems.

5.1 Generating representative networks for South Wales

As an initial step, a set of five representative networks have been generated and mapped onto the South Wales electricity distribution area. This process was based on the network information obtained directly from Western Power Distribution and Wales & West Utilities.

5.2 ASHP and hybrid heating system uptake scenarios

The starting points for this analysis are the ASHP uptake scenarios prepared by Delta-ee which forecast the development of an installed ASHP base in Bridgend. The total population of Bridgend town is taken from the 2011 census (49,404) and the number of households is estimated by assuming an average of 2.5 persons per household. Based on this information, the relative uptake of ASHP systems in the Bridgend area in the period until 2050 is shown in *Figure 20*.

When analysing the impact of ASHP deployment on the entire South Wales distribution area, it is assumed that the same relative uptake of ASHPs will materialise. **The growth rate for baseline (ASHP) demand has been assumed at 0.12%,** based on the first three years' forecast of total substation load increase in WPD's Long-Term Development Statement for South Wales.

The below ASHP uptake is presented as total across all house types. However, the Imperial College model considers the evolution of ASHP and hybrid heating system uptake across different house types (terraced, semi-detached and detached houses) as specified in Delta-ee's scenarios.

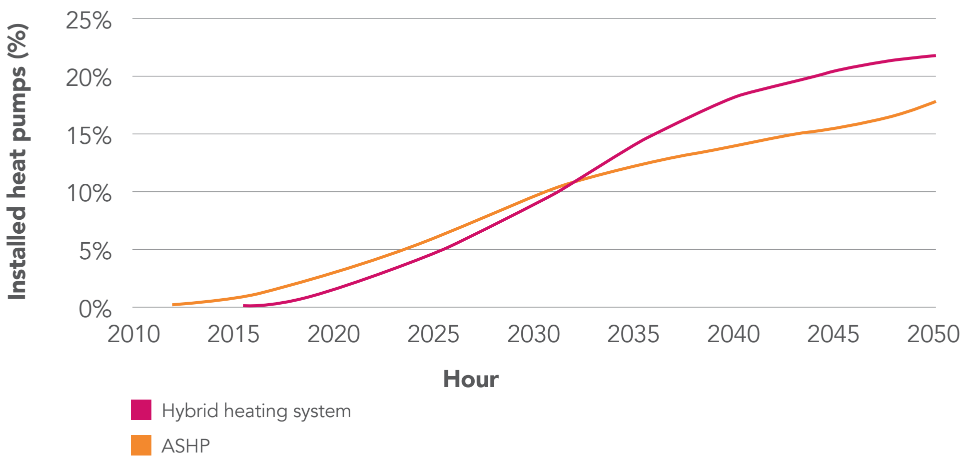


Figure 20: Uptake of ASHP and hybrid heating systems based on number of customers

Considering the household demand profiles provided by Delta-ee for ASHPs and the field trial data collected for hybrid heating systems, the average electricity peak and energy consumption per household across the three house types are given in *Figure 21*.

Key to table
'ASHP' refers to non-optimised electric-only ASHP profiles, whereas 'HHS' refers to non-optimised hybrid ASHP profiles. 'HHS Economy' refers to hybrid heating system installations in homes where Economy 7, Economy 10 or TIDE tariff is applicable. 'HHS DUoS' refers to hybrid heating system installations in homes with DUoS tariff. 'HHS DR' refers to hybrid heating system installations in homes when demand response is applied.

Case	Electric peak (kWe)			
	Morning	Day	Evening	Night
ASHP	2.2	1.9	2.1	1.7
HHS	1.1	1.2	1.1	0.7
HHS Economy	2.1	1.2	0.6	1.5
HHS DUoS	2.5	0.0	0.0	5.5
HHS DR	1.7	0.8	0.7	1.0
HHS PassivSystems Smart	1.3	1.4	0.0	1.0

Figure 21: Table of diversified peak demands

5.2 ASHP and hybrid heating system uptake scenarios

Due to the assumed underlying demand shape, the increase in the evening peak will drive network reinforcement. Given the flexibility of hybrid heating systems to perform fuel switching, in the case where their operation is fully optimised from the DNO perspective, there would be **no increase in peak loading of the distribution grid attributable to hybrid heating systems** (assuming that the gas boiler component of hybrid heating systems is of sufficient capacity to provide the entire heat requirement of a household). This would be ensured by **activating the gas boiler component of the hybrid heating system** whenever the total network demand would increase the baseline peak demand level. At the same time, given that the total heat output of a hybrid heating system is the same, there is **no change in the indoor temperature or customer comfort levels.** This case is denoted as 'HHS PassivSystems Smart' control in this section.

This is illustrated in *Figure 22*, which contrasts the non-optimised vs. PassivSystems optimised hybrid heating system profiles superimposed onto the baseline demand profile. With the ability to switch to gas for heat supply when the electricity distribution network is under greatest stress and assuming an appropriate control scheme is in place, it is possible to avoid any peak demand increase from the baseline demand profile.

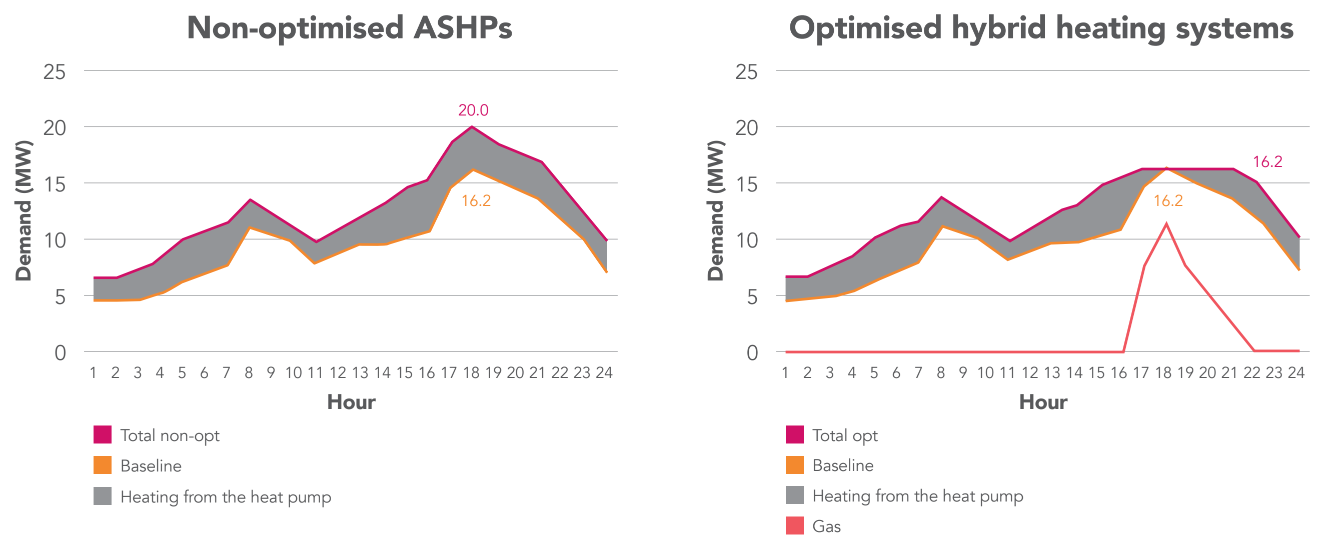


Figure 22: Non-optimised vs. PassivSystems' optimised hybrid heating system profiles

At this stage, the electricity distribution network impact scenarios specified in *Figure 23* were considered.

Scenario	Description
ASHP only	ASHP's provide all heating (assuming the number of installations equal to the sum of projected ASHP and hybrid heating system installations); this is the counterfactual scenario
ASHP and HHS	ASHPs and hybrid heating systems provide heating according to the assumed breakdown of ASHP and hybrid heating system installations, respectively
HHS only	Hybrid heating systems provide all heating (assuming the number of installations equal to the sum of ASHP and hybrid heating system installations)
HHS economy tariffs	Hybrid heating systems provide all heating (assuming the number of installations equal to the sum of ASHP and hybrid heating system installations) on E7, E10 or TIDE tariff
HHS DUoS	Hybrid heating systems provide all heating (assuming the number of installations equal to the sum of ASHP and hybrid heating system installations) on DUoS tariff
HHS demand response	Hybrid heating systems provide all heating (assuming the number of installations equal to the sum of ASHP and hybrid heating system installations) and demand response applied
HHS PassivSystems smart control	Hybrid heating systems provide all heating (assuming the number of installations equal to the sum of ASHP and hybrid heating system installations) and smart control applied to minimise network investment; this would be equivalent to a case when all heating, or whenever there is congestion in electricity distribution network, is generated by a gas boiler

Figure 23: Electricity distribution network impact scenarios

5.3 Freedom field trial case analysis

The key outputs of distribution network case studies for each scenario are:

- Evolution of network reinforcement, both in terms of the number of reinforced elements and their cost
- Breakdown of network reinforcement across voltage levels.

The key learning point is comparing each scenario with the counterfactual, as this will provide an estimate of the potential benefit of hybrid heating systems over electric-only ASHPs as well as the benefit of different approaches to hybrid control.

Figure 24 shows the development of the South Wales electricity distribution network upgrade of network length and number of transformers for the ASHP scenario. The majority of HV network upgrade is thermally driven, followed by the voltage-driven upgrade of the LV network. Any statutory voltage violations in the LV network could potentially be mitigated by, for example, installation of smart distribution transformers that might be a cost-effective measure.

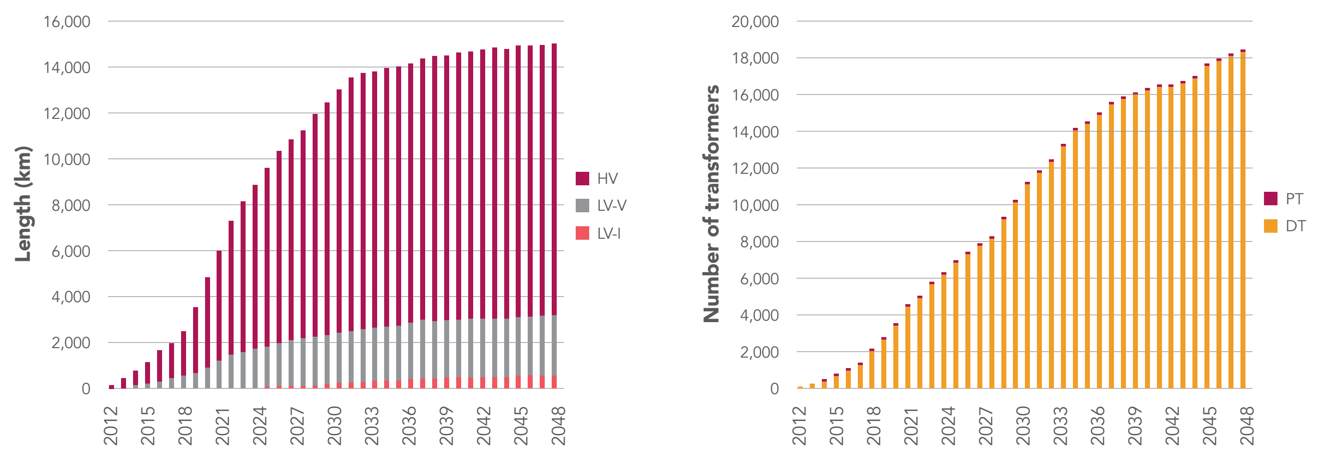


Figure 24: Development of South Wales's electricity distribution network upgrade (left) network length and (right) number of transformers for ASHP scenario; LV – low voltage network, DT – distribution transformer, HV – high voltage network, PT – primary transformer, I – thermal driven reinforcement, V – voltage driven reinforcement

Asset	Cost, £k
1km of LV overhead line and 2 LV circuit breakers	29
1km of LV underground cable and 2 LV circuit breakers	111
Pole mounted transformer	4.3
Ground mounted transformer and ring main unit	27
1km of HV overhead line and 1 HV circuit breaker	38
1km of HV underground cable and 1 HV circuit breaker	118
Primary transformer, 1 x 33 kV circuit breaker, 1 x 11 kV circuit breaker, 1km of transformer cable	840

Figure 25: Asset upgrade unit costs

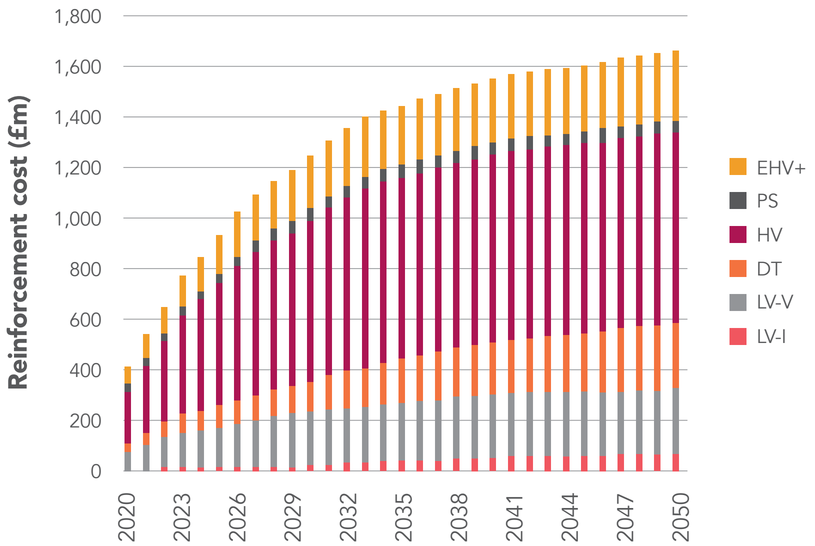


Figure 26: Development of South Wales' electricity distribution network upgrade cost for ASHP scenario; LV – low voltage network, DT – distribution transformer, HV – high voltage network, PS – primary substation, EHV+ - Extra high voltage network, bulk transformers and 132 kV network, I – thermal driven reinforcement, V – voltage driven reinforcement

***Figure 25* shows the assumed unit costs of asset upgrades** applied to network and transformer components in order to obtain reinforcement costs.

***Figure 26* presents the development of the cumulative electricity distribution network reinforcement cost** in the South Wales area until 2050 for the ASHP uptake scenario. This is used as the counterfactual scenario. The reinforcement cost is split per voltage level. Furthermore, for LV and HV networks, reinforcement is split according to the driving factor: thermal and voltage.

By 2050 up to about £1,700m should be invested into the South Wales electricity distribution network to accommodate the baseline load growth and the uptake of ASHP in the ASHP scenario.

***Figure 27* shows the results for ASHP and the hybrid heating scenario.**

The results show that savings from having hybrid heating systems in the heat pump portfolio, where the cumulative reinforcement cost is around £1,400m, are about £300m compared with the counterfactual scenario by 2050.

***Figure 28* shows results for the hybrid heating-only scenario.**

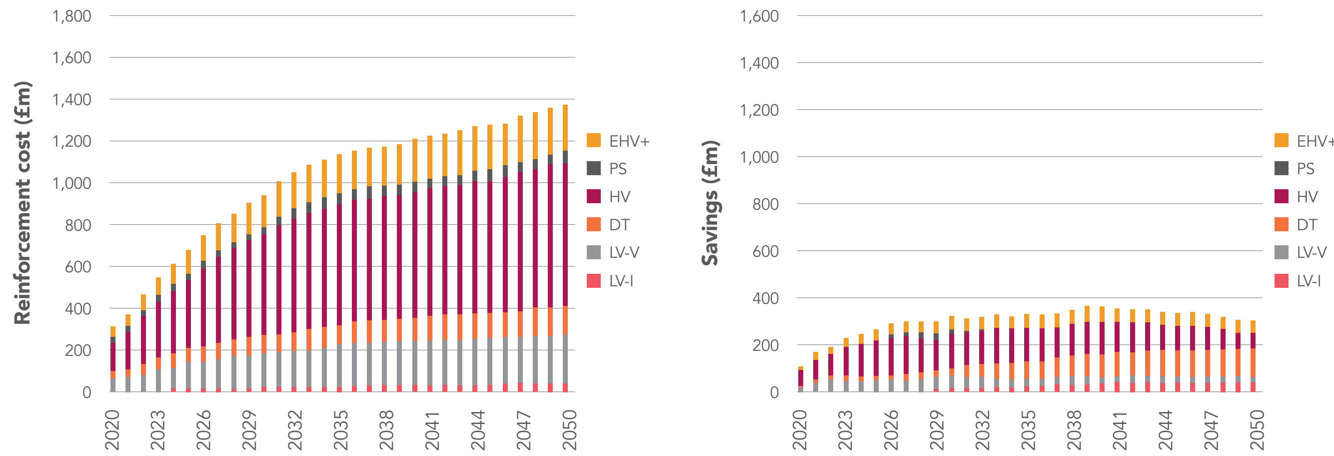


Figure 27: Development of South Wales's electricity distribution network upgrade cost for ASHP and hybrid heating scenario.

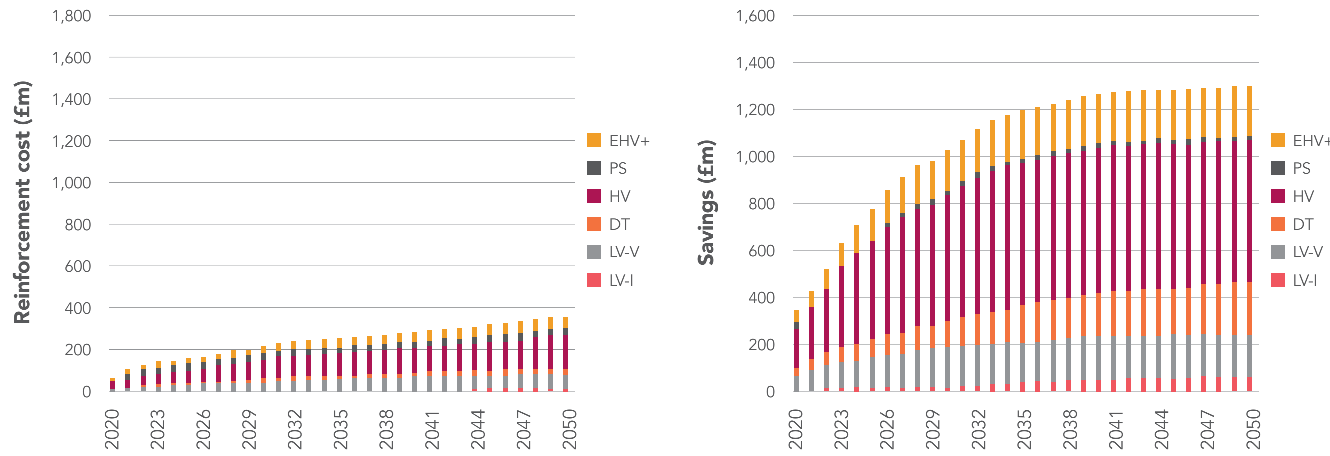


Figure 28: Development of South Wales's electricity distribution network upgrade cost for hybrid heating-only scenario

The results indicate that savings in the hybrid-only scenario, where the cumulative reinforcement cost is at around **£350m,** are about **£1,300m** compared with the counterfactual scenario by 2050.

5.3 Freedom field trial case analysis

Figure 29 shows the results for the hybrid heating system Economy Tariff scenarios. Savings of about **£1,400m** are observed compared with the counterfactual scenario by 2050.

Figure 30 shows results for the hybrid heating system DUoS Tariff scenario with savings of about **£1,450m** by 2050.

Figure 31 shows results for the hybrid heating system demand response scenario with savings of about **£1,400m** by 2050. Demand response assumes the hybrid heating system-only. Further savings could be achieved if other smart appliances are considered.

Figure 32 shows results for the hybrid heating system PassivSystems smart control scenario with savings of about **£1,500m** by 2050. The reinforcement cost is only driven by the baseline demand growth.

Economy Tariff scenarios

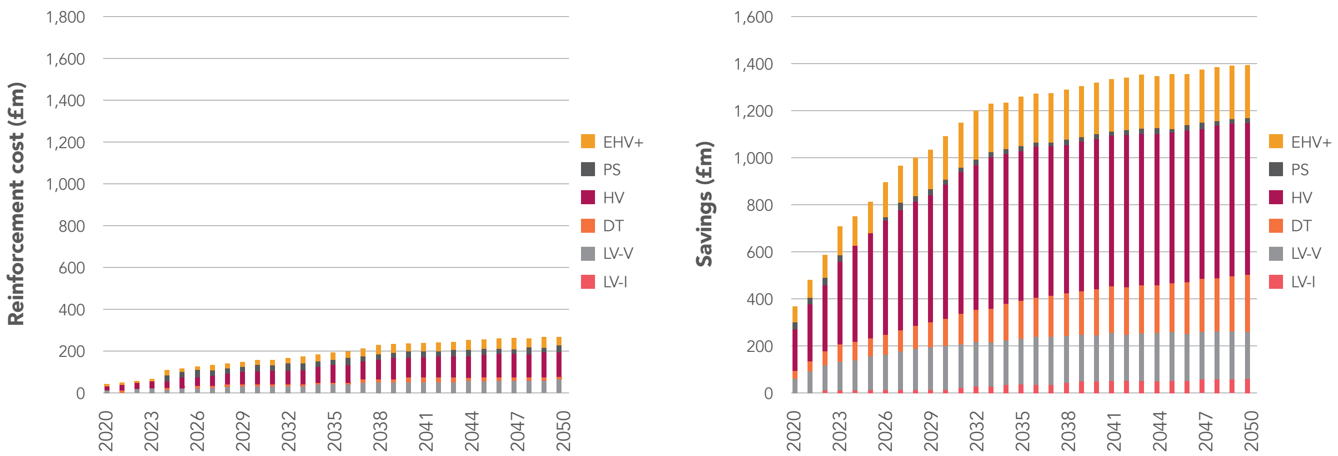


Figure 29: Development of South Wales' electricity distribution network upgrade cost for hybrid heating Economy Tariffs scenario.

DUoS Tariff scenario

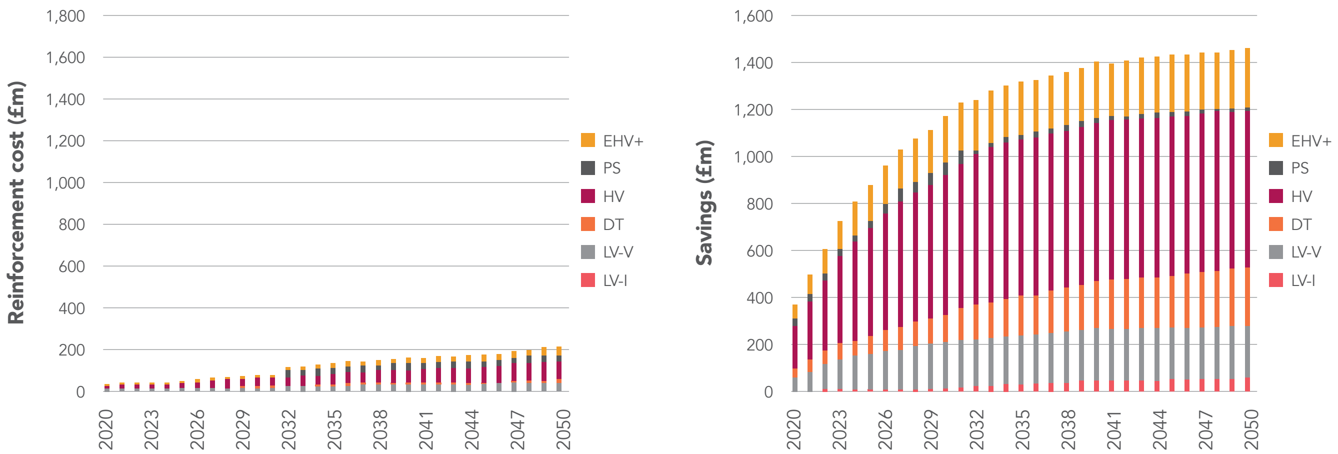


Figure 30: Development of South Wales' electricity distribution network upgrade cost for hybrid heating DUoS Tariff scenario

Demand response scenario

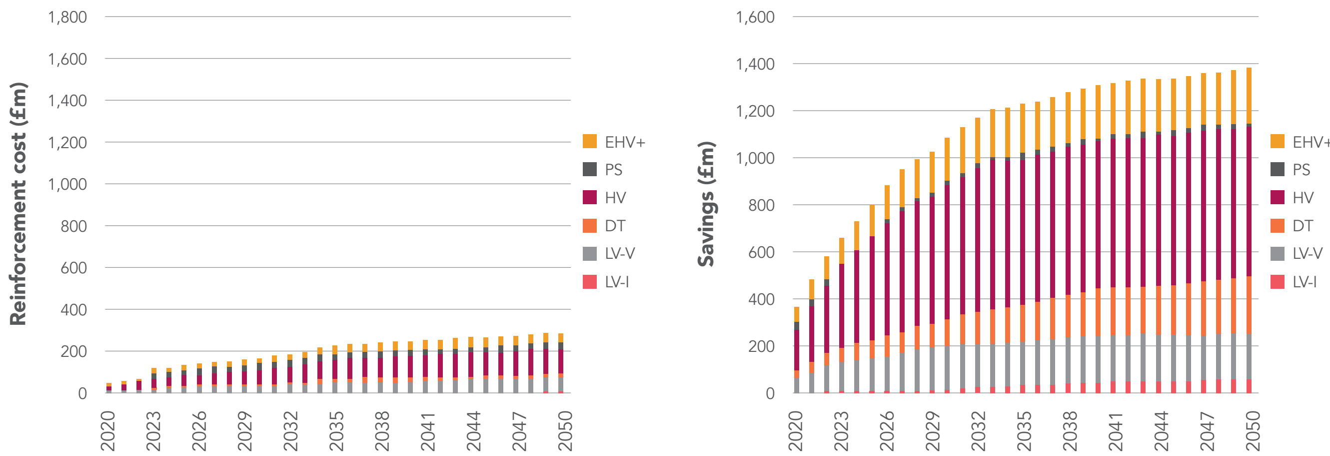


Figure 31: Development of South Wales' electricity distribution network upgrade cost for hybrid heating demand response scenario

PassivSystems smart control scenario

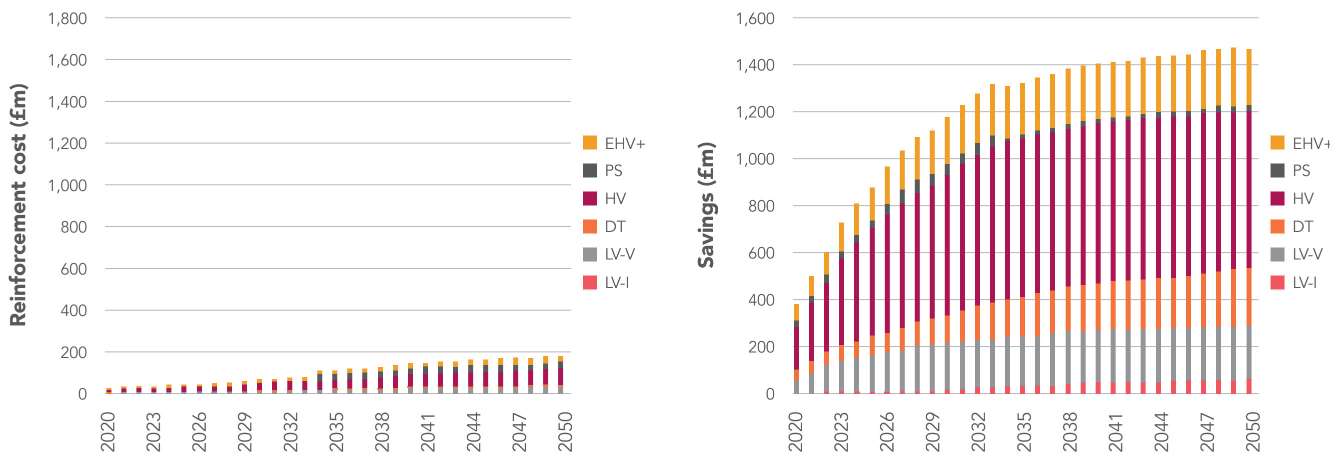


Figure 32: Development of South Wales' electricity distribution network upgrade cost for PassivSystems smart control of hybrids scenario

5.4 Gas network capability

The operational cost of running the gas distribution network has been falling dramatically and within the timeframes set out for decarbonisation of heat, the majority of the gas network distributing gas to housing will be made of polyethylene.

This material has no routine maintenance requirements, has very **low leakage** and hence is very **low cost to operate.** A study carried out for the Department of Energy and Climate Change (DECC) looking at the proposed Bridgend heat networks found no financial benefit of decommissioning the gas network and their detailed review revealed that the polyethylene areas had run at **zero operational cost** since installation. The higher pressure tiers would require some level of maintenance, but these are the pipelines that contain valuable energy storage assets and are used to provide gas to industry and flexible power generation – uses that are unlikely to be redundant. Therefore, overall, the operational costs of maintaining the gas network after 2030 are very modest set against the very high costs associated with the alternatives.

A sequential steady-state modelling was performed by Imperial College to investigate the impact of a large-scale deployment of hybrid heating systems on high and low pressure gas distribution networks.

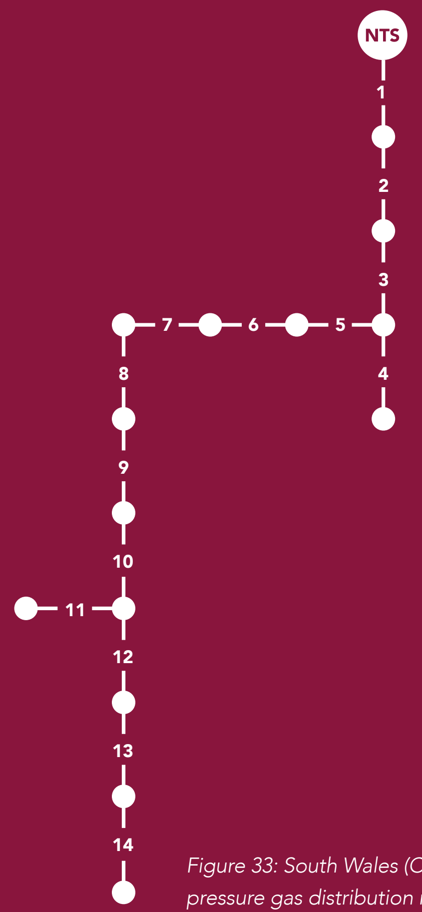


Figure 33: South Wales (Central) high pressure gas distribution network

5.5 High pressure gas distribution network (HighP)

This study simulates operation of the high pressure gas distribution network under the local offtake *(see Figure 33)*. The local offtake receives gas from the National Transmission System (NTS) and supplies Cardiff, Bridgend, Aberkenfig and Porthcawl. The maximum flow limit for the local offtake is 10.42 mcm/day.

5.6 Gas demand profile

For this study, the gas demand of 8.87 mcm/day was used which was a peak gas demand for the local offtake in 2015/2016.

The gas demand was uniformly distributed across the nodes in the high pressure systems that deliver gas to lower pressure tiers (the uniform distribution of gas demand across all the nodes are due to lack of access to spatially resolved demand data). Hourly gas demand at each node was estimated using the profiles shown in *Figure 34*. The gas demand profile in pink represents a baseline scenario in which there is no hybrid heating system installed, and the heating demand is supplied by conventional gas boilers.

The baseline profile was developed as part of a previous project to convert daily natural gas demand in GB into an hourly demand profile. In contrast, the profile in orange represents gas demand for a scenario with hybrid heating systems. In the gas profile with hybrid heating systems, it was assumed that before 07:00 ASHPs fuelled by electricity are used to supply heating. Within one hour from 06:00 to 07:00, hybrid heating systems switch from electricity to gas, and therefore a sudden spike in the gas demand occurs.

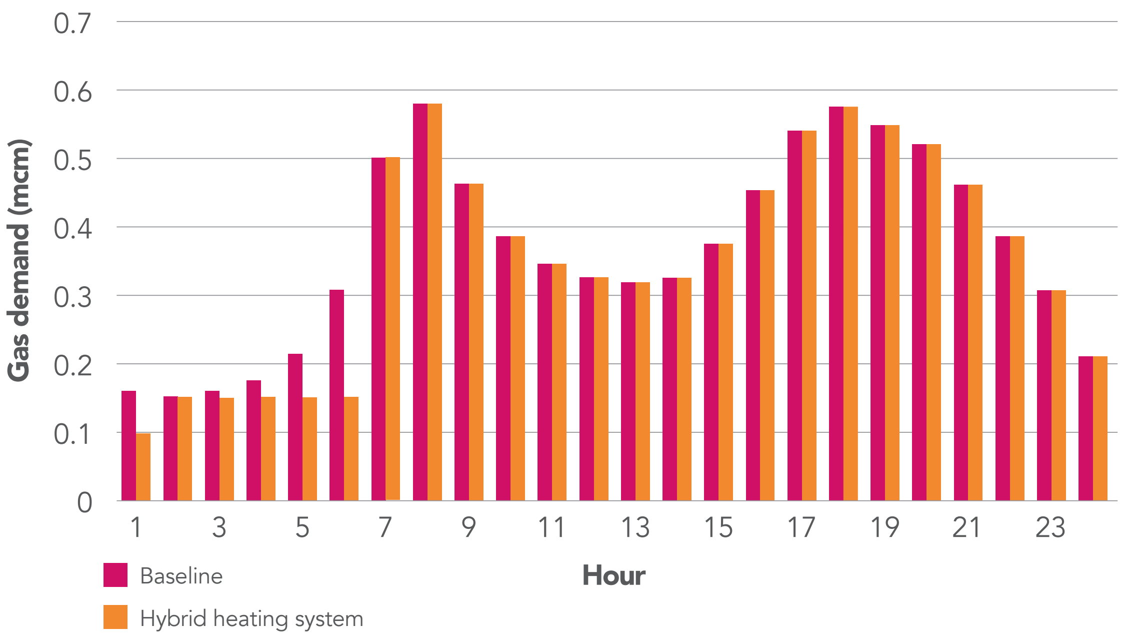


Figure 34: Hourly gas demand profiles for 'Baseline' and 'hybrid heating systems' scenarios

5.7 Impacts of hybrid heating systems on the operation of HighP

The simulation of the gas network for the two gas demand profiles was performed for an hourly time resolution over 24 hours.

One of the key properties of the high pressure gas network is linepack, which is the within-pipe storage capacity of the networks. Sufficient linepack in the network is crucial for dealing with an increase in gas demand. Therefore, when an increase in the gas demand is expected, the gas network is prepared to meet the variation of the gas demand by adjusting its supply gas flow to build up linepack before the abrupt increase in gas demand.

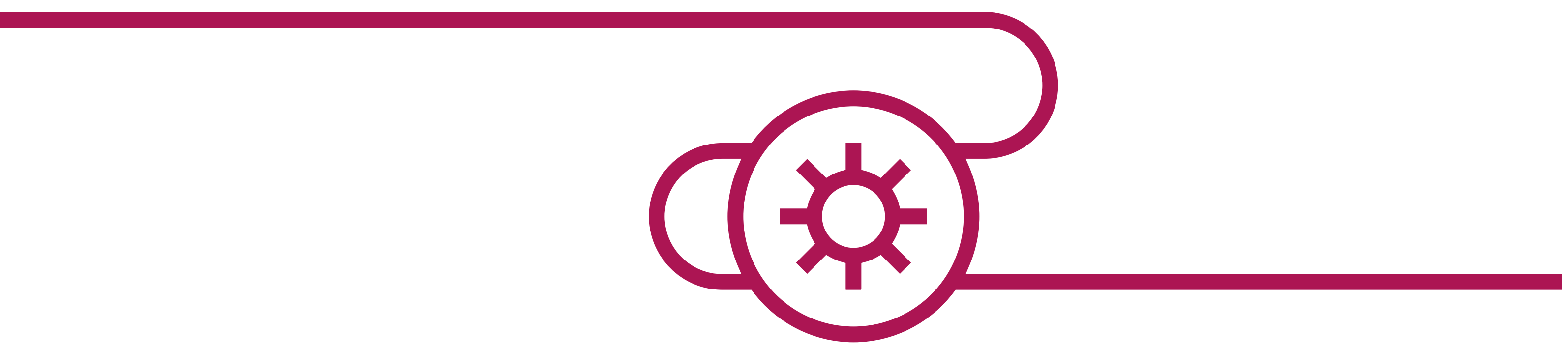
The comparison between the gas network linepack for the two demand profiles shows only small differences *(see Figure 35).*

In the first six hours, the linepack is gradually increased to its maximum for both Baseline and hybrid heating system cases to enable the network to meet the increase in gas demand.

Although the increase in gas demand for the hybrid heating systems profile occurs rapidly within one hour, the introduction of hybrid heating systems reduces the total gas demand during hours 3 and 7 due to the contribution of ASHPs that replace heating supplied by conventional boilers. Due to the sufficient linepack capacity in the South Wales (Central) gas network, the network can handle the abrupt increase in gas demand caused by hybrid heating systems.

For both **'baseline'** and **'hybrid heating system'** cases the demand was totally met without any load shedding and violation of pressure limits.

Figure 36 shows gas supply and demand in the 'hybrid heating systems' case, where almost 0.15 mcm of gas was supplied by linepack depletion to enable meeting the peak gas demand that occurred at 08:00.



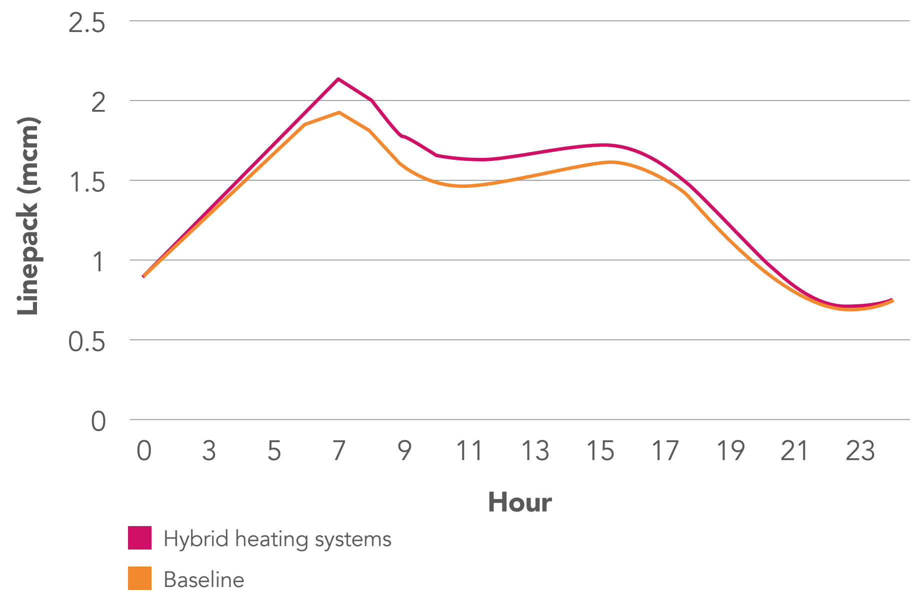


Figure 35: Linepack variations

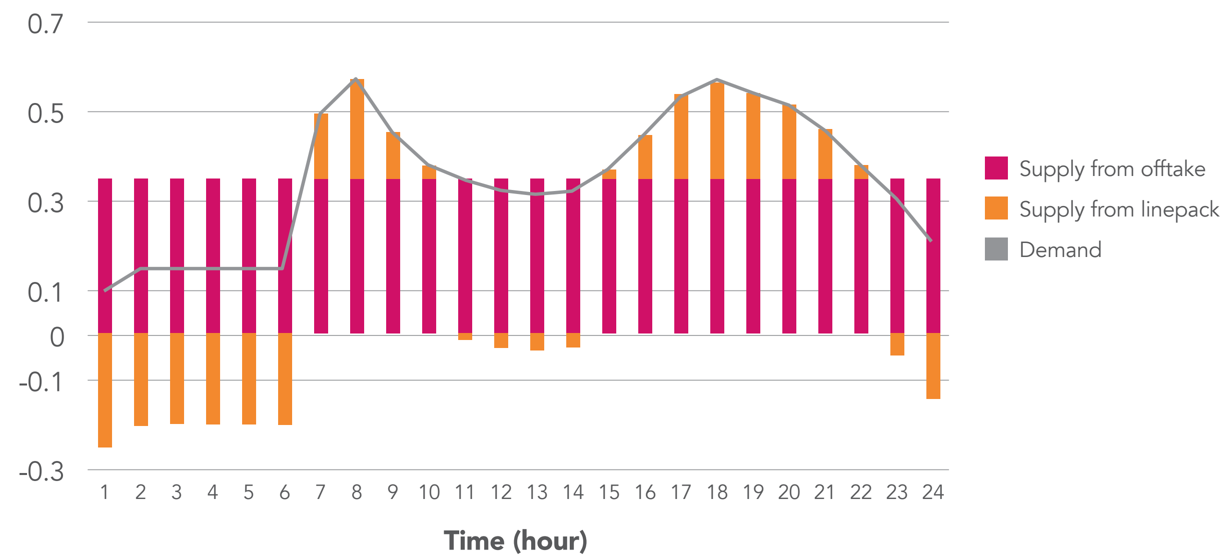


Figure 36: Gas supply and demand for the hybrid heating systems case

5.8 Low pressure distribution networks (< 75 mbar)

The topology of LP#1 is shown in *Figure 37*.

Gas flow analysis was carried out for this test network to investigate how the roll-out of hybrid heating systems could potentially affect the operation of a low pressure gas network. In particular, the focus of this analysis is whether sudden and significant increases in the gas demand can be met. The test network consists of 11 nodes and 14 pipes. The gauge pressure at the source node is **75 mbar.**

The baseline gas demand profiles for various nodes are presented in *Figure 38*. Similar to the high pressure case study, new gas demand profiles were created for each node to consider the impact of employing hybrid heating systems on gas demand. It was assumed that gas demand in the presence of hybrid heating systems is at its minimum level for the first six hours of the time horizon, and then at 07:00 suddenly will increase significantly due to a shift from using electricity in heat pumps to using gas in boilers.

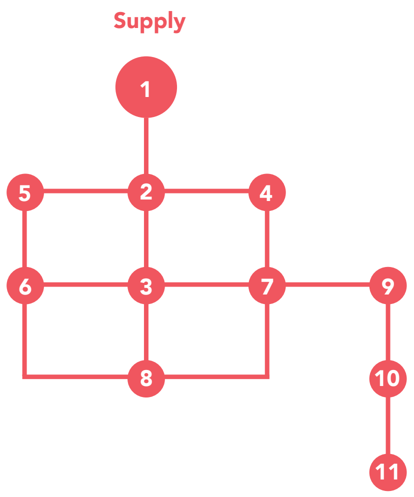


Figure 37: Gas network topology for LP#1

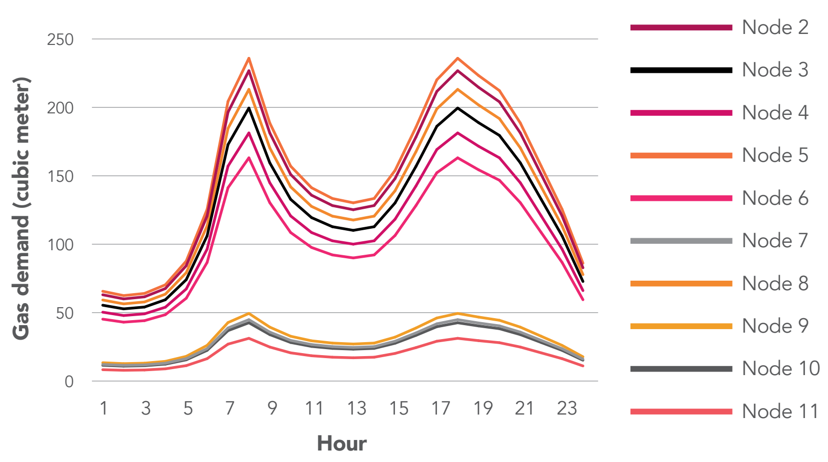


Figure 38: Baseline gas demand profiles for various nodes

Given gas demand for the baseline and hybrid heating systems demand scenarios, gas flows along the pipes as well as nodal pressures were calculated for the whole time horizon (24 hours) to check whether the gas demand will be met without violating pressure limits.

5.9 Impacts of hybrid heating systems on the operation of LP#1

Figure 39 shows the gas supplied from the higher pressure tier and total gas demand are in balance at each time step for the hybrid heating systems demand scenario.

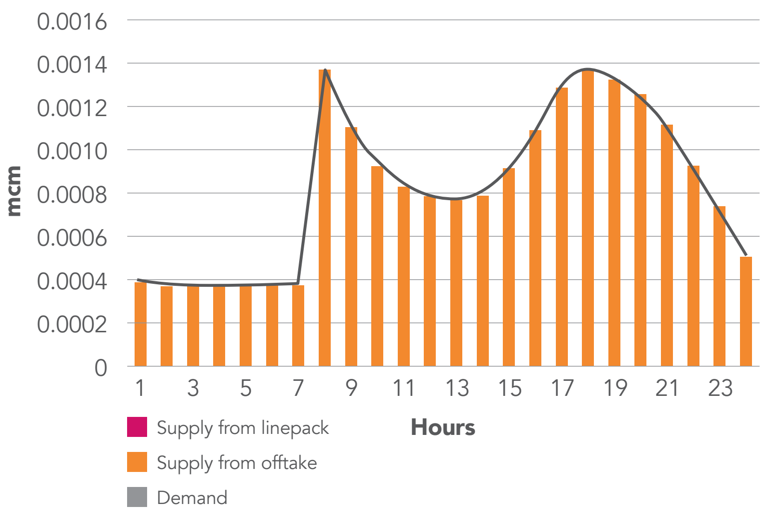


Figure 39: Gas supply and demand in the presence of hybrid heating systems

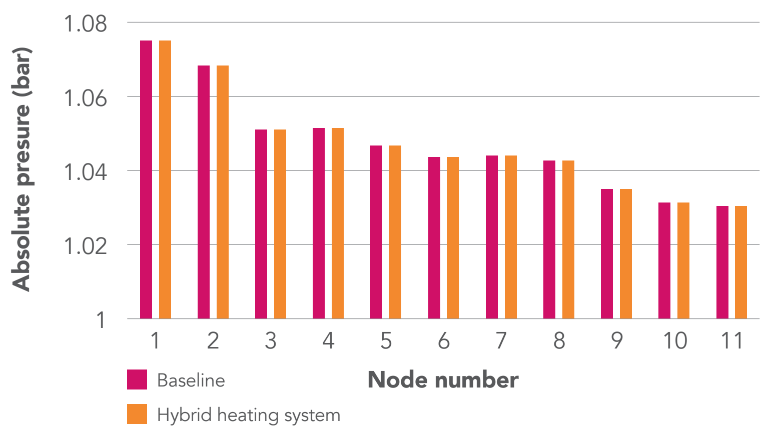


Figure 40: Pressure profile for LP#1 at 08:00 (peak) for different scenarios

Unlike high pressure networks, there is no role for linepack to contribute to supply and demand balancing. This is due to the small within-pipe volume and low operating pressure of the test network, which results in negligible accumulation of gas within the network. As the low pressure network covers a small geographical area (compared with high pressure networks) the time taken for gas to travel from the supply node to demand nodes is negligible and therefore it can be assumed that the low pressure network behaves in a steady-state manner.

Figure 40 shows the gas pressure for different nodes at 08:00 when gas demand is the highest. The results suggest that the pressure profile across the network is almost the same for different demand scenarios and operational approaches.

5.10 Low pressure gas network LP#2

To ensure the conclusion made for LP#1 is valid for other low pressure gas networks, a larger low pressure gas network (LP#2) was also modelled. The topology of LP#2 is shown in *Figure 41*.

The modelling results for LP#2 are in agreement with those of LP#1 and demonstrate that the **large-scale penetration of hybrid heating systems will not affect the operation of low-pressure gas networks.**

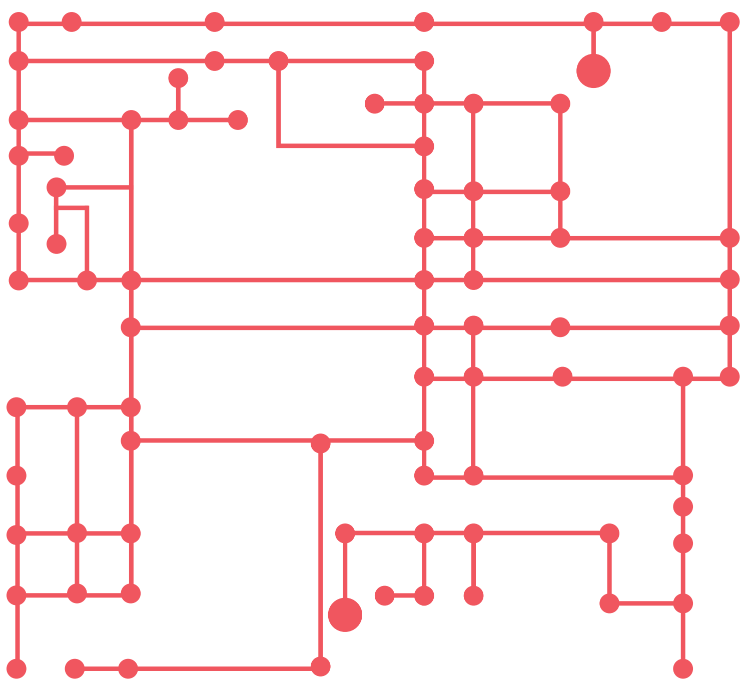


Figure 41: Gas network topology for LP#2

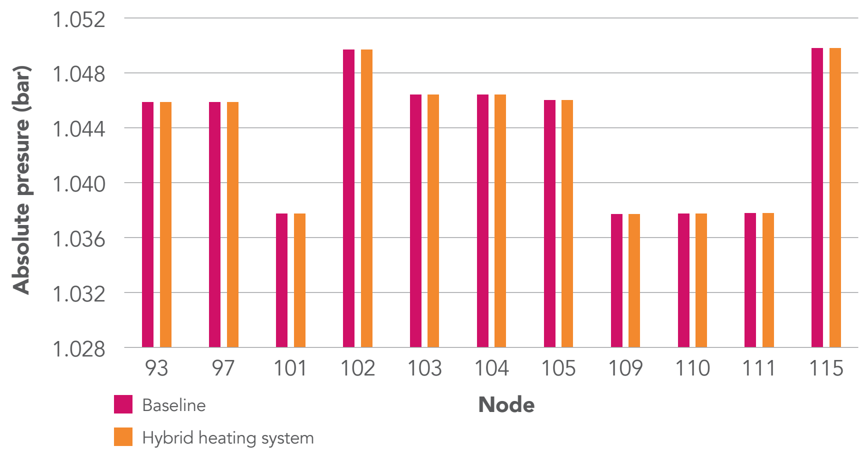


Figure 42: Pressure profile for LP#2 at 07:00 (peak) for different scenarios

5.11 Conclusion

A statistical representative network method based on fractal theory has been applied to calculate the potential benefit of hybrid heating systems compared to ASHP-only installations by mitigating/deferring electricity distribution network upgrades.

Figure 43 shows the Net Present Value (NPV) of saved network reinforcement costs for different scenarios. **Savings over 32 years are estimated at £257m** in the ASHP and hybrid heating systems scenario, **increasing to £820m if only hybrid heating systems are installed.** Demand response could further **increase savings by about £38m,** while Economy and DUoS tariffs could potentially increase savings by **£53m** and **£104m,** respectively. Finally, PassivSystems smart control of hybrid heating systems could potentially provide further benefits of about **£115m.**

Scenario	NPV, £m
EHP and HHP	257
HHP only	820
HHP Demand Response	858
HHP Economy Tariffs	873
HHP DUoS Tariff	924
PassivSystems Smart Control	935

Figure 43: NPV for different scenarios

Sequential steady-state modelling was performed to investigate the impact of a large-scale deployment of hybrid heating systems on high and low-pressure gas distribution networks.

In the high-pressure gas distribution network, the sudden increase in the gas demand caused by the operation of hybrid heating systems can be met through using the gas network's linepack. However, the key factor in the capability of the gas network in dealing with rapid and large increases in gas demand is the 'predictability' of the demand. The preliminary modelling works demonstrated that by having knowledge about the occurrence of a large and rapid increase in the gas demand in future, the network operator can pressurise the network to accumulate more gas in pipelines (increasing the linepack) in advance to deal with the increase in the demand. However, to deal with the increased uncertainty in gas demand introduced by deploying hybrid heating systems, the gas network always needs to maximise its linepack. A possible solution for dealing with the unforeseen and abrupt increase in gas demand is installing fast-cycle gas storage (i.e. high pressure bullets) on gas distribution networks. In addition, a gradual shift from heat pumps to gas boilers gives the gas distribution system operator sufficient time to increase the network's linepack and prepare to supply the peak gas demand.

In the low-pressure gas distribution network, as far as gas is available from the higher pressure tiers, the network can deal with an unforeseen, abrupt and significant increase in gas demand without violating the pressure limits.

6. Whole-system assessment of the impact of hybrid heating systems

Electrification of the heating sector, as part of the overall mission to decarbonise the energy system, will require significant investment in low carbon electricity generation and may also lead to significant increases in peak electricity demand and hence drive distribution network reinforcement and investment in generation peaking plant. In this context, the application of hybrid heating systems that combine an ASHP with a fossil fuel boiler (mostly gas) are showing significant advantages based on the dual-fuel flexibility.

The flexibility of hybrid heating systems to switch between electricity and gas can also provide various services to the energy system, such as peak demand management to reduce investment in generation and network assets, as well as flexible services such as frequency response and reserve services to support electricity system operation in future low-carbon systems.

In light of the above, Imperial College present key results of case studies that investigated the system implications and benefits of adopting PassivSystems' hybrid heating technology in the future UK energy system with different carbon targets. Imperial College has quantified the benefits of smart control of hybrid heating systems, informed by trials carried out in the project.

6.1 The benefits of deploying PassivSystems' smart hybrid heating systems *to the future UK electricity system*

A set of case studies were carried out to investigate the implications and quantify the range of benefits of rolling-out PassivSystems' smart hybrid heating to the future UK electricity systems. The studies focus on:

1. Cost and benefits of using responsive hybrid heating systems[3] compared with the use of ASHPs[4] for two different annual carbon targets, i.e. **100g and 25g CO_2/kWh.** Carbon emissions from electricity, gas, and transport (which is electrified) are considered in this study.
2. Impact of responsive hybrid heating systems on the optimised power system capacity (generation mixes, network) and electricity production (energy mixes).
3. The benefits of implementing PassivSystems' smart control technology to responsive hybrid heating systems that use a preheating strategy and improve the energy efficiency.

The studies consider the decarbonisation of all future UK heat demand (around 630 TWhth) covering domestic and non-domestic thermal loads.

[3] *Assumes a connected hybrid heating system that is responsive to energy system conditions, a subset of the PassivSystems control functionality*

[4] *Assumes a non-connected ASHP operating with standard controls typical of current market products*

6.2 Benefits of responsive hybrid heating systems

Figure 44 **shows the difference between the annual costs of a system with ASHPs (as the counterfactual) and a system with responsive hybrid heating systems for two carbon targets; 100g and 25g CO_2/kWh assuming there is no other demand flexibility and no additional new electricity storage or thermal energy storage/preheating.**

The system costs considered in this study comprise:

- Annuitised capex of network reinforcement (distribution, interconnection, transmission)
- Annuitised capex of generation investment divided into investment in traditional fossil-fuelled power plant and low-carbon power technologies including nuclear, CCS, and renewables (wind and PV)
- Operating cost of electricity including fuel, no-load, and start-up costs of generators
- Operating cost of gas for heating.

The cost of maintaining the existing gas network infrastructure, the cost of heating appliances and the cost of household conversion needed to accommodate ASHPs or responsive hybrid heating systems are excluded from this analysis.

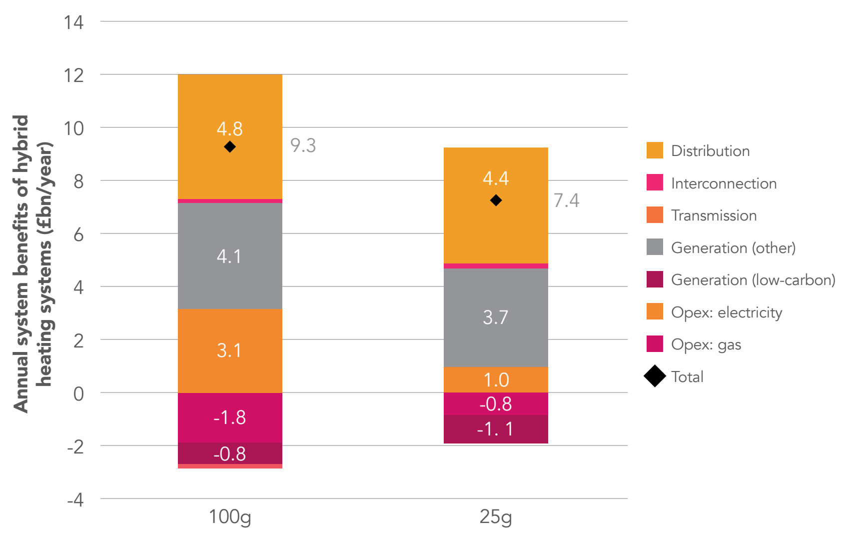


Figure 44: System-level benefits of hybrid heating systems

The results demonstrate that the use of responsive hybrid heating systems reduces the cost of distribution network reinforcement, opex of electricity and the overall generation capex, although the cost of low-carbon generation increases. The impact on transmission and interconnection is modest. The savings are obtained by providing cross-energy-system flexibility enabling the switch between electric and gas heating to minimise the overall system cost; consequently, the opex of gas (for heating) offsets slightly the benefit.

The benefits of responsive hybrid heating systems are lower in a system with a more demanding carbon target as the usage of gas becomes less in the 25g case. This is not unexpected as the gas usage will be constrained by the carbon target. Consequently, this increases the electrification of heat demand and reduces the benefits of responsive hybrid heating systems. Alternatively, the **natural gas can be substituted by biogas to decarbonise the gas system;** this can improve the utilisation of gas-based heating appliances.

The implications of using responsive hybrid heating systems on the power generation portfolio are demonstrated in *Figure 45*.

The results show that **the responsive hybrid heating system cases require less firm generating capacity** (needed for security reasons) than the capacity needed in the electric cases. It is noticeable that the capacities of **open cycle gas turbines (OCGTs), combined cycle gas turbines (CCGT) and nuclear in the ASHP case are much higher than the corresponding capacities** in the responsive hybrid heating system case.

There is a **small increase in the requirement for low-carbon generation** in the responsive hybrid heating system case. This is unexpected since the emissions from the electricity sector have to be reduced to compensate for the emissions from gas.

As expected, t**he total electric demand in the responsive hybrid heating system case is smaller than in the ASHP case** as the use of gas boilers reduces the annual demand consumed by the ASHP. The difference between the ASHP and the responsive hybrid heating system cases becomes smaller in the 25g scenario as the use of gas is constrained by the carbon target.

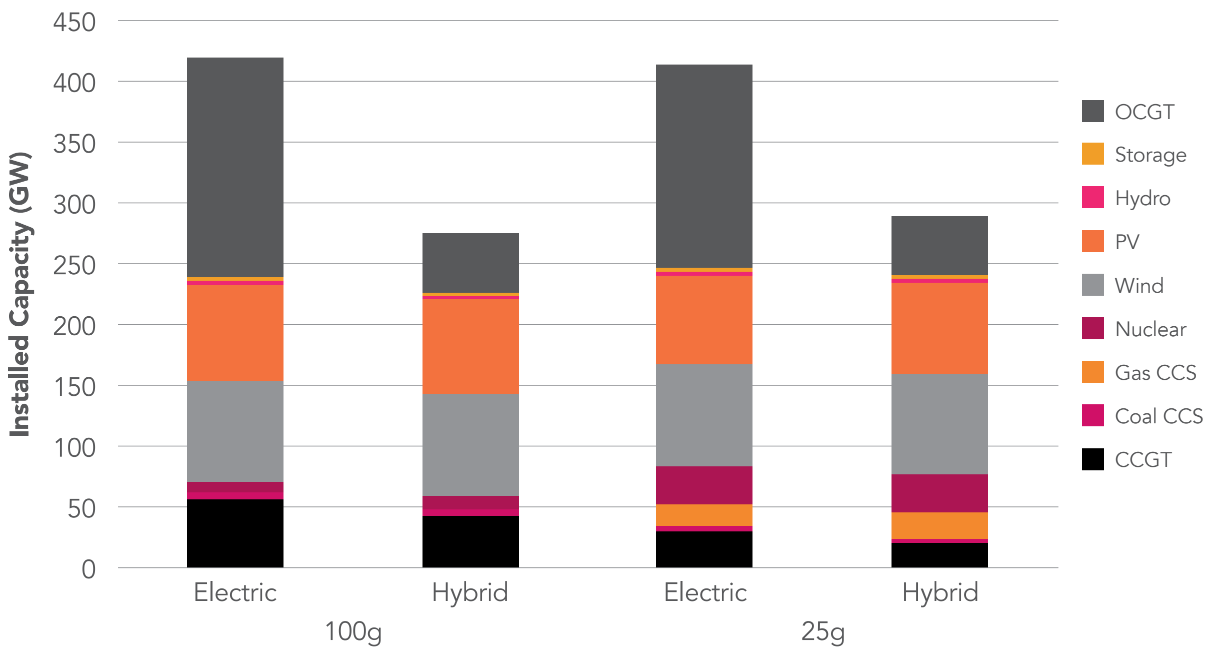


Figure 45: Installed generation capacity

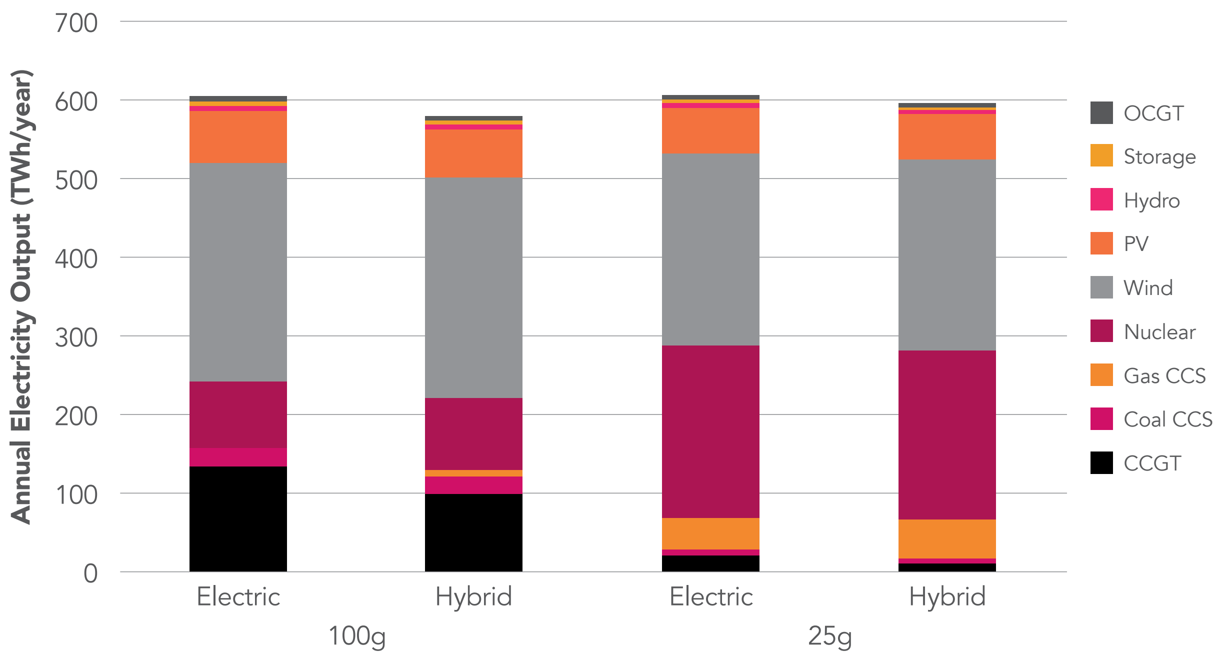


Figure 46: Annual electricity production in different cases

The benefits of responsive hybrid heating systems to ASHPs become less if the system is more flexible. This is demonstrated in *Figure 47*. The benefits reduce from **£9.3 to £5.5 bn/year in the 100g case and from £7.4 to £4.9 bn/year in the 25g case.** In this study, it is assumed that there are other flexibility sources including controllable loads (industrial and commercial loads, electric vehicles, smart appliances) and electricity storage that can be used to shift the load and provide balancing services. In addition, the model also proposes to use electricity storage up to 10 GW.

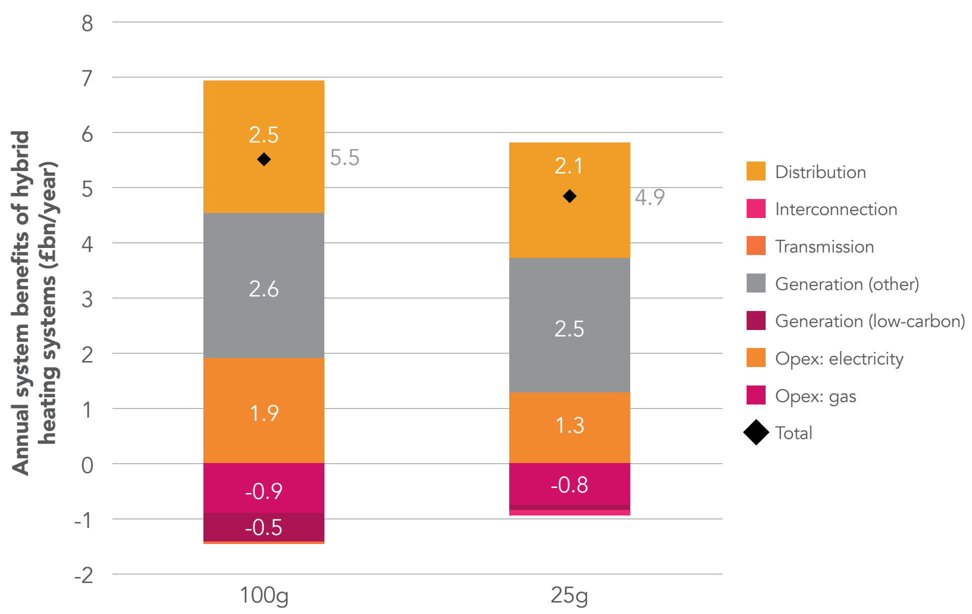


Figure 47: System-level benefits of responsive hybrid heating systems in a system with demand flexibility and storage

This scenario shows the benefits are still dominated by:

1. The reduction in the firm generating capacity and distribution network capacity; and
2. A reduction in the opex of electricity. The benefits are offset by the opex of gas and the increase in the low-carbon generation capex.

6.3 Benefits of providing balancing services

Balancing services are essential for the power system; the value of the services is expected to increase substantially in future as a consequence of having more renewables. Smart control of hybrid heating systems can provide functionality to deliver frequency response and reserve services by curtailing or switching on the electric heating. In this study, the value of providing balancing services is quantified for the 100g and 25g cases.

The counterfactual is the case with responsive hybrid heating systems not providing balancing services. It is assumed that there are no other providers of balancing services except generators. The results of the study are presented in *Figure 48*.

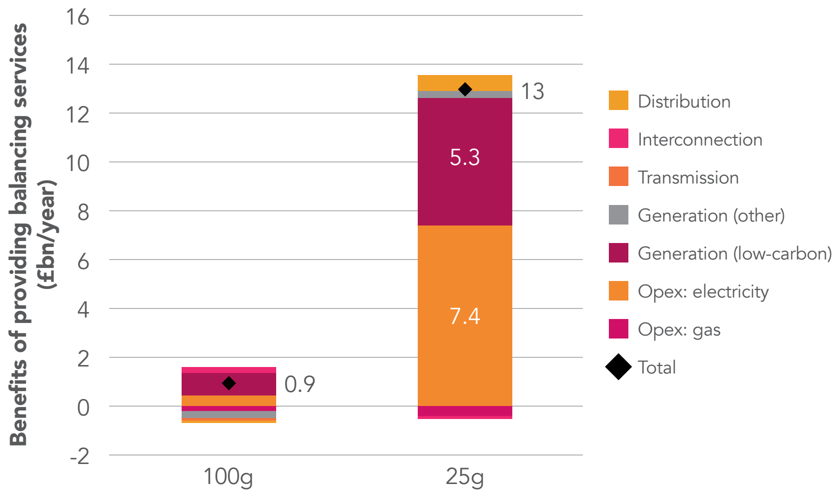


Figure 48: Benefits of providing balancing services by responsive hybrid heating systems

The study provides evidence that the value of balancing services is substantially higher in a system with a more demanding carbon target; the benefits of enabling these services are £0.9 bn/year in the 100g case but increases to £13 bn/year in the 25g case. It is important to note that the system is relatively non-flexible; it can be expected that the values can become smaller if there are other flexibility sources that provide these services.

6.4 Benefits of preheating

In this study, the impact and benefits of preheating have been investigated and quantified. Two levels of preheating were investigated: (i) medium and (ii) high preheating cases corresponding to 25% and 100% of households that are capable of being preheated in advance to meet the peak of heat demand based on the trialled data that have been analysed. In order to optimise the preheating, a smart control trades off the benefits of preheating and the losses incurred in this process.

The results of the studies are presented in *Figure 49*, which shows the difference between the system costs of the responsive hybrid heating system without and with preheating capability for the 100g and 25g carbon targets. It is important to note that in this study, it was **assumed that there was no other demand flexibility or new electricity storage in the system.** Therefore, improving the system flexibility through preheating will bring substantial benefits and therefore the preheating capacity will have a high value.

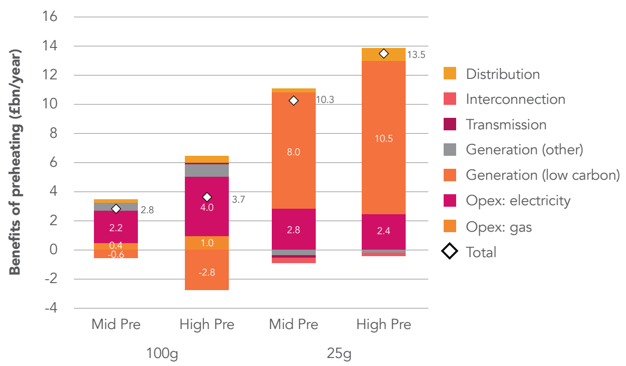


Figure 49: Benefits of preheating for the responsive hybrid heating system

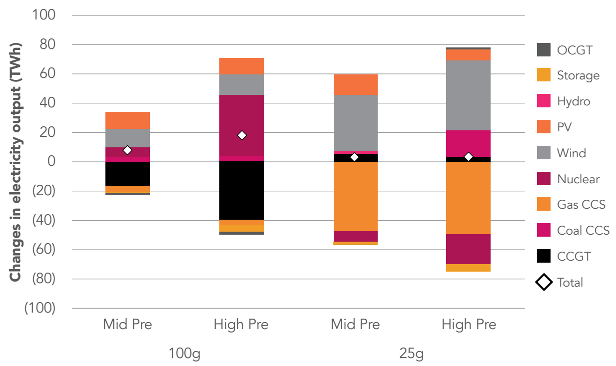


Figure 50: Implications of preheating on the energy mixes

The results demonstrate that in the 100g cases, the preheating increases the cost of low-carbon generation capex but the investment in low-carbon generation also reduces the operating cost of electricity. As nuclear and renewables are zero-marginal-cost plants, increased capacity of these technologies reduces the operating cost. The increased investment in low-carbon generation reduces the utilisation of gas. In the 25g cases, the flexibility provided by preheating enables more utilisation of renewables and other low-carbon technologies *(see Figure 50)*. **This reduces the capacity needed from low-carbon generation** as depicted in *Figure 51*.

The preheating also contributes to savings in the electricity distribution network, which is expected as the preheating can further reduce the peak demand.

The value of preheating increases from £2.8 – £3.7 bn/year in the 100g cases to £10.3 – £13.5 bn/year in the 25g cases. This finding is aligned with the findings from other studies[5 6], which conclude that the flexibility will have a higher value in the system with a more demanding carbon target.

Figure 50 shows the implications of preheating on the optimised energy mixes in different cases. It is demonstrated that preheating will increase the system ability to use low-carbon generation. **In the 100g cases, higher utilisation of nuclear and renewables displaces the output of CCGT and reduces the utilisation of electricity storage** (which implies fewer losses associated with the cycle losses of storage).

In the 25g cases, preheating allows a higher utilisation of renewables and coal-fired CCS plants which substitutes output from nuclear and gas-fired CCS. This will, in turn, reduce the capacity of nuclear and gas-fired CCS as shown in *Figure 51* and reduce the associated cost.

It is important to note that the benefits of preheating presented in *Figure 49* are **based on systems with no other demand flexibility or electricity storage.** Therefore, the values are relatively high. The benefits are less when the system has other flexibility sources, e.g. flexible industrial and commercial loads, smart charging of electric vehicles, or electricity storage. In order to understand the implication of having other flexibility sources, a set of studies were carried out assuming there were other flexibility sources in the form of controllable loads (industrial and commercial, electric vehicles, smart appliances) and electricity storage. The results of the case studies are presented in *Figure 52*.

The results demonstrate that the benefits of preheating in a flexible system are substantially less than its values in a low flexible system. The value reduces from £3.7 bn/year to £1.8 bn/year in the 100g case, and from £13.5 bn/year to £4.7 bn/year in the 25g case. The results are not unexpected since preheating uses the thermal inertia of the building as an energy store to shift the energy demand to periods where the cost of energy is lower in order to minimise the overall cost. Therefore, this function can be displaced by other types of energy storage such as electricity storage where the stored electricity can be used to supply the heat pumps when needed. However, preheating is considered a cost-effective solution as it requires only investment in responsive hybrid heating systems and therefore, the cost of enabling preheating is much lower than the cost of electricity storage. Therefore, **preheating can displace electricity storage** as demonstrated in *Figure 52* (high flex scenario).

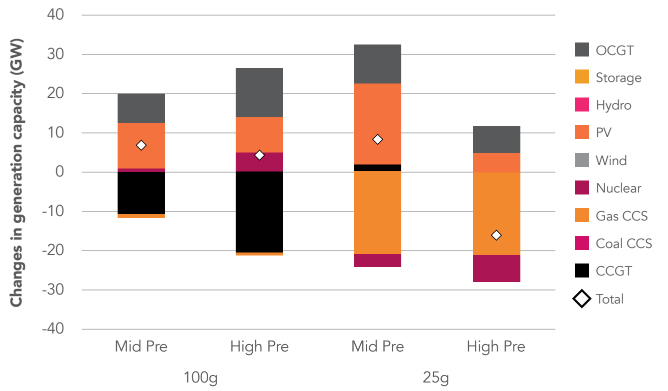


Figure 51: Impact of preheating on the generation capacity

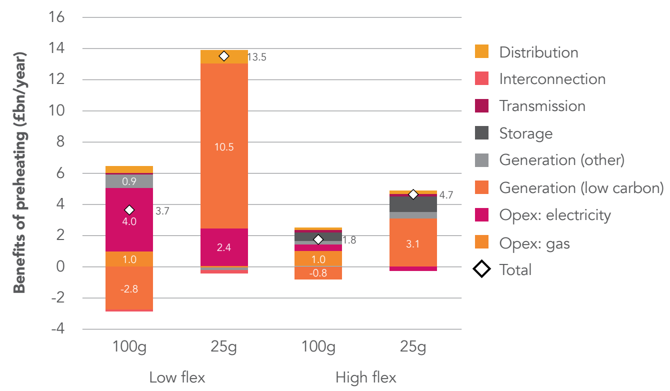


Figure 52: The benefits of high preheating in a low flexible and high flexible system

[5] *Imperial College and NERA Consulting, 2012, "Understanding the Balancing Challenge", analysis commissioned by DECC. Please see https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48553/5767-understanding-the-balancing-challenge.pdf*

[6] *G.Strbac, D.Pudjianto, F.Teng, D. Papadaskalopoulos, G.Davies, and A.Shakoor,"Roadmap for Flexibility Services to 2030," a report to the Committee on Climate Change, London, May 2017. Please see https://www.theccc.org.uk/publication/roadmap-for-flexibility-services-to-2030-poyry-and-imperial-college-london/*

6.5 Benefits of improved energy efficiency via PassivSystems

The optimised control of the hybrid heating system carried out by PassivSystems demonstrated that the efficiency of the hybrid heating system can be improved. In order to understand the benefits of improved energy efficiency if the technology is rolled-out across the UK, a number of studies were carried out assuming that the energy efficiency of the hybrid heating system can be improved by 5% and 10%. The studies were carried out for the 100g and 25g carbon targets. The results of the studies are presented in *Figure 53*.

The results demonstrate **improved energy efficiency** allows a reduction in the opex of electricity, capex of generation and also network costs (primarily distribution network costs) but the **main savings are in the opex of electricity and capex of low-carbon generation.** In the 100g cases, the benefits are between **£1.8 and £2.4 bn/year.** In the 25g cases, the benefits are in the order of **£2.5 – £4.9 bn/year.** This concludes that the system value of improved efficiency enabled appropriate control of the hybrid heating system may be significant, particularly in the system with a stricter carbon target.

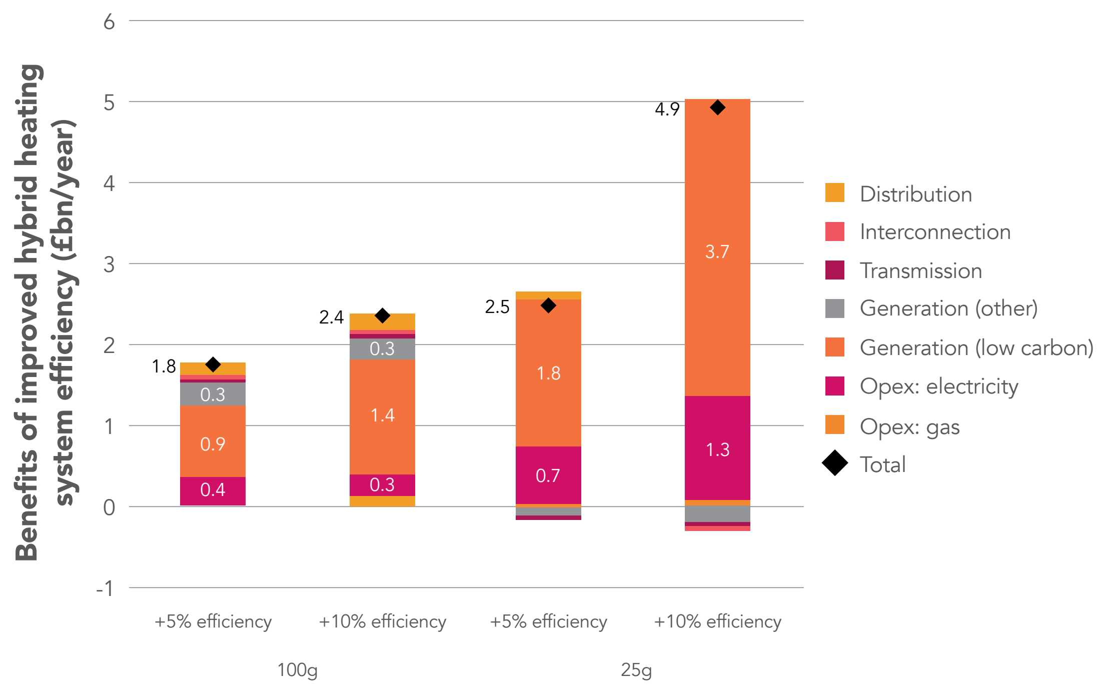


Figure 53: Benefits of improved energy efficiency attributed to PassivSystems smart hybrid heating system control

6.6 Benefits of PassivSystems smart hybrid heating

Combining PassivSystems' smart control functionalities to maximise the benefits of preheating and improving the energy efficiency will bring a higher value for this technology. In this context, two studies with 100g and 25g carbon targets were carried out assuming that 100% of the household can do preheating and 10% improved energy efficiency can be gained.

In addition, **the impact of having other flexibility sources was investigated.** The difference between the costs of the system with and without PassivSystems' smart control in a low and high flexible system is presented in *Figure 54*.

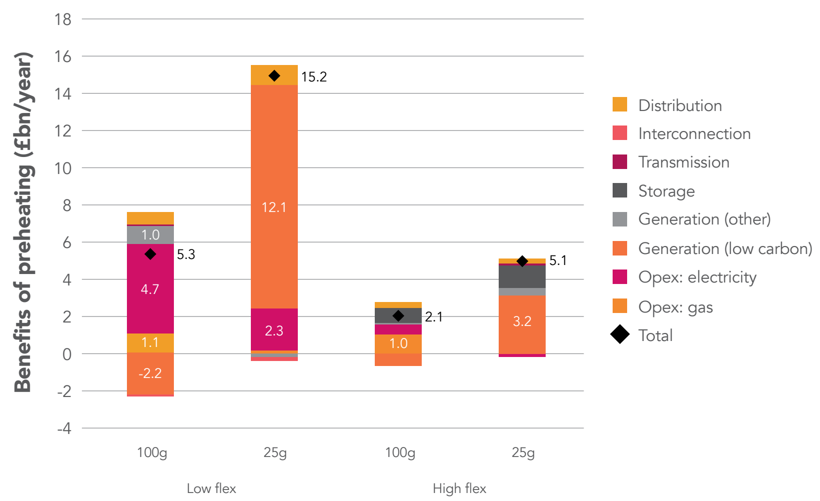


Figure 54: Benefits of PassivSystems' smart hybrid heating system control

The results demonstrate that in the 100g case, PassivSystems' smart hybrid heating system allows more low-carbon and zero-marginal-cost plants to be installed; it reduces the opex of electricity at the expense of higher capex of low-carbon generation and the opex of gas. In the 25g case, the flexibility provided by PassivSystems' smart hybrid heating system allows higher utilisation of renewables and other low-carbon technologies and therefore, reduces the need for nuclear and CCS which reduces the cost of low-carbon generation and opex of electricity. In both cases, the smart control reduces the cost of distribution networks.

In the low-flexible system, the system value of the smart control is £5.3 bn/year in the 100g case. The value increases to £15.2 bn/year in the 25g case. These savings are attributed to PassivSystems' smart hybrid heating system that allows the preheating and operation of a hybrid heating system to be optimised while providing flexibility and balancing services to the electricity system. However, the results demonstrate that there is a synergy across the flexibility and system services provided by hybrid heating systems as the total benefit is not a summation of the benefit of the individual functionality offered by PassivSystems' smart control. In the high-flexible system, the value of smart reduces to £2.1 bn/year in the 100g case and to £5.1 bn/year in the 25g case as other flexibility sources are present in the system.

6.7 Conclusions

Imperial College has presented the whole-system assessment methodology for future low-carbon power systems, implemented through its WeSIM model. The model has been extended to allow for the consideration of hybrid heating systems as a specific demand category with the capability to switch between gas and electricity as sources of heat supply.

The illustrative case study with smart hybrid heating on the 2030 GB system has demonstrated the **significant potential of hybrid heating systems to deliver savings in the electricity system, predominantly by reducing the need to invest in costly generation and network infrastructure** to meet high but infrequent peaks in demand. The overall annual volume of gas used to top up heating demand through hybrid heating systems is relatively small, with a comparatively small impact on the annual carbon emissions, **making hybrid heating systems a valuable, flexible option to cope with the cost of decarbonising future energy systems.**

A spectrum of studies has been analysed focusing on the benefits of hybrid heating systems to decarbonise heat demand compared to the alternative ASHP. All heat demand in the system is considered.

The responsive hybrid heating system can provide a lower cost solution to the system where the heat demand is purely decarbonised through electrification. This technology allows switching between the use of electric heating and gas-based heating to minimise the overall system costs. The savings presented in *Figure 44* are substantial, i.e. £9.3 bn/year in the 100 g case, and £7.4 bn/year in the 25g case[7].

The benefits of hybrid heating system-based heat decarbonisation compared to the application of ASHPs are reduced if other sources of flexibility are available, including demand response and electricity storage. Given the assumptions taken in the study, the benefits of responsive hybrid heating systems to ASHP are reduced from £9.3 to £5.5 bn/year in the 100g case, and from £7.4 to £4.9 bn/year in the 25g case[7].

The results demonstrate that the benefits of preheating in a flexible system are substantially less than its values in a low flexible system. The value reduces from £3.7 bn/year to £1.8 bn/year in the 100g case, and from £13.5 bn/year to £4.7 bn/year in the 25g case. The results are not unexpected since preheating uses the thermal inertia of the building as an energy store to shift the energy demand to periods where the cost of energy is lower in order to minimise the overall cost. Therefore, this function can be displaced by other types of energy storage such as electricity storage where the stored electricity can be used to supply the heat pumps when needed. However, **preheating is considered a cost-effective solution** as it requires only investment in the smart control and therefore, the cost of enabling preheating is much lower than the cost of electricity storage.

Smart optimised hybrid heating systems do not increase peak demand of electricity; this will reduce the system capacity requirements particularly affecting the distribution network and generation capacity while the impact on the transmission and interconnection capacity is relatively modest.

Compared to investment in low-carbon electricity generation in a system with ASHPs, there is a **slight increase (less than £1.1 bn/year) in the cost of low-carbon generation in the responsive hybrid heating system** to decarbonise further the electricity sector to compensate the emissions from the gas sector. This cost can be **reduced to less than £0.5 bn/year using PassivSystems smart controls and it can be reduced further if the gas is renewable.**

The use of gas is reduced in the 25g case and the gas usage will need to be constrained by the carbon target. Alternatively, **the natural gas can be substituted by biogas to decarbonise the gas system;** this can improve the utilisation of gas-based heating appliances. However, even with less utilisation of gas, **the value of flexibility provided by hybrid heating systems is higher in a system with a more demanding carbon target.**

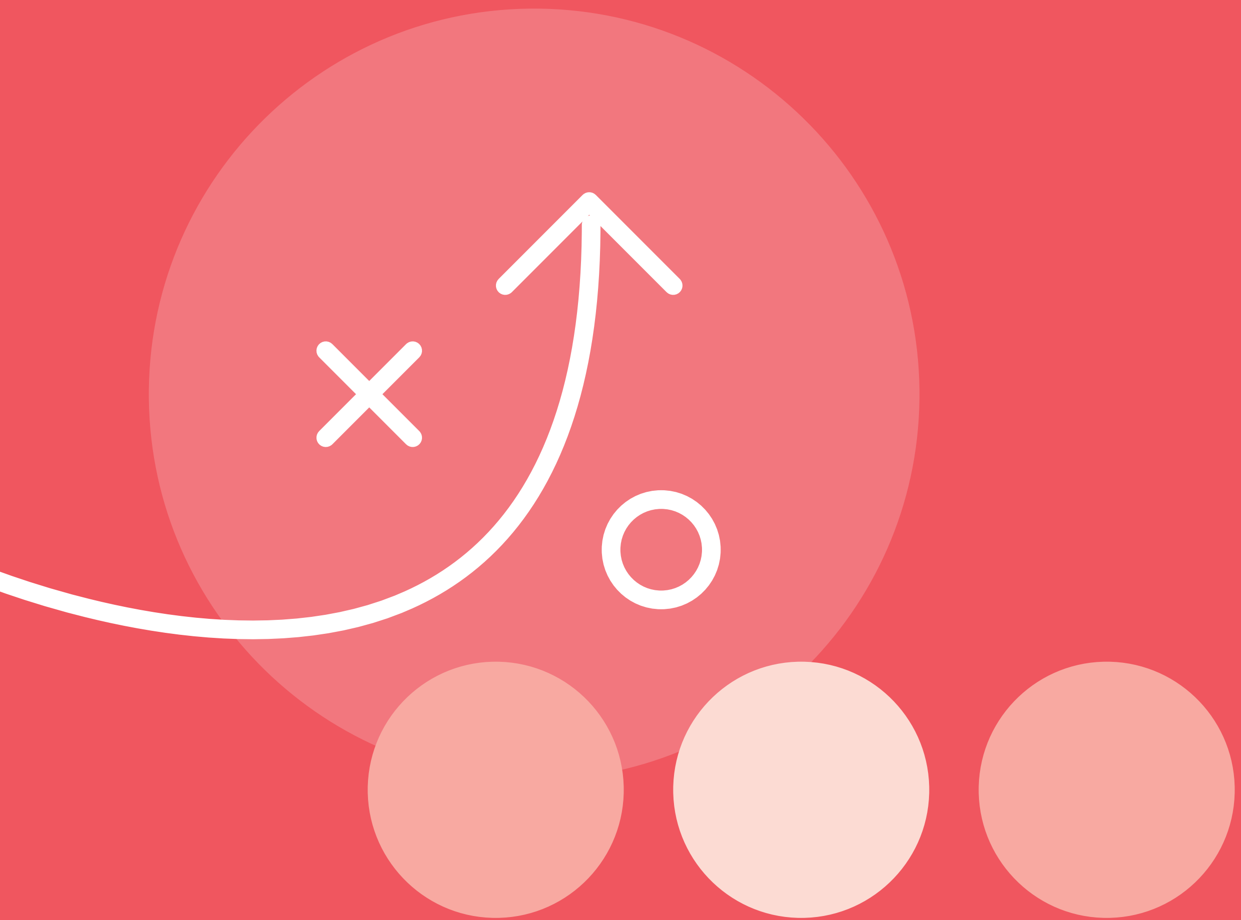
System modelling carried out demonstrated that the rollout of **PassivSystems hybrid heating systems would further improve the value of hybrid heating systems by £5.3 bn/year in the 100g case and £15.2 bn/year in the 25g case.** PassivSystems control would significantly enhance the capability of the system to integrate and utilise low-carbon generation, reduce low-carbon generation requirement and the firm generating capacity needed for maintaining the system security and distribution network capacity. The flexibility also reduces the operating cost of the electricity system.

The flexibility services from the hybrid heating system compete with other flexibility sources in the system. Therefore, the value of flexibility from smart hybrid heating systems reduces to £2.1 bn/year in the 100g and £5.1 bn/year in the 25g case if it is operated in a highly flexible system.

The modelling results also demonstrate that **the flexibility of hybrid heating systems can displace the capacity of other flexibility sources such as electricity storage, which has higher capex.**

[7] This analysis excludes cost of heating appliances, household conversion costs and the cost of maintaining gas infrastructure

7. Commercial strategies for coordinated control



7.1 Introduction

The flexibility of residential heat demand combined with hybrid heating systems can facilitate a cost-efficient decarbonisation of the energy sector, while at the same time offering economic benefits to flexible residential consumers.

The conceptual advantage of a hybrid system is that it combines the high efficiency of supplying heat through an ASHP with the extra heat capacity of the gas boiler during adverse system/market conditions. This aspect enables end-users to select the most appropriate energy source to meet their heat requirements based on energy supply costs; the dual-fuel capability allows end-users to seize arbitrage opportunities in the electricity and gas markets by selecting the most cost-efficient energy medium and at optimum (intra-day) price conditions, while supporting system-wide objectives and meeting the end-user's temperature preferences.

Data collected during the Freedom Project have shown that the **hybrid system users can maximise their benefits** (i.e. minimise cost), under given price signals for electricity and gas, by implementing the smart control solution developed by PassivSystems. To build on these learning points, the **key focus is to assess the customer benefits and therefore establish the value proposition for smart hybrid control** in the context of the future UK energy system, looking at the 2030-2050 horizon and the likely price variation patterns in the future. For that purpose, system-level studies have been carried out using Imperial College's WeSIM model that **consider two future carbon targets for the electricity industry: 100g and 25g CO_2/kWh,** and the resulting market price patterns have been used in this report. These prices include: time-varying wholesale energy prices and associated carbon and system integration costs for both carbon target scenarios; operation and investment costs in conventional and low-carbon generation, and in electricity networks. All of these factors are fully reflected in the energy prices applied to the case studies in this report.

7.2 Value of preheating strategies

The flexibility offered by smart hybrid heating systems in selecting the most cost-efficient energy medium, combined with the household's heat storage capabilities, allows flexible consumers to adjust, by anticipating (pre-heating) or delaying, their heat demand and ultimately reduce their energy costs. The results in *Figure 55* demonstrate the applicability of pre-heating strategies combined with the flexibility of hybrids in reducing energy costs for households in the two carbon scenarios

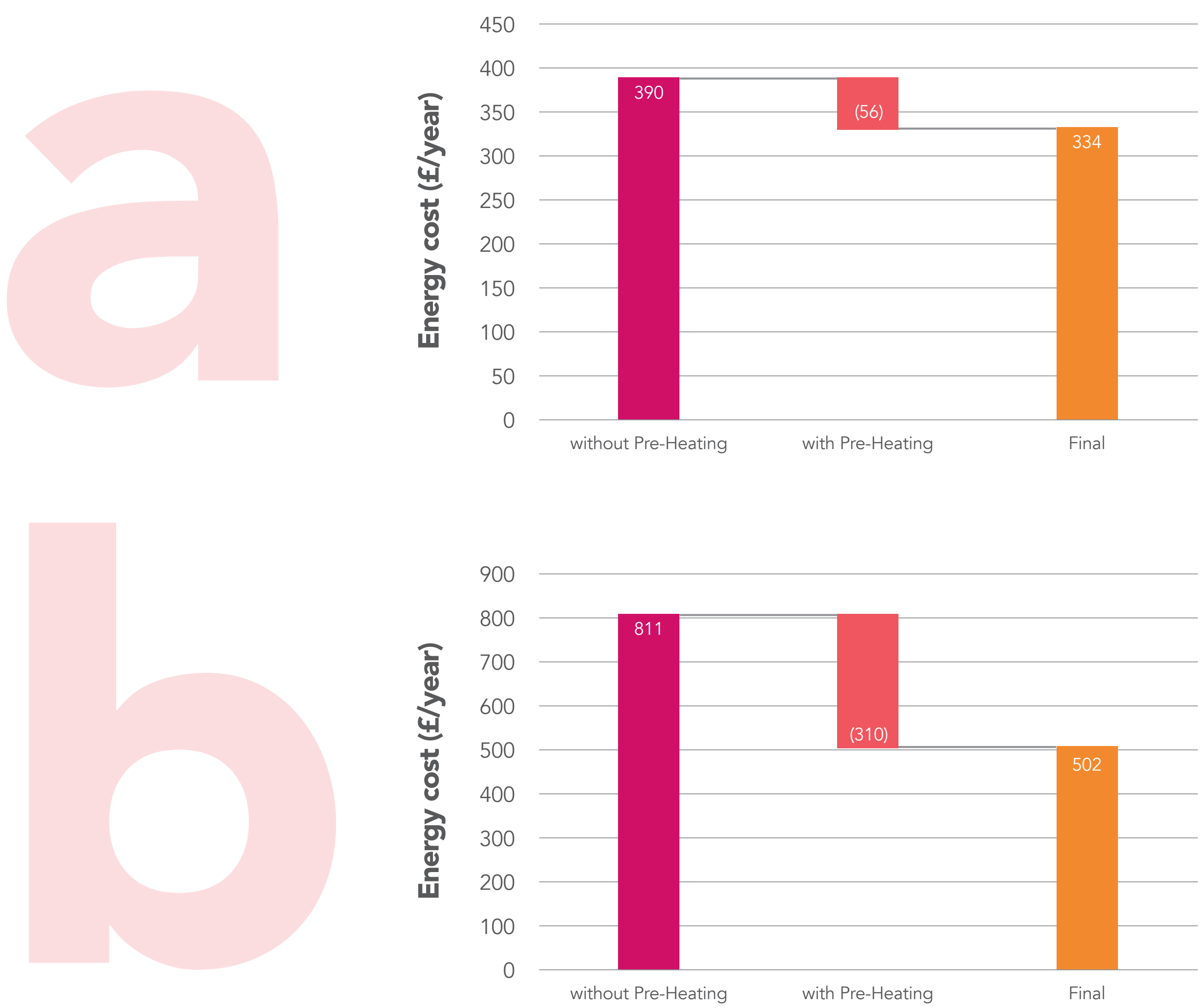


Figure 55: Energy costs for a single household with and without pre-heating strategies, and considering the carbon targets of (a) 100g CO_2/kWh, and (b) 25g CO_2/kWh, for the electricity sector.

The **electrification of the residential heat sector** driven by the ambitious reductions in carbon emissions will lead to **significant changes in the electricity industry,** and particularly affect electricity networks. Considering current system conditions, significant network capacity reinforcements will be required to accommodate the new electrified heat demand; due to the seasonal characteristics of demand for heat (i.e. typically occurring during cold months) the increase in peaks during cold seasons will be disproportionally higher than the increase in energy, resulting in lower utilisation levels for system assets and in particular electricity networks and generation plants.

Therefore the following range of hybrid heating system services/applications is considered:

- **Pre-heating strategies,** which allow end-users to adjust their heat demand and select the most cost-efficient energy medium taking into consideration the dual-fuel capability of hybrids.
- **Balancing services (Frequency Response and Reserve),** given the increasing need for flexibility in future low-carbon power systems and potential synergies with heat demand-based flexibility. Specifically, provision of upwards and downwards balancing services will enable end-users to further reduce their energy bills by securing a revenue stream by allowing a momentary reduction or increase in heat supply.
- **Capacity services,** in the form of network and generation capacity services, will be essential to ensure adequate maintenance of security of supply in a low-carbon energy future due to the seasonal aspect of residential heat demand and its high correlation with adverse weather conditions. In an electricity distribution network context, these are directly associated with the benefit of reduced distribution use of system charges.
- **Supporting low-carbon generation** through hybrid heating is fundamental to achieving a decarbonised energy sector in a cost-efficient way. Although included in the revenue stream associated with generation capacity services, flexibility from residential heat demand should be adequately remunerated for reducing the need to invest in low-carbon generation. Current regulatory framework considers renewable heat incentives for domestic consumers for similar objectives i.e. to reward domestic users for switching to low-carbon energy sources for heat demand.

7.3 Value proposition of hybrid heating systems in decarbonised electricity markets

Fundamentally, the value of smart hybrids are directly associated with the benefits of meeting the carbon targets in the energy sector by improving the utilisation of low-carbon generation and overall system assets, and thus reducing the need for network and generation capacity reinforcements.

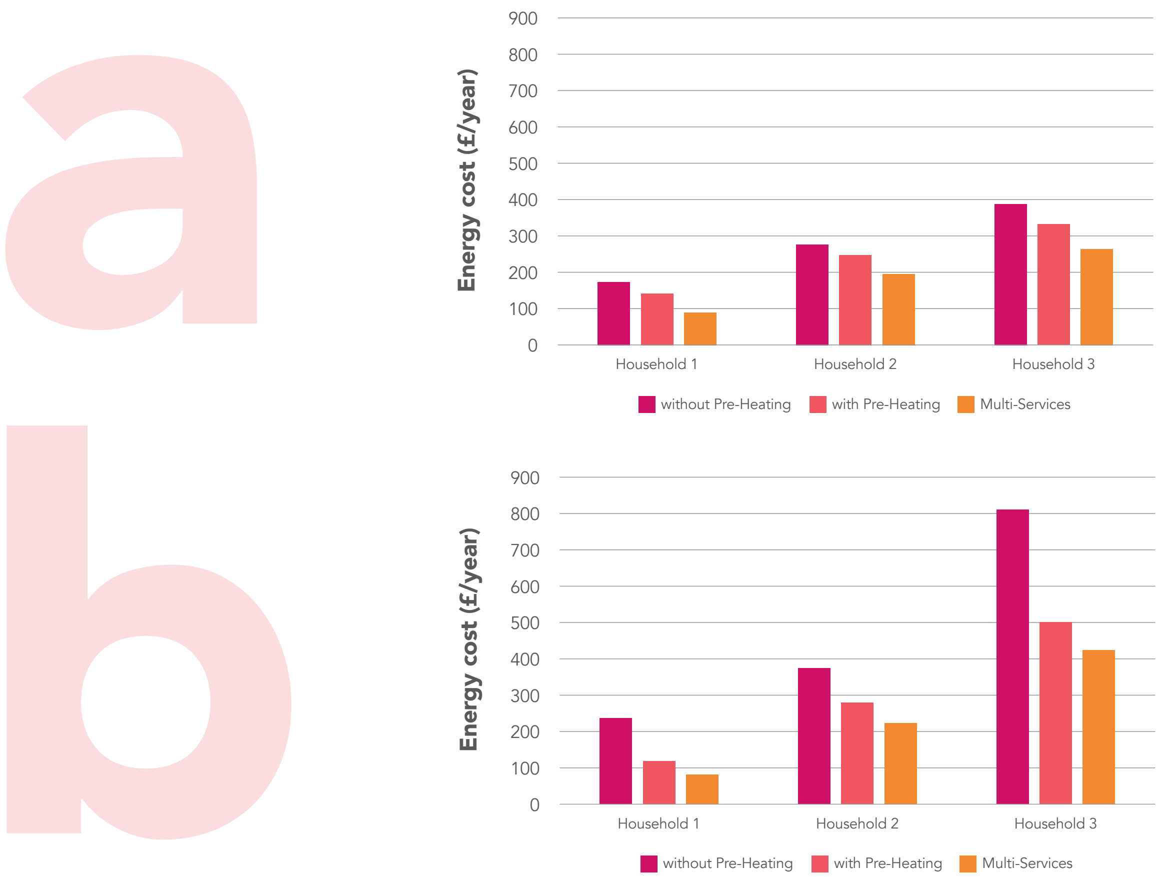


Figure 56: Energy costs when considering the provision of Multi-services (i.e. Pre-heating + Capacity + Balancing), considering different carbon targets for the energy sector (a) 100g CO_2/kWh, and (b) 25g CO_2/kWh. Households 1-3 increase from low to high heat demand

As the energy sector progresses to a low-carbon future, with the ultimate target of near-zero emissions, flexible hybrid heating system end-users can see a **reduction in their energy bills by almost 50%**, as shown in *Figure 56*, without any compromise on the customer's comfort level. For instance, **in the 25g CO_2/kWh scenario the annual heating cost of a household with high heat demand could reduce from around £800 to £400 per year** if business-as-usual operation is replaced with pre-heating strategies combined with multiple service provision.

Note that under the current market and regulatory framework, flexible residential consumers cannot access these multiple sources of value and therefore the market framework will need to evolve to ensure small-scale flexible providers can access these revenue streams.

7.4 Multi-service business models for hybrid heating systems

A multi-service business model framework, which combines the provision of multiple services to various sectors of the electricity industry, results in reduced net energy costs for consumers. Smart hybrid heating systems can participate in the balancing and capacity markets and thus support the energy system and network operators by providing flexibility-based services.

1. When considering pre-heating strategies only,
2. Considering pre-heating strategies and participation in the capacity market,
3. Considering pre-heating strategies and participation in the balancing market and
4. Pre-heating strategies and participation both in the capacity and balancing markets (multi-service provision).

Figure 57 **shows the total energy costs for a typical household over a year, and the breakdown per service component, for 4 commercial scenarios:**

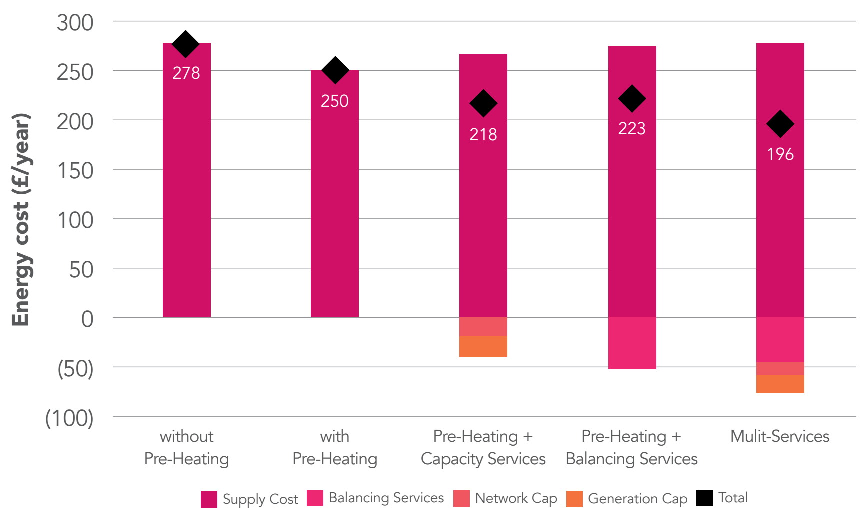
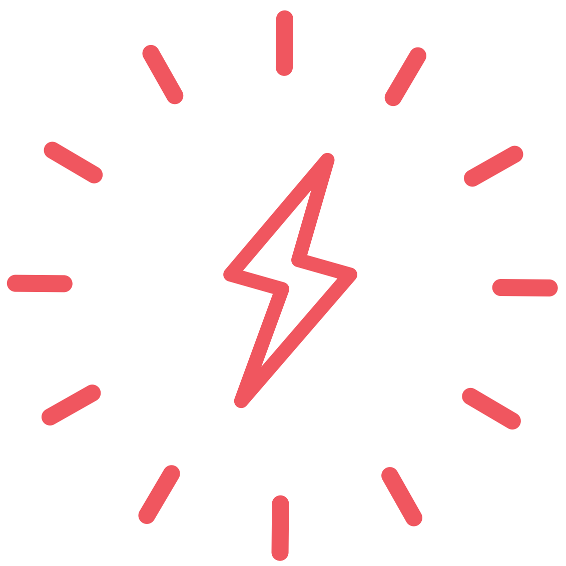


Figure 57: Energy costs when considering: Pre-heating strategies, Pre-heating + Capacity services, Pre-heating + Balancing services and Pre-heating + Capacity + Balancing services (i.e. Multi-service provision)



7.5 Synergies and conflicts among services

In a multi-service business model framework, the interactions between applications/services lead to slight variations in the breakdown across components with different commercial strategies being considered.

Maximising the end-user's flexibility to minimise supply costs only is in conflict with the provision of system services, given that exercising the committed services may result in additional costs to meet the end-user's energy requirements (in this case by using the gas boiler). Also, given that the provision of capacity services and balancing services are mutually exclusive (if offered in the same periods), the **volumes of multiple services being provided are optimised to maximise the synergies between them.**

It has been demonstrated that end-users can effectively reduce the cost associated with their energy needs, while at the same time securing revenue streams from the provision of flexibility-based services, thus supporting the accommodation of increased penetration of intermittent low-carbon generation and a cost-efficient transition to a decarbonised electricity system. The model results demonstrate that PassivSystems **hybrid heating systems combined with heat demand flexibility can support the carbon objectives for 2030 and beyond (i.e. 100g and 25g CO_2/kWh).**

Smart hybrid systems with multi-service provision that relies on the flexibility coming from **switching over to on-demand renewable gas supports the objective of fully decarbonising domestic heat in the most affordable way.**

The overall reduction in consumers' energy bills was found to vary between **27% and 46%,** depending on the household annual heat demand and carbon targets.

8. Market, regulatory and policy recommendations

8.1 Introduction

This section summarises the policy framework around the decarbonisation of the UK energy system and the role of flexibility in facilitating a cost-effective transition to the low-carbon energy future, with a particular focus on the role and value of hybrid heating systems as a core technology in achieving an efficient decarbonisation of the heat sector and providing flexibility through preheating and improved operating efficiency through smart control schemes trialled by PassivSystems in the Freedom Project. Furthermore, gaps in the current market and regulatory framework are identified, with suitable recommendations provided to realise the multiple system benefits of smart hybrid heating systems in energy, balancing and capacity market segments.

8.2 Decarbonisation of energy systems

Energy systems across the world are currently undergoing fundamental changes, mainly driven by the continuously increasing levels of greenhouse gas emissions in the atmosphere and the associated environmental and climate change concerns.

Numerous governments have taken significant initiatives in response to such concerns. In the United Kingdom, the *2008 Climate Change Act* set a legally binding target of 26% reduction in greenhouse gases emissions by 2026 (with respect to the 1990 baseline), extended to a further ambitious target of 80% reduction by 2050. More recently, in its advice to the UK Government on future carbon budgets, the Committee on Climate Change (CCC) has emphasised the importance of decarbonising the power sector and recommended that **the aim should be to reduce the carbon intensity of power generation from the current levels of around 350g CO_2/kWh to around 100g CO_2/kWh in 2030 and potentially 25g CO_2/kWh in 2050[8].**

In the context of addressing the above environmental and energy security concerns, energy systems are facing the challenge of decarbonisation. At the generation side, this decarbonisation is already under way through the wide deployment of renewable and other low-carbon (such as nuclear) generation sources. The European Commission has put forward a legally binding target for renewable energy sources to cover 20% of the total energy consumption in the European Union by 2020, extended to a further target of 27% by 2030. However, the majority of these sources (especially wind and solar generation which constitute the dominant renewable energy technologies in the UK) are inherently characterised by high variability and limited predictability and controllability. Their power output is not only extremely variable, but is also zero during periods of low wind speed or no sunshine, with **solar power being diametrically opposed to seasonal heat demand and therefore being of little value to heat pumps as stand-alone or hybrid installations.**

Furthermore, increased shares of renewables (i.e. inverter-based power generation) in the capacity mix reduce the system inertia which is provided by the stored kinetic energy of the rotating mass of the power generators' turbines. With this reduction in system inertia, any imbalance between supply and demand will change the system frequency more rapidly than today, challenging the stability of the system. Furthermore nuclear generation is highly inflexible, implying that it cannot contribute to the balancing burden of the system.

At the demand side, significant decarbonisation of the heat and transport sectors is expected beyond 2030. Traditional technologies to satisfy consumer requirements of heating and transportation (gas/oil fired technologies for heating and internal combustion engines for transportation) are based on the intense consumption of fossil fuels and the emission of a significant portion of the total greenhouse emissions. In combination with the ongoing and future decarbonisation of electricity generation systems, strong motives arise for the electrification of these technologies; however, **until recently little attention had been paid to the reliable source of electricity generation that could sustain meeting this new demand.** Recent technological developments in the automotive and heating sectors have techno-economically enabled this transition with the production and efficient operation of electric vehicles (EVs) and electric air-source-heat-pumps (ASHP) respectively. Nevertheless, due to the natural energy intensity of heating and transportation loads, the environmental and energy security potential of this transition is accompanied by the introduction of a considerable amount of new demand in electrical power systems. Going further, the introduction of scaled-up electrification of heat and transport sectors will lead to disproportionately larger demand peaks than the increase in the total electrical energy consumption, due to the temporal patterns of users' heating and driving requirements. **At the moment, these added loads onto the electricity system are stretching the flexible fossil generation sources to accommodate them until existing load has been decarbonised.**

[8] www.theccc.org.uk/publication/reducing-uk-emissions-2018-progress-report-to-parliament

8.3 The need for system flexibility

Given the above fundamental techno-economic challenges associated with the decarbonisation of energy systems, a clear need emerges for enhancing flexibility through the efficient integration of new technologies. Such technologies include:

Demand Side Response (DSR) DSR schemes can re-distribute the electricity consumption across time without compromising the service quality delivered to consumers.

Energy storage Energy storage technologies have the ability to act as both demand and generation sources and flexibly schedule their input / output across multiple timescales.

Flexible generation Advances in conventional generation technologies are allowing them to provide enhanced flexibility to the system. This is due to their ability to start more quickly, operate at lower levels of power output (minimum stable generation), and achieve faster changes in output.

Cross-border interconnection Interconnectors to other systems which enable large-scale sharing of energy, ancillary service and back-up resources. However, the source of marginal generation from other countries needs to be considered, as well as continental availability of renewable generation.

Suitable coordination of such technologies has the potential to support system balancing in a future with an increased penetration of renewable generation and therefore to reduce the curtailment of renewable generation and the efficiency losses of conventional generation, as well as limit peak demand levels and therefore avoid capital intensive investments in under-utilised generation and network assets. More specifically, as discussed earlier, the potential value streams of such flexibility technologies are:

- Avoidance of energy curtailment from low-carbon generation sources by increasing demand during periods of abundant renewable generation
- Efficient provision of operating reserve and response services, reducing the operating costs associated with keeping under-utilised conventional generation in the system
- Potential savings in generation capacity investments, including a reduced need for low-carbon capacity (reductions in energy curtailment will result in increased utilisation hence lower capacity of renewable and nuclear generation to meet the decarbonisation targets), a reduced need for peaking plant capacity (as a result of demand peak reductions), and a reduced need for flexible, back-up capacity (as such generation capacity can be replaced by these flexible technologies in the provision of balancing and ancillary services)
- Deferral or avoidance of the network reinforcements / expansions, by deploying flexibility to manage network constraints.

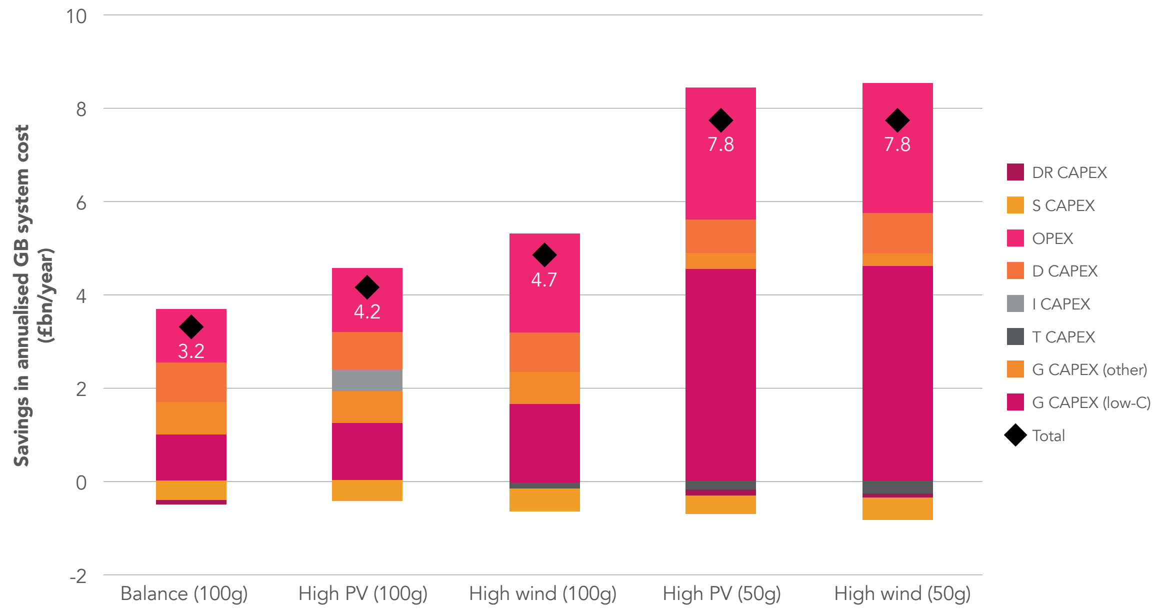


Figure 58: System-level benefits of flexible technologies.

In other words, intelligent coordination of such flexibility sources in both operation and planning timescales can reverse the trend of asset utilisation reduction and enable a more cost-effective transition to the low-carbon future. The size of the above system wide benefits for flexible technologies in the UK is very significant - between £3.2bn and £4.7bn/year in a system meeting a carbon emissions target of 100g CO_2/kWh in 2030. Moreover, a more ambitious carbon reduction target (50g CO_2/kWh) would see a further increase in the value of flexibility (up to £7.8bn/year) as the system would need to accommodate more low-carbon generation *(see Figure 58)*. It can be observed that **the most significant value stream of flexible technologies, especially as the UK moves towards more ambitious carbon targets, is the avoidance of investments in low-carbon generation capacity.**

8.4 Decarbonisation of UK domestic heating

The decarbonisation of the domestic heat sector constitutes one of the core components of the UK low-carbon energy future, since heating currently accounts for nearly half of the total energy consumption and one-third of the greenhouse gas emissions in the UK, and around 50% of the emissions from heating are associated with space heating and hot water in domestic buildings.

One pathway for decarbonising the heat sector would involve the hybridisation of gas and electricity. In this context, the Freedom Project has demonstrated that hybrid heating systems, combining a domestic gas boiler with an AHSP and thus exhibiting a **'dual-fuel' capability, can meet the carbon targets, yet with considerable economic savings with respect to a standalone ASHP pathway.**

According to the results of the system studies carried out as part of the Freedom Project, the net benefits (in terms of total system costs) of smart responsive hybrid heating systems compared to the standalone ASHP case are £4.9bn and £9.3bn/year.

The most significant portion of these benefits are associated with savings in electricity distribution network and peaking generation investment cost, given that the 'dual-fuel' capability can be exploited during peak electricity demand conditions (where heating will be provided through the consumption of gas) relieving the electricity system stress.

8.5 Role of flexibility in facilitating cost-effective transition to a low-carbon energy future

In a future with an increased penetration of variable renewable generation and inflexible nuclear generation, other conventional generation units (such as gas generators) will be producing much less electricity, as absorption of the low-cost and CO_2-free production of renewable and nuclear generators will be prioritised in the merit order.

However, given that renewable generation is variable and intermittent, and nuclear generation is highly inflexible, other conventional generators would need to remain synchronised in the system and operate part-loaded as a back-up electricity source (e.g. operating in periods of low wind speed or low sunshine) and flexibility provider (since renewable and nuclear generators not only have very limited capabilities to provide system balancing services, but they are also making system balancing more challenging). This under-utilisation of conventional generation assets implies that the cost efficiency of their operation will reduce. Furthermore, their cost efficiency will be aggravated by the increase in start-up and shut-down cycles, driven by the system variability and power ramping requirements.

Furthermore, there will be an increased requirement for frequency response to deal with sudden loss of supply to the system (e.g. as a result of a failure of a large generator / interconnector or a rapid change in demand or renewable generation) in order to keep the system frequency within its statutory limits, in the system with reduced inertia. To date, the frequency response service can only be provided by synchronised conventional plants which need to operate part-loaded and produce at least at the minimum stable generation level (MSG). This reduces the ability of the system to absorb electricity production from renewables or other low-carbon technologies. This means that due to balancing challenges, renewable generation assets with high capital costs are also under-utilised and thus may not achieve their CO_2 emissions reduction potential.

The trials carried out by PassivSystems within the Freedom Project have demonstrated that the hybrid heating technology can offer very significant flexibility through advanced smart control schemes, without affecting consumers' comfort levels. Therefore, beyond the savings brought by the 'dual-fuel' capability of hybrids, additional savings can be achieved through smart control strategies through preheating and delivery of higher operational efficiency of the hybrid system. Furthermore, substantial value streams of such flexibility, which is significantly increased when the carbon target becomes stricter, is associated with reductions in investments in low-carbon (including renewables and nuclear) generation capacity. This is driven by the flexibility of the hybrid systems to provide system balancing services and therefore increase the utilisation of available renewable generators and meeting the carbon targets cost effectively.

8.6 Need for new market and regulatory framework

In the deregulated environment, the realisation of the system benefits of hybrid heating and their flexibility requires a suitable energy market design and regulatory structure that captures their multiple value streams, and aligns the cost savings / revenues of those who adopt a hybrid system in the different markets (energy, balancing and capacity) with the respective system benefits created. Significant efforts towards this direction have been recently observed in the UK setting, initiating major debates regarding the transition to a fundamentally new market design; however, there are still certain issues that need to be addressed:

Capturing the whole-system benefits of hybrid heating systems

The current market design philosophy has mainly focused on the trading arrangements for energy as a basic commodity, while suitable trading arrangements for flexibility and capacity services are still under development. The envisaged decarbonisation of the electricity system will lead to a very significant reduction of the electricity production costs (due to the low or zero production costs of renewables and nuclear generation) accompanied by a massive increase of the costs of balancing services (due to the inherent variability of renewable generation and the inflexibility of nuclear generation) and new investments (due to the need for new generation and network assets to support system balancing and the increasing demand peaks). This means that a new market design is required across multiple timescales, ranging from capacity markets with a horizon of multiple years to balancing markets operating very close to real-time, in order to recognise the full system value of smart hybrid heating.

Avoiding constraints on market participants

The limits imposed by market rules regarding the minimum size and the minimum temporal availability of participants in energy, balancing and capacity markets may prevent distributed forms of flexibility, such as hybrids, to access value streams in certain markets. Although the size constraint can be bypassed through the aggregation of multiple hybrid systems, independent aggregators in the UK need to rely on third parties to access the balancing mechanism as they do not have a defined role in the Balancing and Settlement Code (BSC), which discourages small-scale aggregators from accessing value in the markets. Finally, the current market design sets certain restrictive constraints regarding the simultaneous participation in multiple market segments, although these segments remunerate different valuable services.

Recognising the time-specific value of services

The largest proportion of balancing services is currently contracted by system operators with prices being determined based on their own cost projections and being fixed over a long temporal interval (months or even years ahead). However, the economic value of flexibility services, such as frequency response, depends massively on system conditions (e.g. demand level, renewable output, system inertia) that change in much faster timescales. This inefficiency can result in a risk of over or under-procurement of services and a lack of availability of flexible resources for other services, with significant cost implications. Therefore, these services should be procured over shorter timeframes taking account of their mutual trade-off and thus more efficiently reflect the temporal variation in their value in the system. More dynamic price signals can potentially incentivise availability of flexibility by hybrids during periods when it is most needed by the system. As a move towards the right direction, Ofgem has recently announced its plans and a timetable on moving to mandated half-hourly settlement to sharpen short-term signals in order to better reflect the cost to the system and enable new technologies to realise more value and suppliers to develop innovative dynamic retail offerings.

8.6 Need for new market and regulatory framework

Recognising the time-coupling operational characteristics of ASHPs and smart hybrid heating systems in market design

ASHPs and other demand flexible technologies may exhibit distinct operational characteristics that are fundamentally different from the respective characteristics of traditional technologies, given the need for load recovery. These complex, time-coupling operating properties couple the requirements for provision of balancing services across different timescales and therefore should be included in the market design. In other words, the provision of flexibility at a particular timeframe creates additional demand for flexibility at other times due to the above time-coupling effects. If these properties are neglected in energy and balancing market segments, it becomes obvious that the outcome of these markets may not be cost-reflective. In this context, hybrid heating systems would have a larger value than other flexible demand technologies when delivering ancillary services, due to the availability of dual-fuel supply.

Recognising the location-specific value of services

The locational element of energy, balancing and capacity services becomes increasingly important, since different areas and regions are characterised by significantly different generation / demand conditions (especially due to the location-specific availability of distributed low-carbon generation resources) and many parts of the electricity transmission and distribution networks become increasingly congested. Therefore, a need emerges to capture this location-specific value in new market arrangements, through the introduction of locational marginal pricing and emissions. Potential for locational emissions for gas may also need addressing for areas to be rewarded for distributed green gas connections to the local gas grid. Furthermore, the location-specific part of the electricity Transmission Network Use of System (TNUoS) charges and the DNUoS needs to be enhanced in order to properly allocate network charges to parties responsible for incurring network reinforcements. This implies that the reinforcement deferral / avoidance benefits that can be brought by the uptake of hybrids will be remunerated sufficiently through reduced network charges.

Introducing efficient and transparent capacity remuneration mechanisms

Although the most significant economic benefits of hybrid heating systems are associated with avoided investments in new generation and electricity network capacity, this value stream is not properly remunerated in the current market framework. Concerning generation capacity, although a Capacity Market has been recently introduced in the UK, demand technologies are still not able to participate on a level playing field with traditional, large-scale generation technologies. At the network level, the potential capacity provision of new flexible demand technologies, as well as their location-specific value, is neglected in existing network standards. With the emergence of cost-effective non-build solutions such as smart hybrid heating, an update of these planning and operational standards is needed to establish a level playing field between traditional network infrastructure and emerging flexible technologies. As a move towards the right direction, electricity distribution network companies have recently initiated a fundamental review of Engineering Recommendation ER P2, which has acted as the foundation stone for the planning of future distribution networks and this has been supported by Ofgem.

Introducing new mechanisms for remunerating avoided investments in low-carbon generation

The Freedom Project has demonstrated a value stream of hybrid heating system flexibility that has been greatly neglected, namely its ability to reduce low-carbon generation capacity investments without compromising carbon targets. However, suitable remuneration mechanisms for this value stream do not exist in the UK or beyond. Such mechanisms should be urgently developed, either by allowing new flexible technologies such as these hybrid systems to access revenues associated with Contracts for Differences (CfD) offered to low-carbon generation and/or by linking the capacity market with the low-carbon agenda (setting specific rules on the types of capacity rewarded in the capacity market).

Enhanced Electricity TSO-DNO coordination

Domestic hybrid heating systems can offer valuable services both to the local DNO but also to the TSO. However, the coordination of these services entails potential conflicts between the TSO and the DNO (e.g. periods of abundant wind generation at the national system level coinciding with periods of local peak demand at the distribution level). In the current framework, the TSO and the DNOs have limited coordination at both operational and planning activities, implying that such conflicts cannot be properly managed and balanced. This current 'silo' approach for the operation and planning practices of the TSO and the DNOs should be replaced by a 'holistic" approach which will enable stronger coordination between national and local objectives and requirements, maximising the economic value of hybrids for the whole electricity system. In order to achieve that, it will be critical to establish strong coordination and communication between electricity distribution and transmission network operators and clearly define their future roles and responsibilities. Furthermore, an appropriate regulatory framework around the exchange of information and data between them should be established and proper economic incentives to support this communication should be designed. As a move towards the right direction, the Energy Networks Association (ENA) has initiated a Transmission and Distribution Interface Steering Group, aimed at providing strategic directions identifying potential issues around the coordination between electricity transmission and distribution levels. In addition, there would also be considerable benefit from greater coordination across all energy networks (electricity and gas transmission, distribution and system operation).

Factoring and addressing uncertainty in long-term planning

Historically, generation and network long-term planning has involved little uncertainty regarding future developments and has been carried out through deterministic approaches. This landscape is changing due to profound uncertainties around the amount, timing and location of new generation and demand technologies in the system, since these depend on not easily predictable factors such as technological developments, market dynamics, regulatory frameworks, energy policies and consumer acceptance. These uncertainties will prevent planners from making fully informed decisions, should they continue to rely on deterministic approaches, with non-trivial cost implications involving inefficient investments and stranded assets. Therefore, alternative analytical methodologies factoring these uncertainties in planning practices need to be adopted, including stochastic, risk-constrained and robust optimisation approaches. By employing such approaches, new flexible technologies such as hybrid heating systems can contribute to dealing with the above uncertainties in a more cost-effective fashion, as they can defer commitment to capital-intensive conventional reinforcement projects until the need for such investment is fully established.

9. The gas network in an integrated energy system by Wales & West Utilities

9.1 Introduction to an integrated whole-energy system

The energy sector is going through significant change as it adapts to the trilemma challenges of affordability, security of supply and carbon reduction. Against this background, much research is taking place around future energy scenarios.

With respect to heat, **the cost and practicality of full electrification are being extensively challenged,** particularly around electricity network capacity and seasonal storage, with analysis and evidence recently published [9, 10, 11, 12]. **The UK needs to look to diverse decarbonisation pathways and consider the role of hydrogen, biogases, heat networks, electrification and a hybrid of these in combination.**

The whole energy system is already becoming more integrated and greener, with a shift change in the interaction between the electricity and gas networks:

- **Over 50% of generation** coming from gas during low renewable periods (over 60% at peak times)
- **New peaking power generation** responding to intermittency of renewables
- **Combined Heat and Power (CHP)** and low carbon energy centres
- Gas and electric **vehicle growth.**

As the networks continue to integrate, variation of demand and supply on the electricity network will have immediate impacts on the gas network.

[9] *'Review of Bioenergy Potential: Technical Report' for Cadent Gas, September 2017*
[10] *'H21 Leeds City Gate', Northern Gas Networks, Wales & West Utilities, Kiwa Gastec and Amec Foster Wheeler, December 2016*
[11] *'2050 Energy Pathfinder – Short Paper', Wales & West Utilities, February 2018*
[12] *'Consumer Willingness & Ability to Pay for Decarbonised Heat', Wales & West Utilities, April 2018*

9.2 Gas demand in the region

National Grid Future Energy Scenarios (FES) recognises the view of Annual Demand in Wales & West Utilities' Local Distribution Zones (LDZs).

For peak 1-in-20 demand, a bottom-up review of non-daily metered and daily metered loads, power generation and shrinkage has led to the development of peak forecasts in the Wales & West Utilities region. These forecasts have remained flat for a number of years but due to growth in domestic demand and power generation, there is an emerging upturn in peak demands for all LDZs in the network *(see Figure 59)*. **The peak 1-in-20 demand forecast in the Wales & West Utilities network is now projected to increase by 3.9% by 2022/23, largely as a result of increasing demand from power generation and new housing. Combined heat and power plants and heat networks could result in further increases in peak demand.**

In summary, the relationship between peak and annual demands is becoming increasingly weak with peak demand increasing and annual demand remaining flat or reducing.

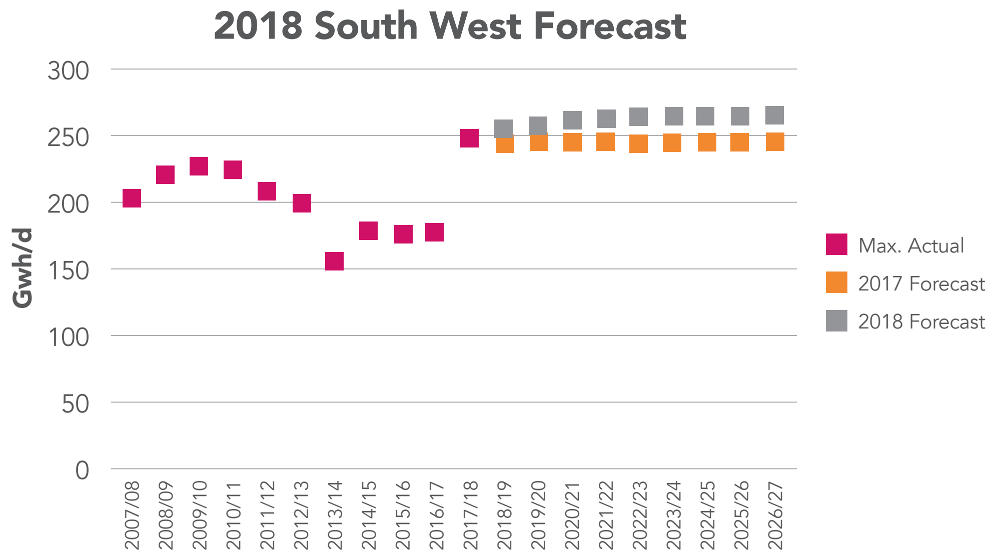


Figure 59: Actual peak demand on the Wales & West Utilities South West of England LDZ since 2007/08 with a re-forecast for 2018/19 and beyond

9.3 Power generation connecting to the gas distribution network

Gas is vital in ensuring a reliable and secure UK electricity supply with gas generation peaking plants supporting the growth of renewable generation by being available to maintain power supplies when intermittent low carbon sources are unavailable.

In the current gas regulatory price control period (RIIO-GD1, starting 1 April 2013), **Wales & West Utilities has seen significant change in this area. The total connected power generation has increased from ~1,200 MW output to ~1,700 MW output following the connection of an additional 24 small flexible generation sites in RIIO-GD1, which brings the total number of power generation sites connected to the Wales & West Utilities network to 33.** Sites already connected are shown in *Figure 60*, along with connection requests accepted and anticipated connection requests as a result of recent T1 and T4 capacity auctions.

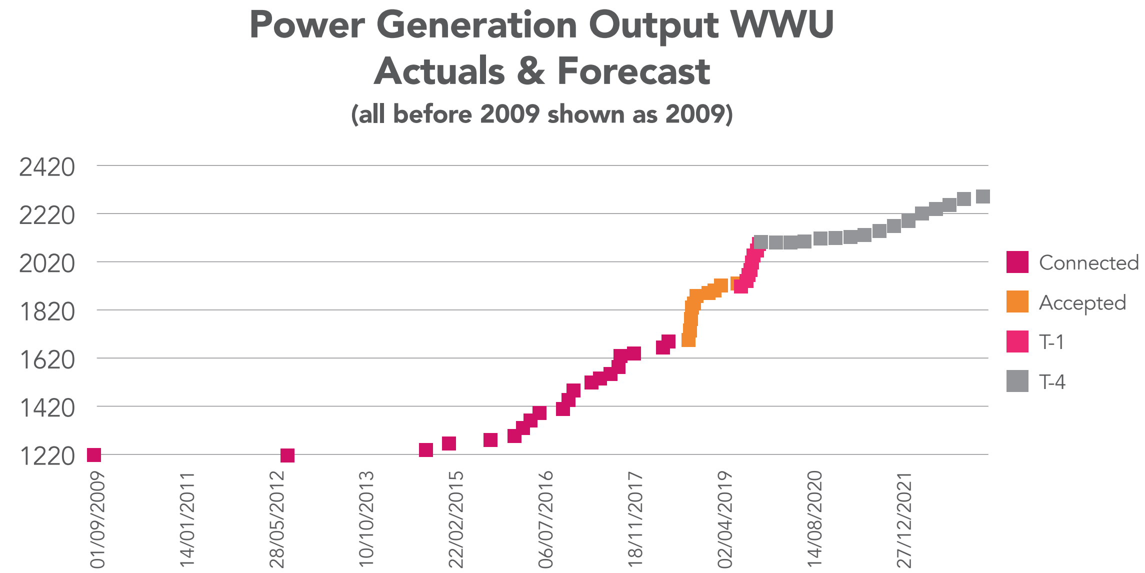


Figure 60: Gas-fired power stations and output capacity and projection on the Wales & West Utilities network

At the same time, the behaviour of these peaking plants and legacy generation customers has changed significantly. Gas generation is no longer base load, rather it is being used increasingly to balance the generation available to the electricity networks, being used less when new renewable generation such as solar and wind are available, and then being relied upon to maintain supply at other times.

The impact of this changing behaviour on Wales & West Utilities' gas distribution network is being monitored closely, and is clearly visible in *Figure 61* showing UK combined cycle gas turbine (CCGT) output in 2011/12 and 2017/18.

9.3 Power generation connecting to the gas distribution network

The increasingly intermittent nature of flows of gas for power generation has an impact on the use of storage in the gas distribution network. Wales & West Utilities has reviewed its processes and made some changes to facilitate this behaviour. The improvements and learning have been implemented in the last few years and continue to be applied; however, **the continued increase in capacity of power generation from gas is forecast to require network investment in storage as the full capacity of the existing network is reached. The implementation of smart hybrid heating would avoid even further capacity of flexible gas-fired generation requiring a connection to gas distribution networks.**

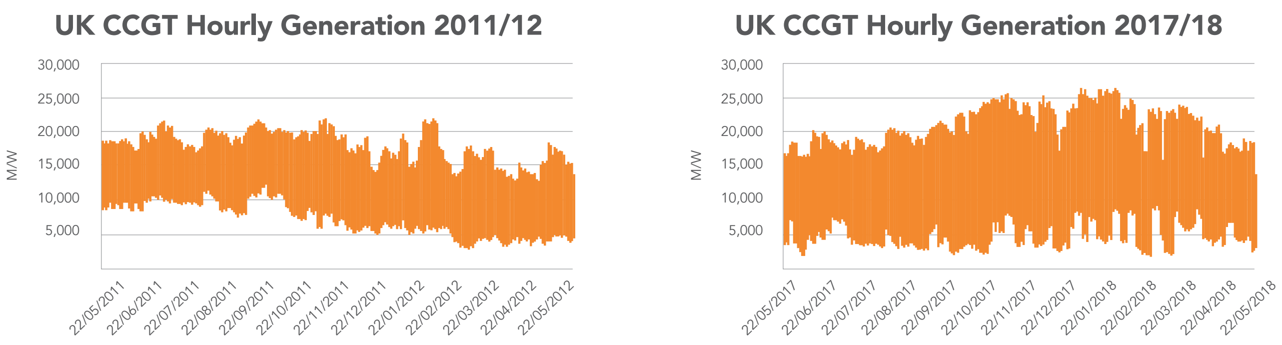


Figure 61: UK CCGT hourly output (2011/12 vs 2017/18)

9.4 Marginal carbon emissions

Currently existing electricity load (lights, white goods, sound and vision equipment etc) in the winter is met by generation with a typical mix made up of a baseload of nuclear, wind, gas and coal, with some appreciable input from interconnectors and biomass.

As load is added in winter, coal generation sources are typically stretched to capacity first, followed by other flexible sources such as gas and some further interconnection and biomass. **This behaviour is indicative of the response to new loads, such as heat pumps and electric vehicles, being added to power demand – new loads cannot be decarbonised until the existing load has been dealt with.** Solar, of course, does not feature in *Figure 62* as generation in winter is negligible.

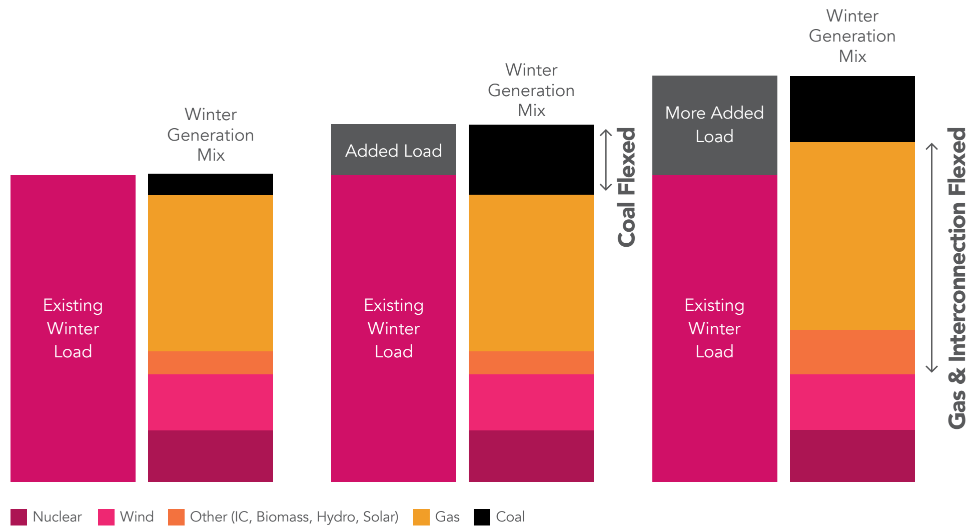


Figure 62: Illustration of generation sources meeting current power demand and added loads

As the Freedom Project has been able to demonstrate, **smart controlled hybrid heating systems are able to switch to a lower carbon fuel vector** by moving heat demand over to natural gas in the boiler, rather than increasing marginal emissions from stretching flexible generation sources to meet heat pump demand when insufficient renewable power is available.

Equally, *Figure 63* can be used to articulate the value of efficient heating appliances and the installation of demand reduction measures. Taking the same example of existing load on the electricity system as above, a c.10% reduction in demand from efficiency measures shows the marginal emissions from flexible sources being constrained, removing coal and potential interconnected marginal coal elsewhere in Europe.

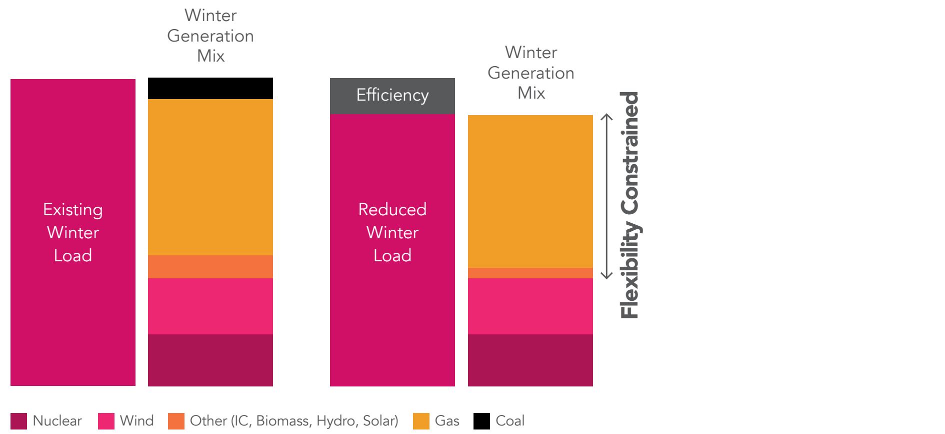


Figure 63: Illustration of generation sources responding to reduced demand from efficiency measures

9.5 Hybrids in a patchwork pathway for affordable, low carbon domestic heat

The increasing use of gas for flexible power generation, for transport, and in the case of power-to-gas for managing electricity constraints mean that a multi-vector approach is essential. Deployment of any solution for domestic heat will depend on customer acceptance and key to consumers will be that any change is the least cost to give them warmth when they want it and that it has the least disruption associated with it.

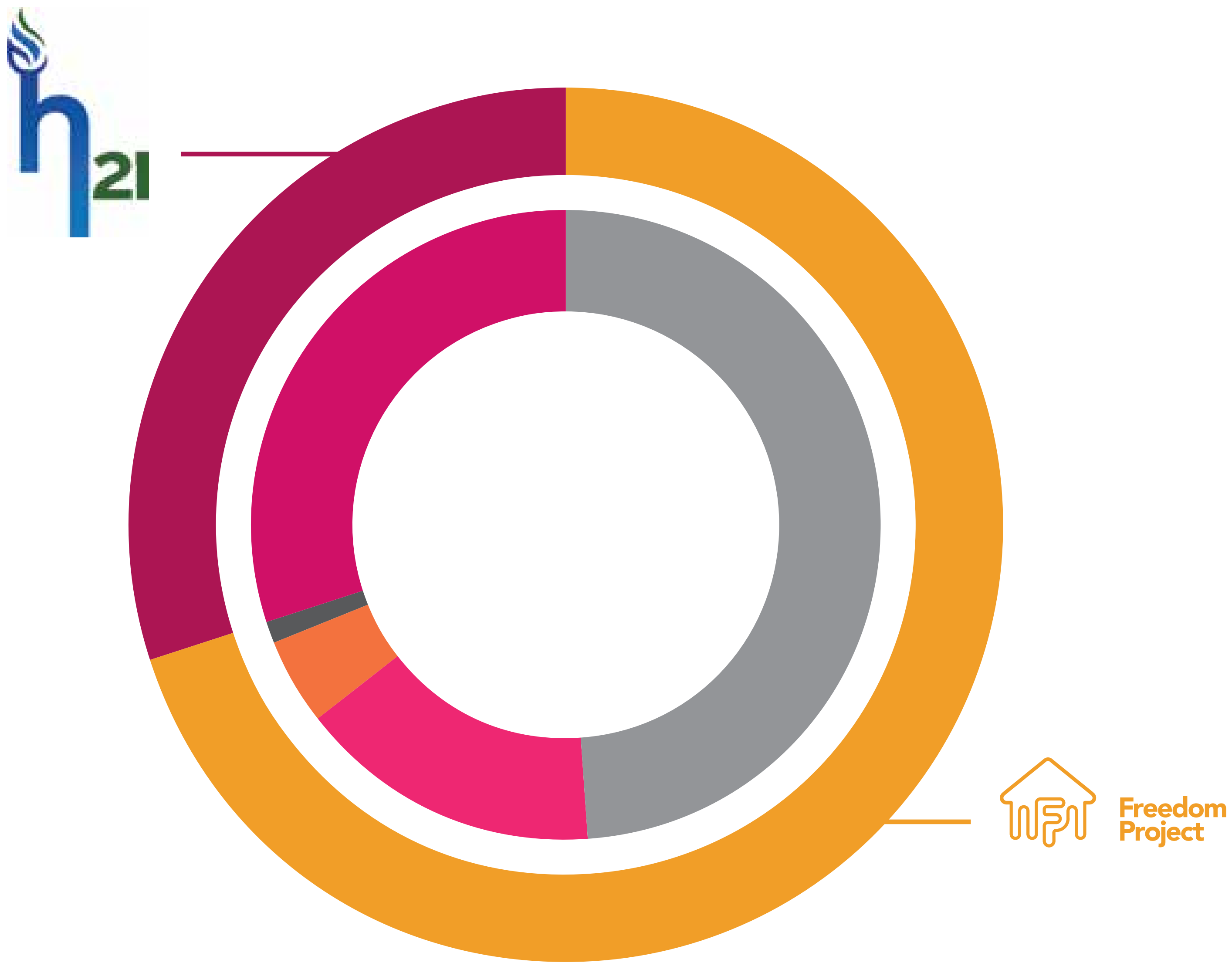
Using the 2050 Energy Pathfinder model, Wales & West Utilities has taken into account a combination of technologies and solutions, which smart hybrid technology is the key enabler.

A plausible solution to decarbonise domestic heat, which makes the best use of existing utility infrastructure, is described and shown in *Figure 64:*

1. Convert cities or the north of England region to hydrogen to decarbonise domestic heat by 30%
2. In remaining regions on and off the gas grid, maximise the use of domestic smart hybrid heating solutions to decarbonise domestic heat for the remaining 70%, which prioritises efficiently delivered electrified heat through an air source heat pump for approximately 70% of hybrid operation and falling back to gas boilers for remaining heat demand, using:

- Wind and other low carbon electricity sources when available
- Decarbonised gas (biomethane, BioSNG, synthesis gas, potentially BioLPG and blended hydrogen from constrained power) when renewable generation sources are unavailable for heat, with some left over to support decarbonisation of heavy transport.

Although the hybrid solution, compared to hydrogen and electrification, was identified as the lowest cost pathway to decarbonise heat in the recent Imperial College report for the UKCCC[13], the combination of solutions regionally with hydrogen and hybrids was identified as an even lower cost approach and is similar to the Wales & West Utilities patchwork pathway outlined here.



2050 Domestic Heating Fuel Supply

- Wind 49%
- H_2 30%
- BioGas 16%
- Other 5%
- H_2 blend 1%

2050 Future of Domestic Heat Technology Approaches

- 17 Hydrogen Cities 30%
- On-Gas & Off-Gas Smart Hybrids 70%

Figure 64: Wales & West Utilities' patchwork solution of fuel and technologies to deliver decarbonised domestic heating

[13] *'Analysis of Alternative UK Heat Decarbonisation Pathways', Imperial College London, June 2018*

10. Business models for hybrid heating systems

10.1 Introduction

The Freedom Project has provided evidence on the role and value of flexibility that residential consumers and gas network flexibility and storage can provide to the future low-carbon heat market. Primarily, an analysis is being carried out to identify potential services/applications that can be provided to system and network operators by hybrid heating systems while still ensuring that heat requirements (and thus end-users' comfort levels) are still met. Mainly, the flexibility associated with residential heat demand can be exploited to offer frequency response services to the system operator and even support DNOs to manage peak demand at the distribution level.

10.2 Arbitrage between electricity and gas markets

The characteristics of a hybrid heating system allow it to operate using electricity and gas supply sources. This aspect enables end-users to outsource to an aggregator the complexity of selecting the most appropriate energy source to meet their heat requirements based on energy supply costs, i.e. the dual-fuel capability of hybrid heating systems allows end-users to benefit from arbitrage opportunities between the electricity and gas markets.

Overall this means that it can ensure that their energy needs (i.e. heat requirements) are met at the lowest supply cost but fundamentally without compromising their comfort levels.

10.3 Demand-side management service

Demand-side management (DSM) services have been widely investigated and applied by industrial/large consumers with the objective of reducing their energy bills by providing a price-responsive demand curve. When applied to industrial consumers, DSM considers the flexibility offered by a specific production process, for example the flexibility associated with over or underproduction, and thus adjust the demand for electricity based on real-time pricing while still meeting the long-term production targets. A similar method can be applied to residential heat demand by taking into consideration the potential thermal inertia of buildings and a price-responsive demand curve.

In this context, the r**esidential heat demand curve** (which for the sake of clarity will be identified as **'original heat demand'** throughout this section) will be subject to small adjustments in order to **reduce consumers' energy bills** through time arbitrage. Allowed ranges for a potential increase / decrease away from the original heat demand have been set according to three levels of DSM: 2%, 5% and 10%.

The value associated with DSM, namely the **reduction on heat supply cost,** should then be compared with end-user's loss in comfort levels and willingness to **adjust their heat requirements.** *Figure 65* shows, for the same day, the heat supply cost associated with the different levels of DSM.

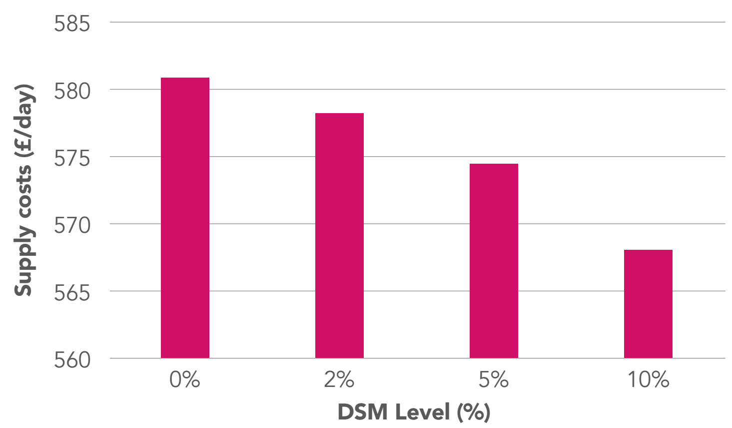


Figure 65: Heat supply cost associated with different levels of DSM

As demonstrated in *Figure 65*, **a 10% variation in heat demand (10% DSM) can achieve a reduction of up to £15/day in heat supply cost.** Note that 10% flexibility in heat demand will have a potential effect of raising the temperature of the indoor air mass of a typical three-bedroom flat of ca. 4°C, and so additional comfort control, such as in bedrooms, may be required to reach this level.

The flexibility associated with hybrid dual-fuel operational capabilities can further benefit consumers and other stakeholders in the electricity industry, such as electricity network operators (as detailed in the next section) and gas distribution networks who are providing the storage and flexibility available to the hybrid system.

10.4 Network service:
supporting integrated distribution networks

The full electrification of the heat industry, driven by the ambitious reductions on carbon emissions across the various energy sectors, would lead to significant changes in the electricity sector, particularly affecting electricity networks and significantly impacting consumers' bills.

In this setting, considerable electricity network reinforcements, alternative seasonal storage and wholesale insulation retrofits to existing housing stock would be necessary to accommodate the new electrified heat demand. The seasonal characteristics of demand for heat (i.e. typically occurring during colder months) and the increase in peaks will be significantly higher than the increase in energy demand on the reinforced electricity system, resulting in low network utilisation levels outside of peak demand periods.

The dual-fuel capability of hybrid heating systems can potentially provide the necessary flexibility to defer and even avoid the need for network reinforcement without compromising the comfort levels of consumers. The ability to use gas as the primary energy source to supply the demand for heat can support network operators to reduce local electricity demand during congested periods in the network, for example, in the event of a sudden loss of network capacity (due to a network fault or planned maintenance) heat load can shift to the gas networks and/or consumers can provide a service to the electricity network operator by reducing their demand for electricity.

Figure 66 shows the electricity demand at the primary substation level in a typical winter day and the associated secured network capacity.

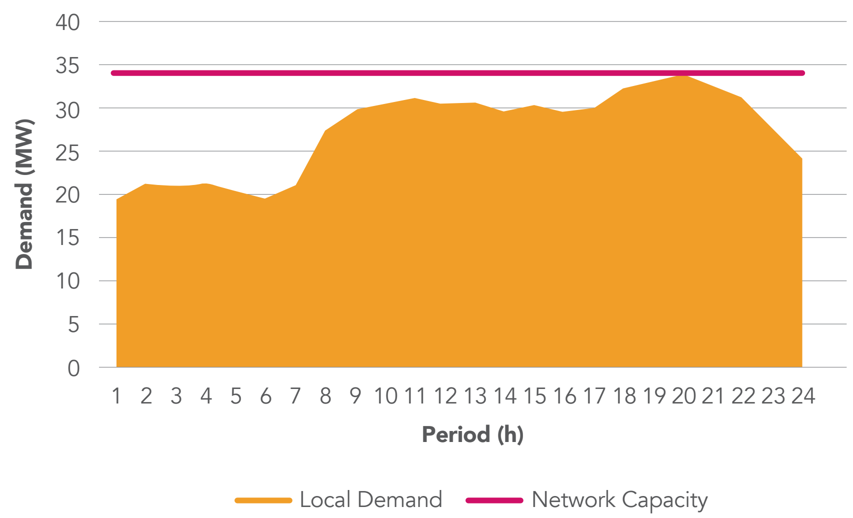


Figure 66: Local electricity demand at primary substation level and secured network capacity in a typical winter day

Figure 67: Local and electrified heat demand at the distribution network (a) without and (b) with network support service

As shown, **during the evening hours (i.e. between 19:00 and 21:00) the primary substation demand is at its peak** and is nearly overloaded. Adding further to the local demand (due to the electrification of residential heat demand) will inevitably overload the distribution network and lead to necessary network reinforcements. To counter this problem, t**he dual fuel flexibility of the hybrid heating system can be exploited** to support network operators and defer network reinforcements without compromising heating comfort levels. *Figure 67* illustrates the aggregated energy supply for a hybrid heating system in the same day as without network support service (a) and considering network support service (b).

The change from electricity to gas as the energy source to supply the residential heat demand at a time of electricity network constraint may imply additional costs to end-users to maintain security of heat supply, subject to future time of use pricing ratios. Therefore, the service provided to network operators should be adequately remunerated to both compensate a potential additional cost incurred by switching to gas supply and reflect the actual benefit of deferring network reinforcements.

10.5 Frequency response service to the system operator

The penetration of renewable energy sources in the electricity industry associated with the decommissioning of flexible energy sources (such as coal and oil fired power plants) has led the system operator in GB to expand the procurement process for flexibility from gas peaking generation and also the demand side. In this context, hybrid heating system flexibility can be used to provide frequency response services to the system operator and bring additional value to the system.

11. Operator business models for hybrid heating systems

11.1 Operator business model aims

One of the aims of the Freedom Project was to establish what the future role of energy network operators could be in the hybrid heating market. In particular, focus is on the variety of ways in which networks could participate in the market, and whether they have a role in some, all or none of the these types of activity.

Financier

Providing finance, investment for hybrid heating systems free-of-charge or some other sort of financial funding or supporter

Market promoter

Awareness-raising activities, trusted advisor to customers and/or installers

Active participation in the market

Including partnerships with installers, suppliers/ network operators setting up an installer/ supplier business

Trusted advisor

Creating partnerships with stakeholders (such as social landlords) and providing evidence-based advice which could help promote hybrids

11.2 Route to market (R2M) for operators

There is currently no typical or traditional route to market for hybrid heating systems; however the most common route to market is via manufacturer – installer – customer.

For low-carbon heating systems, the wholesale route to market is not typically utilised, this is because the **costs and volume of sales are not yet attractive.** However, as low-carbon technologies become more 'mainstream', **the wholesaler channel is expected to become a key route,** particularly for hybrid heating systems where heat pumps are combined with a boiler with wet heating and are potentially easier and more familiar for installers to engage with.

In the future, the route to market will be much more open for hybrid heating; however, installers will always be a critical customer link in the UK market.

- Online hybrid heating system quotes and installer bookings are emerging and disrupting the typical R2M. Customers are becoming more engaged, so the installer influence over brand (near term) and technology (further away) is expected to diminish. Nevertheless, the installer will always be the person with access to the home, so it is critical to engage them in the short to medium term so that they (and in turn their customers) can become more engaged with hybrids.
- Targeting building developers and registered social landlords (RSLs) in the near term could positively increase the uptake of hybrids; developers are regulation-driven and RSLs are more engaged with 'low carbon' as a way to protect tenants from rising fuel bills. If energy network operators can support education here to develop the supply chain it could impact on future sales. RSLs also tend to have access to funding streams to support the roll-out of new technology.

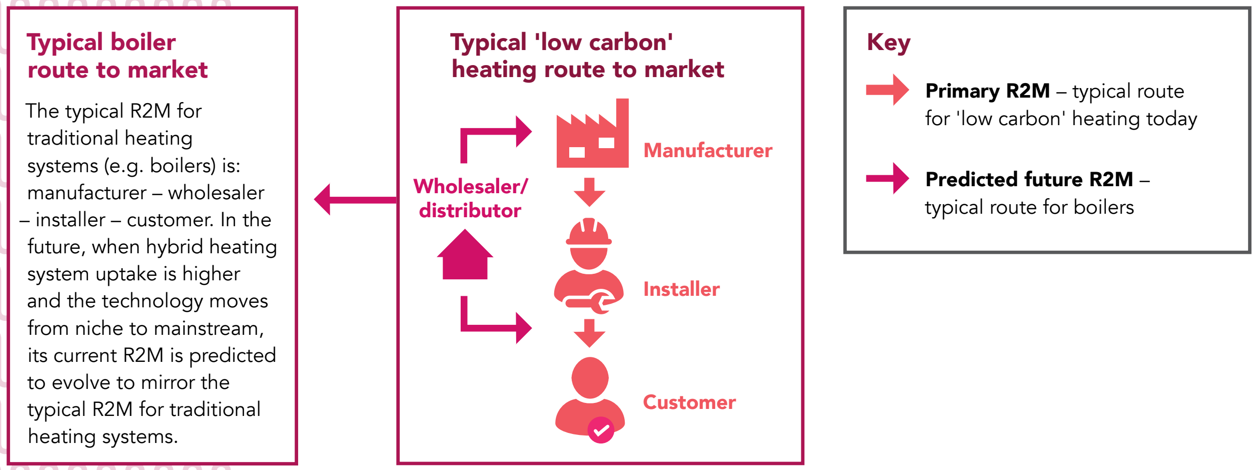
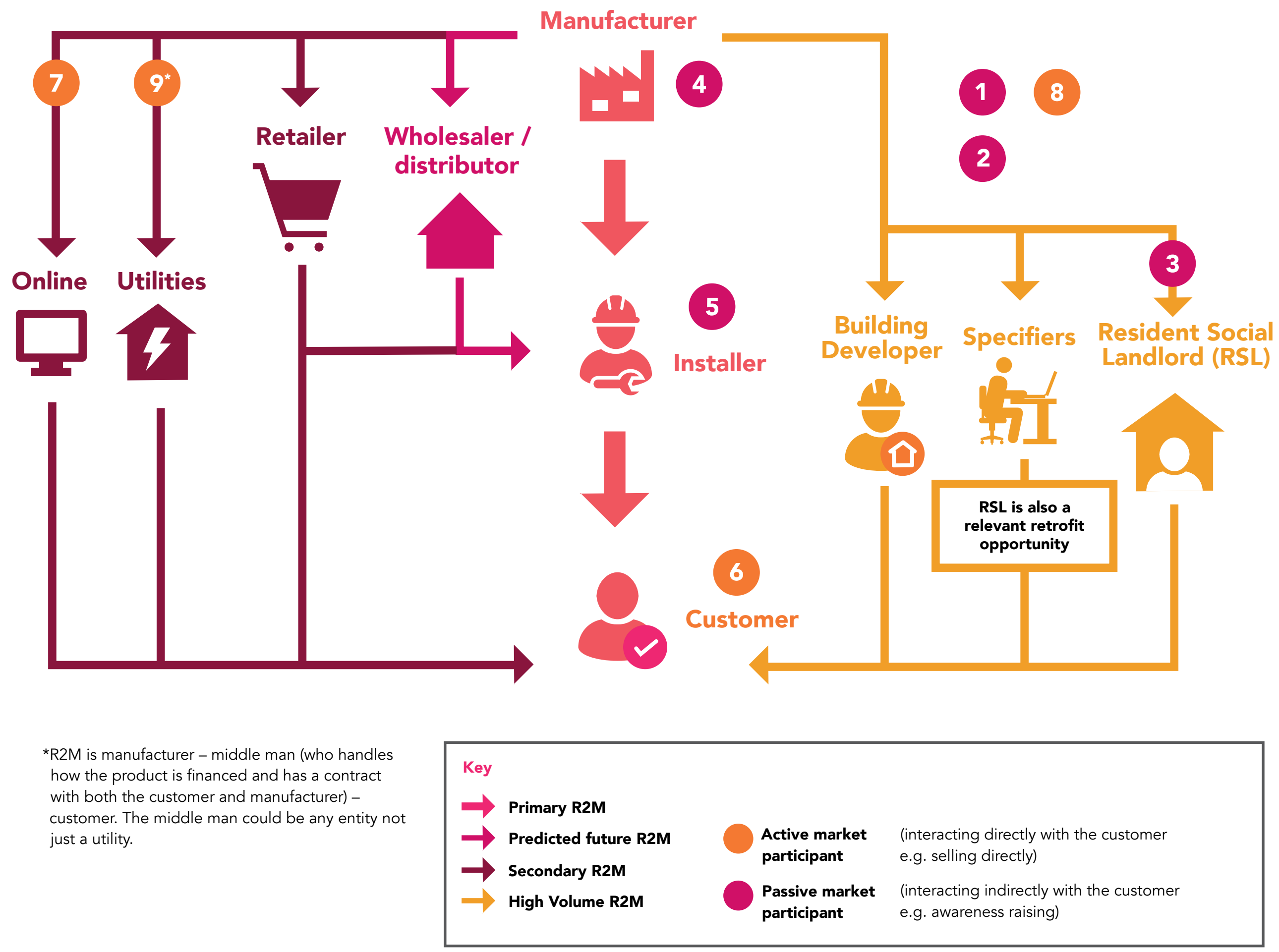


Figure 68: Hybrid heating system installation journey



Business opportunity number	Business opportunity description	Example
1	Lobbying	EHPA
2	Increase hybrid heating system awareness and education	E ON UK
3	Resident social landlord (RSL) trusted advisor	Nobody is taking this role
4	R&D / innovation support through partnership manufacturer	Grasterra Gasunie
5	Installer partnerships	Training workshops/academy
6	Innovative financing schemes direction with the customer	Flow
7	Online sales / quotes	Thermondo
8	Spin out company	Liander
9	Heat as a service	Best Green

Figure 69: Hybrid heating system business model journey

Nine business opportunities at different points along the R2M have been identified. These business opportunities involve energy network operators being either an active or passive market participant. These different business opportunities have varying degrees of suitability and are detailed in *Figure 69*.

11.3 Policy framework

The incentive-based period is the most promising period for hybrid heating system uptake. The current pace of change and policies will result in the UK failing to meet the fifth carbon budget, resulting in a policy gap emerging which needs to be addressed.

The medium-term (2021–2030) will be the period with the biggest opportunity for uptake of hybrids – it is predicted that at this time the policy framework will be incentive-based to support the development of low carbon heat. In the long-term, the policy framework could be standards-based (e.g. kgCO_2/m²), which will require the gas supply to homes to be largely decarbonised *(see Figure 70)*. **Hybrid heating will provide valuable whole energy system and customer benefits both on and off the gas grid.**

Timeframe	1 **Short-term:** *present – 2021* Includes the 3rd carbon budget	2 **Medium-term:** *2021-2030* Includes the 4th and 5th carbon budgets	3 **Long-term:** *2030 onwards* Requires an 80% reduction (from the 1990 baseline) in carbon emissions by 2050
Policy framework	BAU	Incentive based	Standards based
Overview	Policy is likely to include a framework of measures that aim to phase out the installation of high carbon fossil fuel heating and support low carbon heating post 2020. These policies will need to prepare households for standards based policy from 2030 onwards.		This is likely to take the form of a sequential tightening of standards over time with the aim for near zero emissions by 2050.

Figure 70: Policy overview

An **incentive-based period** should result in favourable policies for hybrid heating systems. Given the UK's dependence on gas as an energy source in the foreseeable future, the potential network benefits, and the potential emission savings provided by hybrid heating systems means they are likely to play a key part in the UK's decarbonisation strategy. The 'incentive-based period' should result in the government creating a framework of policy measures which should tip the economics in favour of solutions such as smart hybrid heating systems. This would likely include a **financial incentive** that would extend or replace the Renewable Heat Incentive (RHI). **Hybrids are presenting as a no-regrets long term solution, supported by gas grid decarbonisation with roles for green gas and hydrogen.**

Not seizing the long term heat decarbonisation pathway offered by smart controlled hybrids, and **mistakenly treating the technology as transitionary would fail consumers and miss the opportunity to flexibly optimise heating at the lowest possible cost,** saddling them with significantly more expensive options, such as full electrification.

11.4 Current policies will result in failure to meet the fifth carbon budget

According to the Committee on Climate Change, carbon emissions from buildings in the UK will have to fall by 20% by 2030 with options to develop near-zero emissions by 2050. In order to deliver this, a joined-up strategy is required for both energy efficiency in buildings (to reduce the demand for heat) and the supply of low carbon heating into residential dwellings and commercial dwellings.

At the current pace of change, carbon budgets will not be met and there is a clear policy gap emerging that needs to be addressed for the pathway to zero carbon to be realised *(see Figure 71)*. Energy network operators could play an instrumental role in providing evidence, facilitating change and influencing the ultimate pathway that is taken.

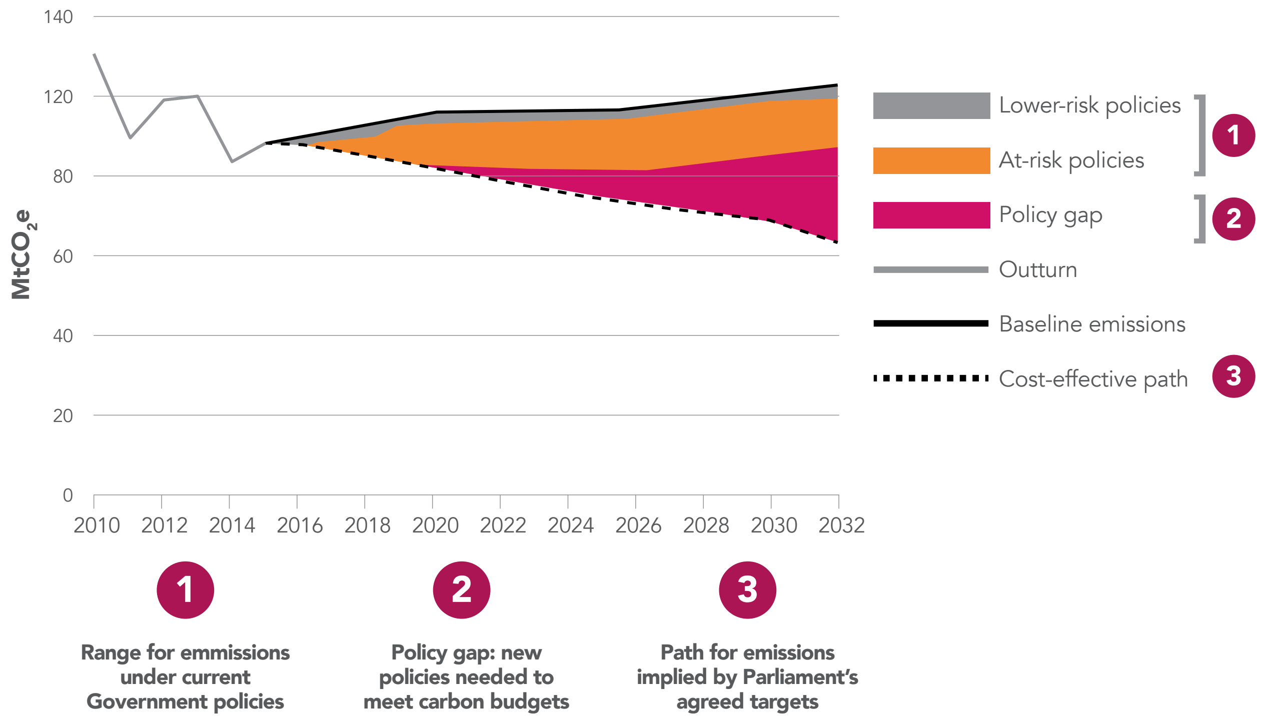


Figure 71: Policy gap risk

11.5 Policies to meet the carbon budget can be split into three separate time periods

There is a range of policy options between now, 2030 and beyond: if it is assumed that the government (and subsequent governments) will stick to the carbon budgets, then there is a range of different policy measures that could be undertaken.

Those summarised in *Figure 72* are those that will be necessary to meet the carbon budgets. In the near term there is good visibility of which policies will play out, however for further out in the time periods, it becomes harder to predict the policy outlook. The information presented here is only relevant to the supply of low carbon heat and hybrid heating systems for residential buildings. The policies presented are high-level and draw heavily from the Committee on Climate Change 2016 and 2017 reports.

	1 Business as usual period	2 Incentive based period	3 Standards based period
Timeframe	**Short-term:** *present – 2021* Includes the 3rd carbon budget	**Medium-term:** *2021-2030* Includes the 4th and 5th carbon budgets	**Long-term:** *2030 onwards* Requires an 80% reduction (from the 1990 baseline) in carbon emissions by 2050
High level policies	Renewable Heat Incentive Energy Company Obligation Stage 1 new boiler standards	Reform support for low carbon heat – attempt to increase customer awareness and provide upfront payments Prioritisation of low-regret measures (e.g. biomethane to gas network, low carbon heat networks etc.) when allocating low carbon heat support New support for fuel poor (e.g. supplier obligation grants)	Emission standards (e.g. $kgCO_2/m^2$) at point of sale and rental of all existing homes Roll out of low carbon heating across properties on the gas grid
Overview	Policy is likely to include a framework of measures that aim to phase out the installation of high carbon fossil fuel heating and support low carbon heating post 2020. These policies will need to prepare households for standards based policy from 2030 onwards.		This is likely to take the form of a sequential tightening of standards over time with the aim for near zero emissions by 2050.

Figure 72: Policies to meet carbon budget

11.6 The policy outlook for hybrid heating systems is positive *especially during the incentive-based period*

In the short term, unless there is an unexpected change, hybrid heating systems will generate no real value to networks as customer uptake is unlikely, except for off-gas grid homes where running cost savings and RHI are attractive and even more so with third-party assignment of rights to RHI with investor intervention.

However, post-2021 when the policy-tipping point has been reached and the economics become more favourable, there is a strong opportunity for hybrid heating growth and for the technology to contribute significantly to meeting both the carbon targets and assisting with energy network challenges. **In the longer term, the opportunity for smart hybrid heating systems is accentuated by the opportunity to decarbonise the gas grid, with green gas and hydrogen presenting the most promising future.**

11.7 Standards based period

2030–2050

At this stage, the analysis focuses on three potential gas scenarios rather than specific actions that can be undertaken, as post 2030 it is hard to predict what policies will be in place.

The three scenarios are:

1. Low carbon gas is utilised for peak heat demand and when intermittent renewables are not delivering
2. Hydrogen has replaced natural gas as the primary fuel source in the UK
3. The gas network is no longer utilised

11.8 Scenario 1

Low carbon gas is utilised for peaking

The low carbon gas utilised for peak heat demand and backfilling for the intermittent power-generation scenario can be described as an evolution of the gas network rather than a revolution. In this scenario it is assumed that standalone boilers are not a heating system option as they are not efficient enough to meet the required emission standards (kgCO_2/m^2).

Under all scenarios there are new and interesting opportunities for energy networks, however there are also a wide range of risks.

Possible revenue stream

A gas connection is still required if utilising the hybrid heating system and gas networks could look to develop the following opportunities around domestic heating:

Business as Usual (BAU)	Services	Flexibility
The existing asset base is utilised and therefore no drastic change in strategy is required. However, although peak gas usage is unlikely to go down, it is probable that annual gas demand will reduce (due to an increased price and carbon pressure) and could potentially only be used for peak and backfilling intermittent renewable-power generation In this scenario gas pricing is important and could potentially shift from a per kW connection to a fee/subscription model.	These can be broken down into two buckets: 1. Services associated with the hardware (e.g. maintenance and installation) 2. Heat/energy as a service	The ability to switch between two different fuels presents benefits to the electricity grid and opens up opportunities for gas networks to offer flexibility services to the grid (particularly during peak times where the gas peak demand can be six times as high as the electrical peak demand).

Associated risks

In these scenarios it is assumed that gas is still required to meet domestic heat demand. However, it is recognised that if the UK is to meet its 2050 carbon target, building emissions will need to be (at least) nearly zero. Thus, if gas is to be used in the future it will need to be decarbonised to a certain extent. If gas is successfully decarbonised it is likely that the price will be high and therefore there will be a steep supply curve associated with it. This will limit its demand and therefore reduce the number of domestic gas connections as well as the manner in which gas is used (i.e. it will most probably be used for peaking and in the absence of winter renewable generation). This presents risks to the current gas network business model and thus will require a restructuring of the way gas is priced/charged for domestic consumption.

11.9 Scenario 2

Hydrogen is the primary fuel source in the UK

This scenario can be described as a revolution of the gas network as opposed to an evolution. If hydrogen does become the primary fuel source in the UK it could have these impacts on heating technologies:

1. The price of hydrogen is comparable to natural gas and it is used in abundance, therefore end-user technologies are very similar to those in use today.

2. Hydrogen is expensive and therefore demand is limited which results in high efficiency technologies (e.g. hybrid heating systems) becoming dominant. When considering the 2050 targets and current plans for hydrogen being explored, a conversion of 17 cities utilising a new hydrogen transmission system is achievable by 2050 and so only supports the decarbonisation of those urban areas, therefore the potential for hydrogen is limited and it is unlikely to be the dominant fuel source in the UK by 2050.

Possible revenue stream

There are a number of different hydrogen opportunities for gas networks (plus a number of unknown opportunities which will develop in the future) which can be assessed, with two presenting as the most likely:

Business as Usual (BAU)	Transport
As natural gas will effectively be replaced by hydrogen, end-user technologies are very similar to those today, which negates the need for gas networks to significantly alter their business strategy.	It is possible that electric vehicles will be powered by hydrogen fuel cells as opposed to batteries, which will further increase the demand for, and transportation of, hydrogen.

Associated risks

Reliance on the presence of a CCS network and increasing imports of LNG – this could limit the amount of hydrogen which can be produced as well as potentially result in a high hydrogen cost.

The upstream market becomes more complicated – due to the need to transform either methane or electricity into hydrogen. This should not be a major risk.

11.10 Scenario 3

The gas network is no longer utilised

This scenario presents the highest risk to stranding the existing asset base. It could occur if the government decides to push ahead with a high electrification strategy and aggressively pursue the development of heat networks and electric heat pumps. In this scenario there are no possible revenue streams which a gas network, under its current mode of operation, could pursue – aside from maintaining the network for the benefit of energy storage and distribution to local peaking power generation and industrial consumers. Clearly, however, the learning from the Freedom Project has identified the value of maintaining the gas network across all pressure tiers.

What should network operators do?

In the short-term it is recommended that networks continue to provide evidence for sound policy decision-making and pursue options which increase the awareness, knowledge and perception of hybrid heating systems. In essence, 'laying the ground-work' for the uptake of hybrids in the medium-term.

In the medium-term it is recommended that networks take action to support the increased sales of hybrids, thereby capitalising on the ground-work laid in the shorter term. This action would need to be led by a non-regulated section or spin-off business of network operators, and it is acknowledged that this is a stretch from current operations and activities.

In the long-term there is high uncertainty regarding the future of the gas network and therefore no specific actions are recommended. However, possible scenarios and opportunities, including around flexibility services, have been identified.

Four key elements that influence the business opportunity recommendations:

1. **Key aspects of the time period** (e.g. awareness of hybrid heating systems, the economic case for hybrids, end-user demand for gas)
2. **End-user willingness** to interact with energy networks
3. **'Value' of the business opportunity** (i.e. how useful the option is to utilising the existing asset base by furthering the uptake of hybrid heating and ensuring that a domestic gas connection is maintained to ensure flexibility is available in consumers' homes to deliver them lowest cost heat)
4. **Ability of network operators to execute options** (skills needed, resource intensity and any risks).

11.11 Summary:
Network operator business opportunities

2018

Today to 2021

In the short term, network operators should focus on being a 'trusted advisor' and 'market promoter' as their brand is not largely recognised by customers.

Unsurprisingly, customers are not all familiar with the network operators that serve their region, they do not sell directly to customers and energy suppliers are the 'face of energy' for customers. However, networks have a unique position: they have the right to reach out to and engage with customers on energy-related topics, and will not be perceived as 'trying to sell' something. Networks could lever this position to share information with customers and become a 'trusted advisor'. Network operators also have access to local installers; upskilling installers and promoting lower carbon heating technologies to them is critical given the central role installers play in the sales journey for heating.

2021

2021 to 2030

In the medium term there is a big opportunity for hybrid heating systems. Operators could be pivotal in this if they are able to support through unregulated activities or spin-off businesses.

The period to 2030 is the critical time for market creation for hybrids. The emergence of disruptive business models are expected in this time period, which will make the customer proposition for hybrids more attractive as heating transitions from 'old' to 'new' energy. Significant uptake of hybrid heating would secure a role for gas in the longer term (as well as provide benefits for electricity networks) so network operators need to act. Activities could range from those easier to do, for example, like taking an advisory role, to networks using resources and finance from its unregulated business, or business spin-offs, to invest in market creation activities, like providing training or even opening a 'showroom' to engage customers on the role of low carbon heating in the future home in a similar high street position exploited by local gas undertakings in the days of town gas.

2030

2030 and beyond

In the long term it is much harder to predict policy, but the future role of gas is anticipated to have been clearly defined. Network operators could take a role in service offerings (e.g. flexibility) if smart hybrid heating systems have become the technology of choice.

By 2030, the technology choices of policy makers will be 'locked-in' and it should be easier to predict longer term how end-users will heat their homes. Assuming the hybrid heating market has succeeded, its future from this point onwards will be highly linked to the future composition and regional / national use of gas. In all these scenarios there is the opportunity for network operators to explore additional service offerings, ranging from how they charge for connection to the gas grid, or manage flexibility services on the network.

12. The network technical impacts

12.1 Introduction

Hybrid heating systems provide potential benefits to many players in the energy system.

Hybrid heating systems combine gas and electric heating technologies enabling end-user customers to play a major part in the energy transition with homes becoming an aggregated flexible load connecting heat and electricity energy vectors.

The Freedom Project trial of 75 smart hybrid heating systems has tested a range of potential benefits including:

Network benefits

Can hybrids reduce or remove the impact of some electrification of heat on the electricity distribution networks by using the peak capacity of gas distribution networks?

Economic value

How can hybrid heating provide benefits to and obtain value from the wider energy system, and how could this benefit customers?

Retrofitability

Can hybrid heating systems provide a solution to reduce energy demands and CO_2 emissions for a large number of the UK's older housing stock, meeting customers heating needs with minimal additional improvement works?

The wide range of hybrid systems and operation modes means that matching technology and customer profiles is important. The experiments with optimised controls in this trial have explored a range of these factors across different customer types.

Hybrid heating systems could be a major component of residential heating decarbonisation if the value can be levered.

The results from the trial and simulations demonstrate the potential benefits that large uptakes of smart hybrid heating systems could have in the UK housing stock. Under current market conditions, modelling by Delta-ee shows that uptake of hybrids is likely to be modest (less than 10% penetration) by 2050 if the flexibility benefits identified by Imperial College are not valued.

Increasing the uptake requires the realisation of identified value streams to be accessible to customers from optimisation of the energy system:

Electricity system

Partial electrification of heat allowing significant CO_2 reductions in residential heating from low carbon electricity and modifying heating loads to maximise use of the existing capacity in distribution networks and avoid reinforcements to meet peak demand.

Gas system

Using future forms of low carbon gas such as biomethane, BioSNG, synthesis gas or hydrogen when needed to meet peak winter heating demands and during times of low renewable power generation output, drawing on the existing peak capacity of the gas distribution networks.

Current market drivers are not sufficiently strong or focussed on cross-vector operation to stimulate the market for smart hybrid heating. Changes in energy policy combined with new business models could help drive the market to larger scales of deployment.

The trial results demonstrate that optimised control of hybrid heating systems can help manage and limit additional loads on the electricity distribution networks.

Conventional air source heat pumps could increase loads by approx. 2 – 2.5 kW per house in a typical winter, rising to 5 kW in extreme winter events. This would require major reinforcement.

The trial results demonstrate that smart hybrids can be operated to minimise or prevent any additional peak loads on the electricity networks:

- **Energy cost drivers** The trial has examined a number of different future energy price scenarios and tariff structures which drive the control system and determine when the heat pump or boiler operates. Time-of-use tariffs demonstrated the ability of a relatively simple mechanism to control loads and mitigate any additional peak impacts on the electricity networks *(see Figure 73)*.
- **Network constraint drivers** Aggregation of the control systems with overall network capacity constraints applied demonstrated the ability of the control system to maintain use of the heat pumps for heat delivery, but with shifting of operation outside the peak periods.

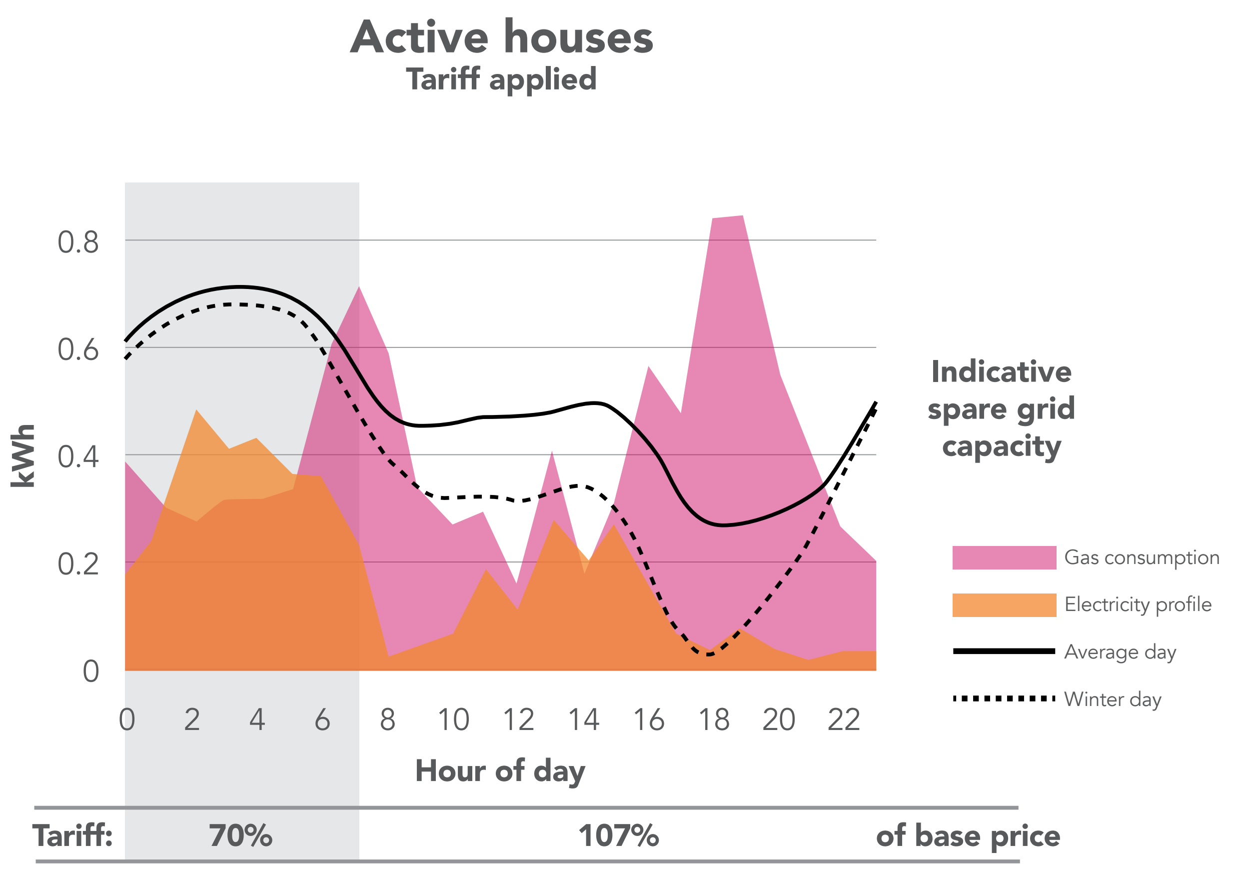


Figure 73: Economy 7 tariff

The use of hybrid heating systems could have a significant cost benefit to consumers.

Network modelling of the South Wales area under different load scenarios has assessed the potential reinforcement and cost impacts *(see Figure 74)*. Translation of these upgrades using the trial load data and different uptake scenarios shows that:

- With 100% penetration of air source heat pumps, customers would pay around £50 per year for network upgrades, without considering the exorbitant costs of seasonal storage requirements – the severity of which depends upon the seasonal performance of different renewable power generation sources
- **Smart hybrid heating systems** could reduce this to less than £5 per year if all these systems were controlled to minimise impact on the distribution networks by using gas boilers at peak demand times – and **eliminate the seasonal storage problem and associated costs from a fully electrified solution.**

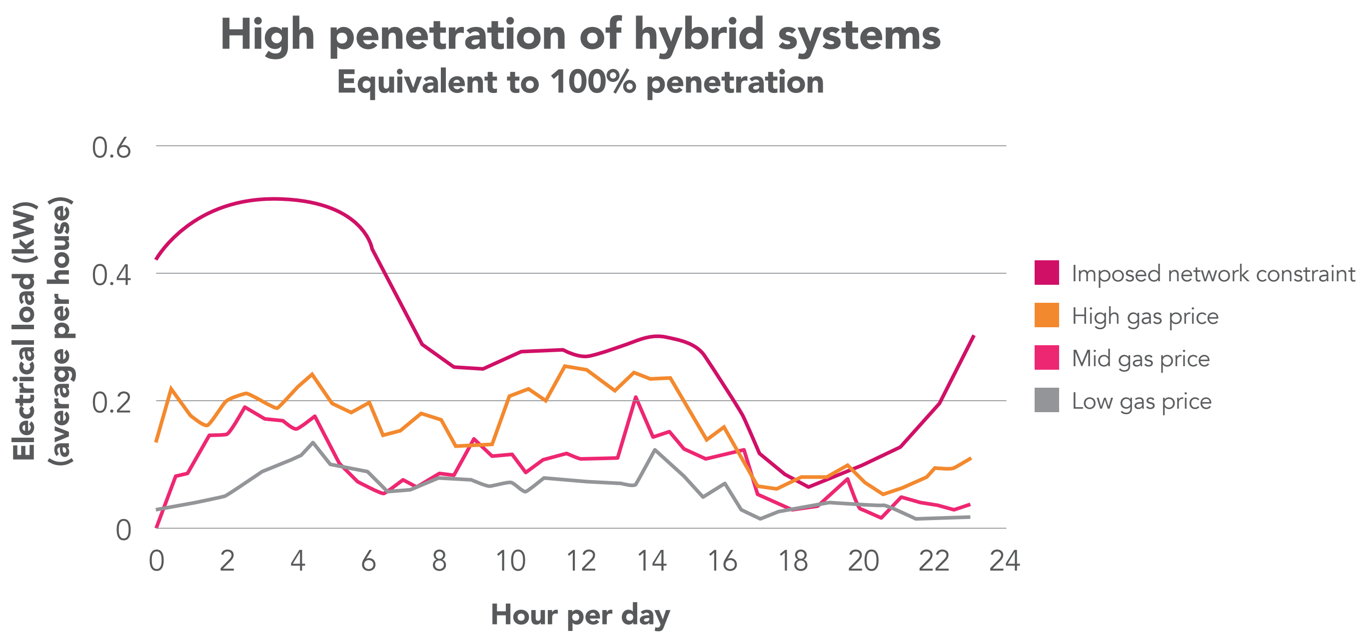


Figure 74: Technical constraints experiments

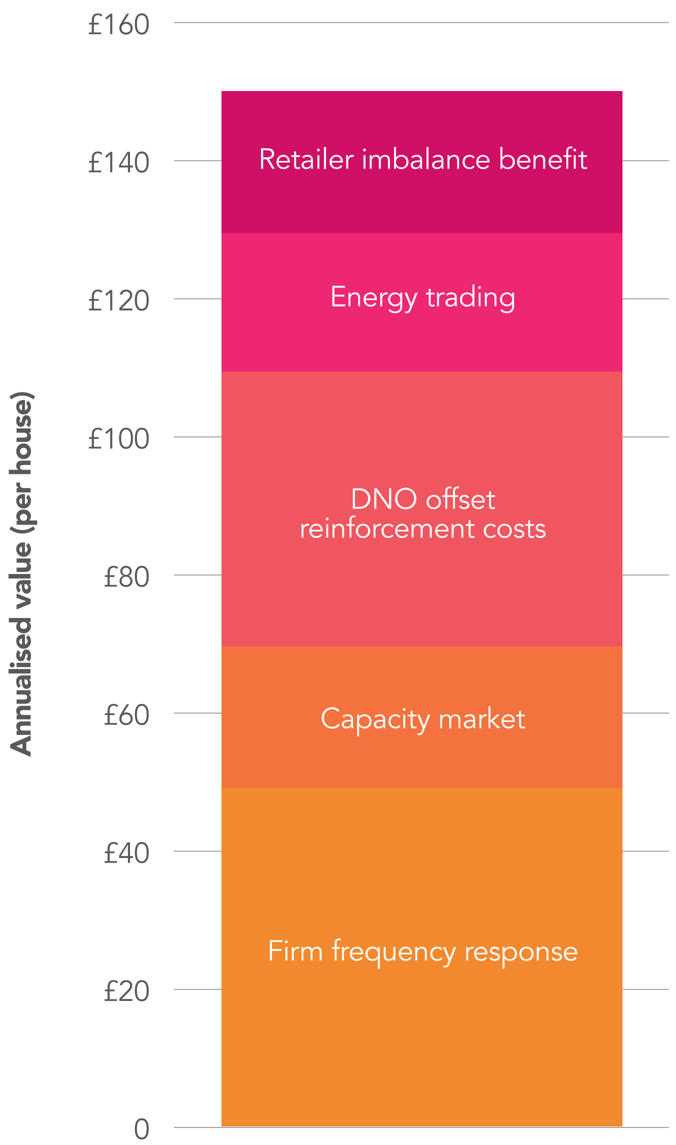


Figure 75: Hybrid heating lifecycle costs

Smart hybrids could lever around £150 per annum per household in energy system values.

The flexibility provided by having two heat sources, combined with the thermal storage inherent in buildings, allows a number of different system values to be obtained. The future value of these revenue streams is very uncertain and will depend on how the market evolves and the competition in the market for flexibility services.

Analysis in this report identifies around £150 in additional value which may be obtained by each smart controlled hybrid heating system, which includes the benefits of reduced electricity distribution reinforcements over conventional air source heat pumps *(see Figure 75)*.

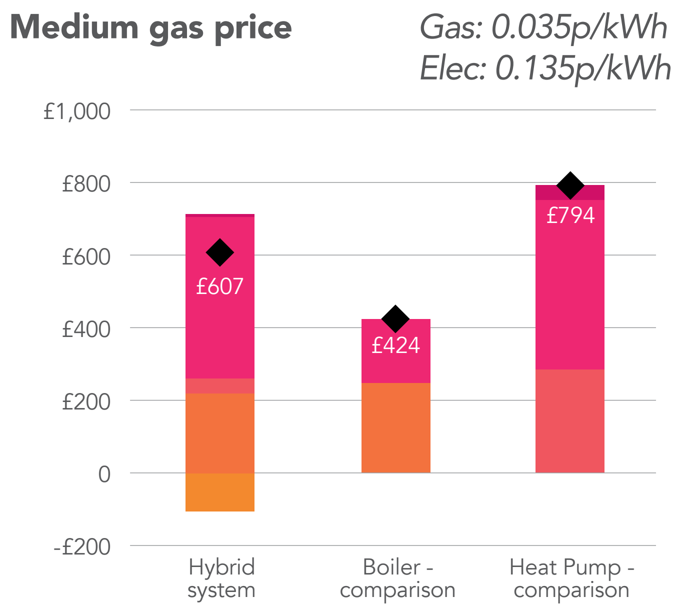


Figure 76: Domestic heating lifecycle costs comparisons

Lifecycle costs to households are higher for a hybrid system than for a gas boiler but lower than a conventional ASHP *(see Figure 76)*:

- The energy bill portion (gas and electricity) of the average lifecycle costs are very similar between the hybrid system and the gas boiler comparison
- However, the lifecycle cost is much lower for gas boilers due to the capital cost making up the largest proportion of annualised cost to the customer for a hybrid system and ASHP
- The revenue from flexibility services is shown to make a significant contribution to hybrid systems being economically viable, and the additional network costs of the hybrid system are shown to be much lower than for the ASHP solution.

12.2 How will smart hybrid heating systems impact gas demand?

The results from the simulations and field trials show that smart hybrids will have a number of significant impacts on gas demand:

- **Gas demand will be much less predictable** in the intermediate temperature regime representative of large parts of the shoulder heating season.
- **At low temperatures, typically less than 0°C, existing demand-Composite Weather Variable (CWV) relationships will hold,** but some heat pump operation will remain under variable electricity price tariffs, which provide economic opportunities for heat pump operation (typically night-time use).
- **Individual operation regimes may provide an identifiable relationship,** but a mix of systems, tariffs and operation in different house types means that the level of diversity will be large, with significant uncertainty in forecast demand *(see Figure 77)*.

The key challenge for forecasting will be around day-ahead analysis. The complexity of the electricity market and the many interlinking factors and metrics mean that identifying individual metrics and relationships (such as marginal electricity CO_2 intensity or day-ahead pricing) will be challenging and unreliable and a number of new techniques may be required.

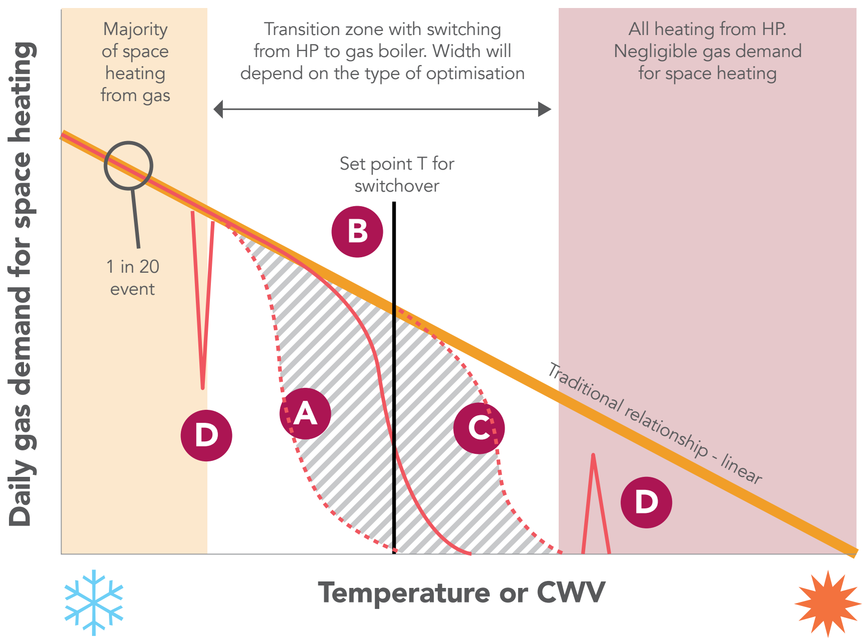


Figure 77: Hybrid heating system impact on gas demand

A

The availability of lower price electricity, lower marginal carbon emissions of electricity and improvements in system efficiency will result in a lower temperature switchover regime.

B

With a setpoint switchover, daily demand will still vary slightly depending on daily heat profiles and the need to use gas boilers for initial boost.

C

Higher electricity prices, higher marginal carbon emissions of electricity and lower heat pump system efficiency (perhaps with a cold morning start-up) will result in greater gas demand at higher temperatures.

D

Spikes in heat pump or boiler output may occur outside of the transition area due to extremes in stimuli such as extreme price or carbon events. These could be triggered by variable rate tariffs.

13. Customer engagement

13.1 Introduction

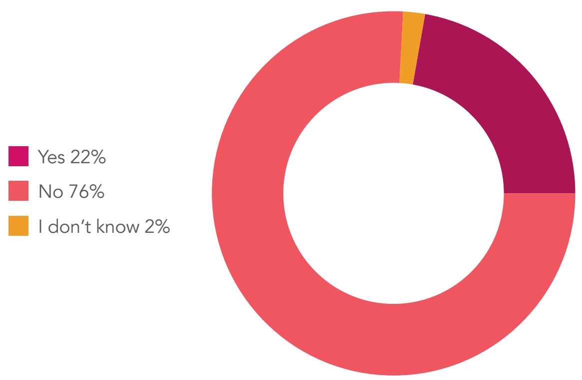
Throughout the Freedom Project a combination of in-depth interviews, focus groups and surveys were utilised at various stages of the trial in order to assess customer experiences and perceptions of smart hybrid heating systems. Delta-ee also completed one GB representative survey with its own customer panel.

13.2 Installation feedback

The majority of installations were problem-free, but there is room for improvement.

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 *(see Figure 78)*.

A majority of installations were problem free with positive fedback on the installers and a high level of trust



Q: Did you have any problems during the installation process?

85% Of respondents feel they can trust an installer

Figure 78: Customer feedback: installations

However, 1 in 5 installations did have issues indicating that there is room for improvement

- Reduce installation time
- Minimise hassle and disruption
- Increase instructions on how to use the system

"I would highly recommend them for any future work"

"Made the experience stress-free"

"Friendly and happy to chat about the installation"

13.3 Initial customer experience of the hybrid heating system is 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 *(see Figure 79)*.

At the mid-way point, the hybrid heating system has met the majority of customer's expectations

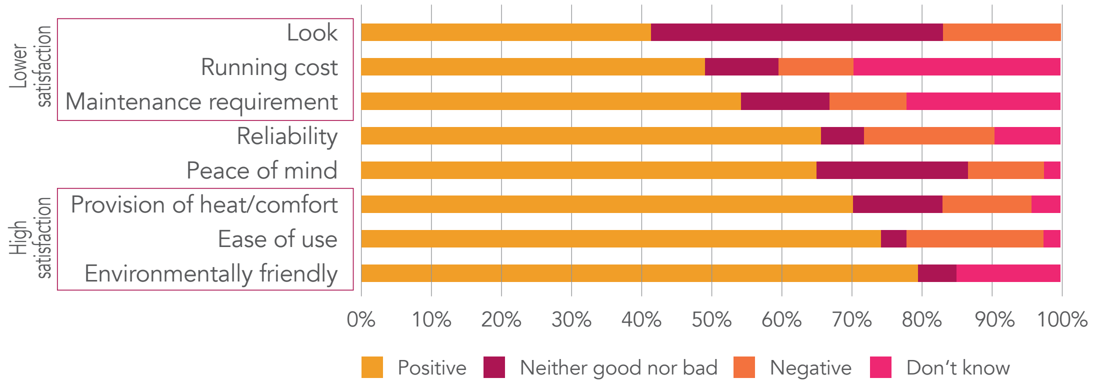


Figure 79: Customer feedback: the hybrid heating system

74% Of respondents said they would recommend a hybrid heating system to their friend with only **16% stating they would not**

Temperature control was a concern for participants, and highlights the need for ongoing education and support – particularly on the heat pump operation as part of a hybrid heating system. Temperature control was perceived as a problem for some of the participants in the trial. Although the hybrid heating systems were consistently rated highly for their 'provision of comfort' (in survey 3, 83% of respondents said the provision of comfort was 'good to excellent'), some participants reported having issues with the temperature control of their heating. In particular, overheating in the evenings and at night, and being too cold at some times of the day. While there were some instances where a technical fault was the culprit, the reality of the data highlights that this was most likely a problem with the heating schedule set (or not set) by the occupants themselves. This highlights that customers may not have understood how to effectively provide the comfort levels they wanted with a heat pump as part of their hybrid heating system *(see Figure 80)*.

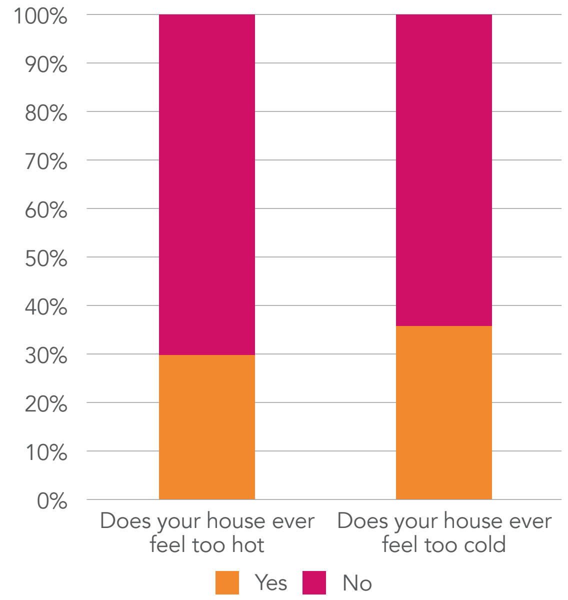


Figure 80: Customer feedback: education and support

30-40% of respondents stated they sometimes felt too hot or too cold. However in a majority of cases this does not impact on customer satisfaction, and the problem was resolved by altering the temperature on the thermostat or app.

Only **24% said being too hot or being too cold 'bothered' them** a lot. For everyone else it was not a major issue.

The most common way to deal with the problem was to alter the temperature with the thermostat or the app – this mostly resolved the problem **(80% of the time)** indicating that systems were working correctly. Some more technical customers also stated they would check the app to understand why.

The most common rooms where overheating was reported were in the bedrooms, at evening and at night.

The most common rooms where under-heating was reported was the living room and during the day, but there was much more variations, and more that said this affected the whole house.

Overall overheating bothered the respondents more than under-heating.

Overheating was a problem for focus group participants which highlights how important it is for customers to have 'ultimate control' of their system.

In the focus groups, a number of participants said overheating was affecting them significantly, waking them up in the night and impacting on their sleep. In these households they believed this was due to:

- Poor siting of the thermostat, in a cold area of the house (such as the hallway)
- Lack of responsiveness from the thermostat, so the set-point differential does not respond to their input
- Being set incorrectly, or controlled at that time by a third party

These perceptions can be challenged by the trial data itself – in particular the hybrid heating system challenged users expectations on energy efficiency and heat provision. For example, they were uncomfortable with needing to specify long term comfort in advance (rather than relying on bursts of high temperature heat) and perceived that if the heat pump was running in the background this was energy wasted (rather than how to optimally run the system).

13.4 Running cost savings are a concern for participants

Running-cost savings were never included as part of the trial aims – but throughout customers have 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 *(see Figure 81)*.

Respondents are confident the hybrid system is working correctly, but are less certain that they are saving energy and money – this highlights again how important the economic criteria are if customers are to invest in this technology outside of the trial.

Money saving and energy saving are linked (as saving energy will save you money) and it is here customers are less confident in the system's performance.

However there are a high number of respondents who don't know whether the system is delivering on these points compared to other areas. This should not be taken as a negative response, but it could indicate that these customers do not understand their bills.

For example:

A number of customers stated they were seeing big increases in their electricity bills – but did not mention a reduction in gas bills, this might indicate they are not holistically looking at their bills together.

One customer said they had spent a lot of the 'credit' they had accumulated with their energy provider, however this would be expected as direct debits are set at a level whereby you would usually build up a deficit so this could be because this customer is paying more attention to their bill now.

In the focus groups customers reported bills increasing by '£20 a week' – but it was also clear the running cost savings they expected would be in the future rather than today given this is a trial and this level of cost has not been substantiated by data.

The LPG users included in the trial already reported significant running cost savings since having the hybrid heating system installed.

The main aim of the trial was to prove the technical ability of a hybrid heating system, and a high level of confidence that it is working and will keep you warm is a strong indicator that the trial has been successful. Of the 75% who thought the system would keep them warm, half felt "very confident" about this. In terms of meeting comfort criteria, a hybrid system is comparable to an existing heating system when operated correctly.

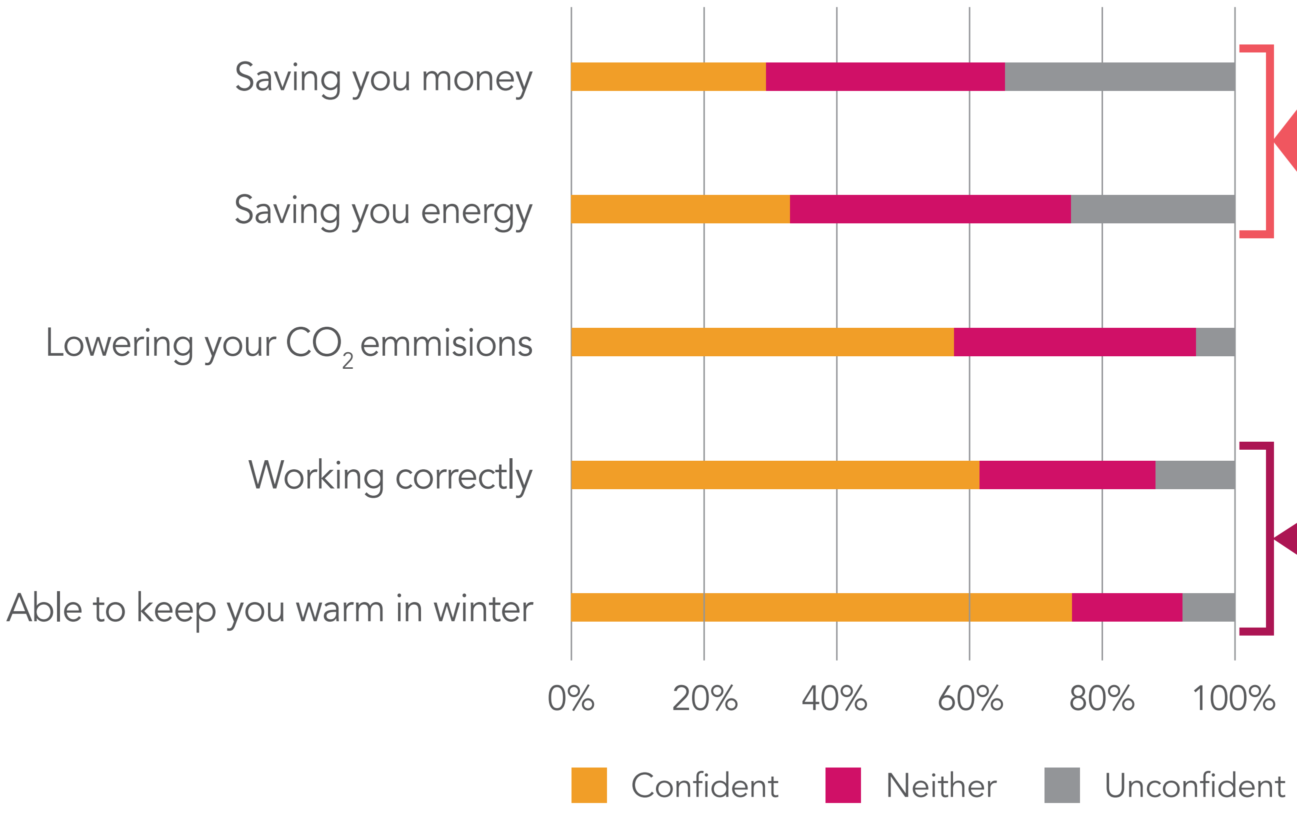


Figure 81: Customer feedback: the hybrid heating system

13.5 Customer attitudes and appeal towards the hybrid heating system

During the course of the trial, respondents were mostly positive about the hybrid heating system and their experiences with it. Unsurprisingly the up-front and running costs would likely be critical barriers to hybrid heating systems outside of the trial conditions, so the industry needs to innovate. However there are also simpler things, like bundling with an app which could improve customer appeal.

Overall participant satisfaction remained consistently high throughout the trial. The majority of respondents would be likely to recommend a hybrid heating system to a friend.

13.6 Key findings

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.

The app was a top-rated feature of the hybrid heating system as customers really liked the ability to remotely control the system.

The aesthetics of the hybrid heating system should not act as a deterrent to uptake. Although there are minor improvements that could be made to external units, correct siting of the unit was more important.

13.7 Recommendations

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.

13.8 Freedom Project participation satisfaction

Overall, participant satisfaction remained consistently high throughout the trial. No obvious aspects of the hybrid heating system were flawed, which shows that from an operating perspective, as a whole, the product met customers' needs.

Customer satisfaction was consistently high for both: (1) the duration of the trial and (2) the different aspects of the hybrid heating system *(see Figure 82)*. This shows that hybrid heating systems can compete with existing heating systems in terms of meeting the basic heating and comfort needs of customers, and if up-front and running costs were also comparable then expectations would be for market uptake to be reasonable. Environmental friendliness, provision of heat/comfort and maintenance requirements were the highest rated; this indicates that potentially customers might be willing to invest based on the 'greenness' of a product, however, we know from further research this would only be the case if it meets economic criteria too.

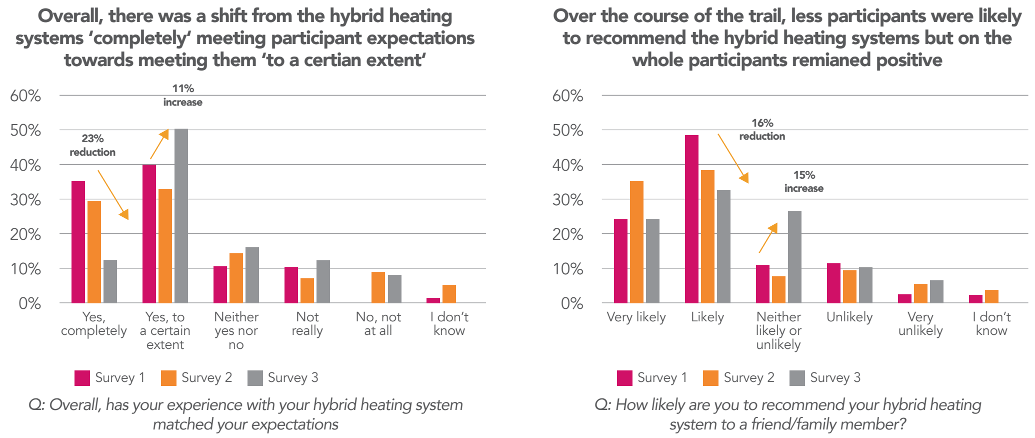


Figure 82: Customer feedback: overall satisfaction

13.9 Participant expectations being met

The hybrid heating system matched respondent expectations less as the trial progressed. In survey 1, 75% of respondents stated it met their expectations completely or to a certain extent, but by survey 2 and 3 this reduced to 64%. While it is positive, a majority still said yes to this question after a longer period of use, many more shifted to a "yes to a certain extent" response indicating overall that satisfaction was generally lower.

This finding appears to conflict the positive findings reported when asked about user-experience (which were consistently higher). So while the hybrid heating system performed to a highly satisfactory level, some customers may have had raised expectations of the system i.e. they expected to see much bigger cost reductions, or significant improvement in comfort rather than these aspects 'just' remaining constant/behaving like their previous heating system.

The change in participant satisfaction for running cost is an interesting finding. It is most likely explained by high participant expectations for reductions in their heating bill (survey 2) coupled with disappointment once they had received their heating bill (survey 3).

This indicates that trial participants might need further information about their anticipated running cost savings (if any) into the future, and how to optimise their systems.

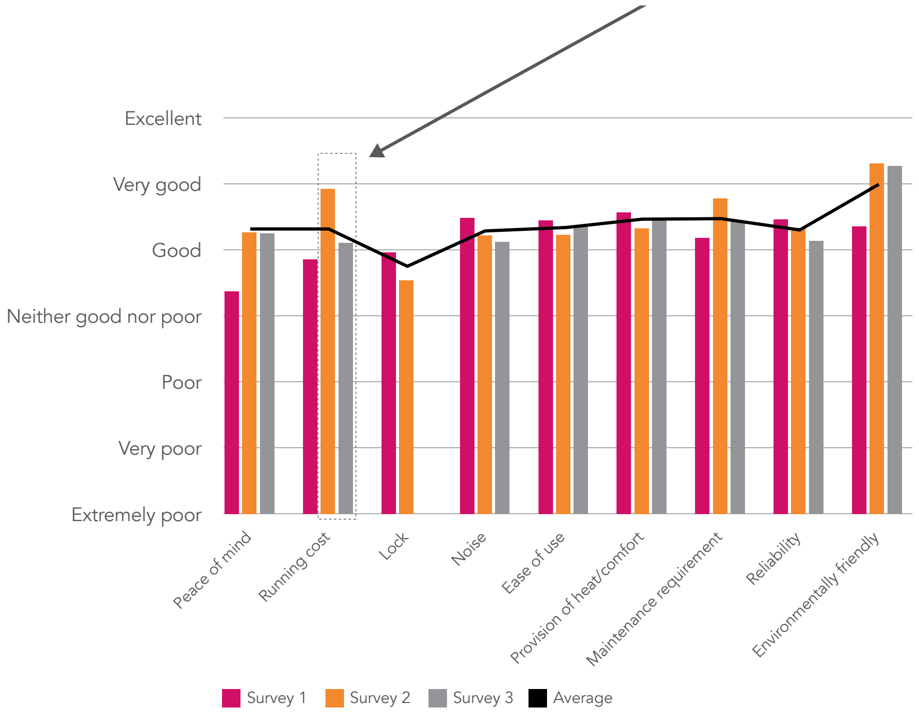


Figure 83: How triallists rated their hybrid heating system experience

13.10 Summary of findings

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.

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.

Recommendation:
a trusted advisor role needs to be filled to engage customers and installers, with off-gas homes being the initial target.

The technology has been proven and customers were overwhelmingly positive about the Freedom Project hybrid system. The trial has proven that the installation of hybrids on a significant scale, and the long-term use and operation of hybrids in a whole variety of house types and customer types, is possible. Freedom hybrid systems largely met the comfort and reliability challenge, and the majority of customers were satisfied. The most satisfied customers experience a high-quality customer journey throughout, from the information at pre-trial, to the installation and follow-ups. This highlights how important it is to get the customer journey right. Bundling with an app also proved popular, and can support increased customer confidence.

Recommendation:
offer an end-to-end service, from pre-install to aftersales support to ensure customer 'peace of mind'. Bundling with an app should be standard.

Financial criteria are a key priority for customers – innovative business models will be needed for market creation – participants were drawn to the trial because they would get a heating system for free, but also because they believed they would save money on their energy bill (even though this was not a stated aim of the trial). Energy prices today make this difficult, and up-front costs are higher than a standard boiler replacement so the market will need to address these challenges to capture customer attention, as identified by Wales & West Utilities' work in Bridgend on customer willingness and ability to pay[14].

Recommendation:
consider the potential of hybrids being supplied for free, heat leasing or other innovative financial models.

There is an opportunity around Demand Side Response (DSR) which needs further exploration – the trial participants in this research demonstrated a high level of interest in future DSR propositions, although it is clear that many struggle to understand the concept, so there is an education need here too. However, once it had been explained, respondents were open to DSR. With the right incentives in place DSR could offer significant network benefits and support the creation of innovative energy tariffs, which in turn could support hybrid uptake if it provides the running cost saving customers require in order to invest.

Recommendation:
explore potential DSR opportunity with further research, and consider what sort of incentives or tariffs it could support.

The survey sample is environmentally conscious and representative of the UK in terms of income and house types.

There have been three survey samples to date and all share similar characteristics. The average response rate is 68% of all participants – this is high by industry standards for this type of research. The sample also proved to be consistently "greener" than average UK homeowners and their experience of the controls suggests that they may be more engaged with energy or more likely to be early adopters. Although 'green', financial considerations and reliability of on-demand heat were higher priorities.

Overall, a majority of respondents had a very positive customer experience throughout the trial. There are some simple steps that could be taken to ensure customer satisfaction remains high, for example, ensuring that everything is left tidy before the installer leaves the home, and providing a follow-up visit as standard to check everything is ok with the homeowner and that they understand how to operate it.

[14] *www.wwutilities.co.uk/media/2718/integrated-gas-and-electricity-networks-support-the-journey.pdf*

14. The installation of 75 PassivSystems hybrid heating systems

14.1 Installation summary

The main phase of hybrid heating system installation commenced in June 2017 and was completed in early October 2017. Typically, a hybrid heating system installation was completed in two to three days and an additional day was allocated for the installation of the meter and monitoring equipment.

The installation plan was designed to start slowly and initially only installing MasterTherm hybrid heating system units; this was to ensure that any potential installation issues would be highlighted and could be addressed. Once confident of installing multiple units of the MasterTherm unit the programme delivered an identical process with the Daikin unit and eventually the same exercise with the Samsung unit.

PassivSystems ensured that all installations complied with Construction Design Management 2015 regulations, this included: a pre-construction information pack, construction phase plan and appropriate pre-construction meetings. Since the installations commenced, PassivSystems has had weekly reviews with all sub-contractors and the Registered Social Landlord (RSL) partner, Wales & West Housing Association (WWHA).

At the end of each installation, a PassivSystems representative demonstrated to the tenant/homeowner the PassivLiving app and answered any questions about the app or project.

PassivSystems has demonstrated that it is feasible to install optimised hybrid heating systems and smart controls on 3 different hybrid heating systems in 35 private homes and 40 social homes.

PassivSystems has demonstrated retrofitting 75 hybrid heating systems to existing homes with wet systems, including; 3 hybrid systems with a system boiler setup, 3 hybrid systems not on the gas grid and using LPG (Calor gas) and an ASHP retrofitted to an existing boiler to become a hybrid heating system.

14.2 Installation contractor *(Spire Renewables, Thermal Earth and WDS Green Energy) feedback*

How easy was it to install a hybrid heating system?

The connection style we 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 you 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 you 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 you 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 you sell/install more hybrid heating systems? What would be the challenges that you would face?

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 you face?

Scaling up and educating non-experienced 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.

Next steps
& opportunities

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 non-domestic 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 a multi-occupancy 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 socio-economic 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.

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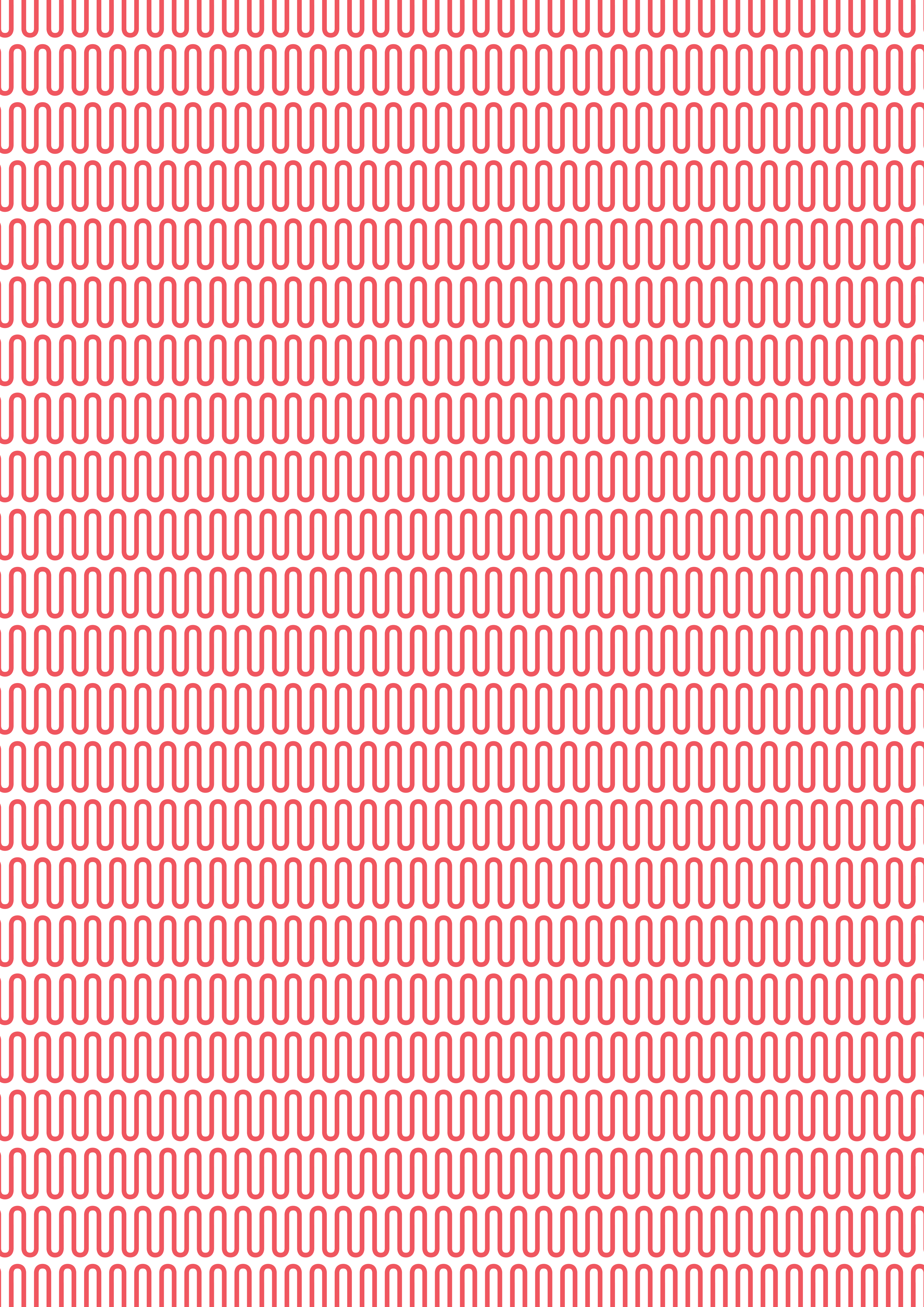

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