Peak Heat

NIA Project Closedown Report

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Name	Role
	Author
	Reviewer
	Approver

Contact Details

Email :

Nged.innovation@nationalgrid.co.uk

Postal :

Innovation Team

National Grid

Pegasus Business Park

Herald Way

Castle Donington

Derbyshire DE74 2TU

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1. Executive Summary

The majority of existing domestic heating in the UK is provided by natural gas. Decarbonising domestic heating is a key requirement of the move towards net zero in 2050. The transition from natural gas could mean a large increase in electrically powered heat pumps (HPs) connected to the distribution network, and thereby increase the peak electrical loads observed. The Peak Heat project aims to assess the impact that a wide roll-out of HPs could have on peak loads, at the individual household level, and at the network level. This Closedown Report summarises the scope of the Peak Heat project, the key findings, and opportunities for future investigations.

The project consisted of five separate work packages, covering:

1. WP1: Archetype creation
2. WP2: Heat market landscaping
3. WP3: Customer modelling
4. WP4: Area typology modelling
5. WP5: CBA, Analysis and recommendations

House archetypes were developed which were used to represent the housing stock supplied by three primary substations that were selected for this project.

A model was developed within the PLEXOS software program to undertake domestic heat modelling at the individual customer level. The outputs included modelled half-hourly time series load data at the individual household level for each of the house archetypes, and for different temperature profiles (an average winter period, or a 1-in-20 winter period), and including different flexibility measures. The output profiles covered a two-month period.

The load profiles from the individual customer modelling were scaled up within PLEXOS to create profiles of the demand at the distribution network level. The output profiles covered different distribution substation archetypes, and again included different scenarios based on the temperature profile and flexibility uptake scenarios.

It was found that based on the forecasted high heat pump uptake scenario, peak network loads in a 1-in-20 winter could be between 1.8% and 12.0% larger than an average winter period, dependent on the substation archetype, and if no flexibility measures were implemented. Flexibility measures were found to provide a benefit in peak load reduction at the individual customer level, but at the network level the reduction in peak load offered by flexibility measures was only up to 2% aside from the battery flexibility scenario which offered improved peak load reduction, but only when there was a significant level of battery uptake in homes with heat pumps.

A cost benefit analysis demonstrated that significant investment will be needed to reinforce the distribution network so it is able to support the forecasted heat pump loads. Some of the flexibility measures displayed a more favourable net present value compared to traditional network reinforcement to support loads, but the costs to implement the flexibility measures will need to be confirmed with heat pump installers and / or energy suppliers.

2. Project Background

Heating currently accounts for around one third of the UK's CO_2 emissions, predominantly resulting from natural gas combustion in boilers, with small amounts of electric and oil-based heating. A range of possible pathways and solutions exist for decarbonising heat, with some relying on the future use of low carbon gas (primarily biogas and hydrogen) and others based on the electrification of heat (likely in combination with different energy efficiency measures). Irrespective of how these future pathways evolve, it is likely that the current mix of heating (dominated by gas boilers in on-gas grid areas) will change substantially, and this could have a significant impact on electricity distribution networks.

A major challenge for electricity network operators is the current uncertainty around what the future heat market will look like. It is likely that large scale changes to the heating market will be required at a fast pace to achieve the UK's net zero by 2050 target, and therefore early decisions will need to be taken by network operators to adapt and meet the needs of the changing market. However, without knowing the exact pathways heat will take this will be difficult and business planning and investment decisions for RIIO-ED2 will need to be based on a least-regrets route.

Domestic heat electrification is likely to have a major impact on LV and MV distribution network peak loads by adding a significantly larger load than the network has experienced to date. There is a range of uncertainties which need to be explored to inform future network investment plans, as follows:

- The resultant load profiles incorporating new electricity loads and technology shifts (e.g. from Economy 7 storage heaters to HPs). How are these likely to vary with customer behaviour, customer segments, different business models for delivering heat, and new tariff structures like Time of Use (TOU) tariffs?

- What is the role of thermal storage? What types of storage may be deployed and how will these impact on heating and therefore electricity loads? Can we use storage to our advantage?

- What is the inherent flexibility in domestic heating? How much potential is there for modifying heat demands to facilitate increased uptake of low carbon electric heating solutions whilst minimising the impact on the distribution network?

Off-gas grid areas and new build homes are of particular interest since they are likely to experience transition to electric heating early on (there is a stronger case in both economic and decarbonisation terms), and insight is needed as we move into the RIIO-ED2 (Electricity Distribution price control 2) period (2023-2028) and ensure that business planning is robust and supports least-regrets investment decisions.

There are many ways to electrify heat (storage heating, heat pumps etc.), each with different load profiles and flexibility potential. There is an opportunity for Distribution Network Operators (DNOs) to help to accelerate the decarbonisation of heat, by understanding the system and network impacts of increased electricity demand from the electrification of heat, as well as the value of the associated flexibility and the potential benefits domestic storage could offer in managing network constraints.

The Peak Heat project intends to provide understanding of the impacts of electric heating loads on the distribution network, and the role that flexibility (including thermal storage) could take in helping to mitigate network impacts. This will provide a baseline of evidence to allow further research streams and potentially trial projects to be developed.

3. Scope and Objectives

Table 3-1: Status of project objectives

Objective	Status
Look at the latest heat pump loads based on currents strategies around heat pump operation (it should be noted that there has been significant development in controls and optimisation strategies for heat pumps in the last few years).	✓
Investigate the impact of heat pumps based on specific typology areas, considering the effects of clustering on our network.	✓
Investigate the trade-off between smart shifting of loads and cost to upgrade the network.	✓
Access the impact of a peak winter (1 in 20) on the network due to both direct (e.g. poorer heat pump performance in cold conditions) and indirect (e.g. customer behaviour during these events) effects.	✓
Examine the potential market and role for domestic thermal storage.	✓

4. Success Criteria

Table 4-1: Status of project objectives

Objective	Status
Creation of demand profiles that can be incorporated into main business planning tools for future network development planning and load growth modelling.	✓
An assessment and understanding of how heat pumps operate in different types of buildings (e.g. construction, size) and regions of our network. Clarity and further understanding of the impact of factors such as building stock and climate on profiles	✓
A better understanding, including profiles, of how heat pumps perform in cold weather conditions.	✓
Assessing the impact that the electrification of heat will have on different LV distribution network typologies.	✓
An understanding of how and when can heat load be shifted to manage network loading whilst maintaining the required customer service.	✓
An overview of the sources of flexibility and how thermal storage stacks up as an enabler of flexibility. This includes assessing the overall economic case for these sources versus upgrading the network.	✓

5. Details of the Work Carried Out

The project was broken down into five work packages. The methodology behind each is discussed below.

Work Package 1 – Archetype creation

The focus of this work package was to select trial areas from across WPD's network to investigate over the duration of this project, and to characterise the housing stock in each area into house archetypes to be taken forward into subsequent work packages.

The three primary substation areas were selected based on geographical spread across the WPD network, their forecasted heat pump uptake, and the current level of demand headroom available. The substations selected were:

- Mackworth (East Midlands licence area)
- Newport East (South Wales licence area)
- Bath Road (South West licence area)

For each of these areas, Energy Performance Certificate (EPC) and census data was gathered and analysed to inform the development of eight representative house archetypes. Consistent archetypes were required across all three areas for the physical factors that influence thermal demands and heat losses. These factors include building type, wall and insulation type, glazing type and building age. Other factors, such as existing heating system type and occupancy profile, could vary between study areas.

This process resulted in the development of eight house archetypes, which were defined primarily based on the residential building type (detached, semi-detached, mid-terraced and flats) and the building fabric performance (good/insulation present and poor/no insulation). Secondary characteristics (building age, wall type, glazing type, heating system, and occupancy profile and floor area) were assigned to each of these archetypes, based on the median (floor area) and modal values (other inputs) for each archetype whilst ensuring that the distribution as a whole was representative.

For each secondary characteristic, the total percentage of building stock for all customer archetypes with that characteristic (the modelled data) was compared to the actual percentage of building stock with that secondary characteristic (taken from the actual EPC data) to confirm the validity of the simplifications and assumptions that have been made. The average absolute discrepancy between the actual and modelled values for each parameter across each area is less than 5%, with the largest discrepancy being 16%, found for the percentage of properties with

uninsulated solid walls in Newport. This is judged to be within acceptable bounds and therefore the archetype distribution is deemed to be suitably representative of the actual housing stock.

Work Package 2 – Heat market landscaping

Work package 2 formed the 'landscaping' element of the Peak Heat project, which outlined how the heating market is changing and will likely change in future (both qualitatively and quantitively), how and where domestic thermal storage might be used, and how these technologies might be used to provide flexibility. The findings were captured in the work package 2 report.

The report included an outline of existing heating systems in the UK today and the potential options for decarbonising heat, as part of new builds and retrofits, and which types of buildings present the best growth potential for electric heat. It described forecasted trends in the UK heating market and the forecasted heat pump uptake within WPD's network area based on the Distribution Future Energy Scenarios (DFES). Possible threats to electrification of heat, including increase of hydrogen being used for domestic heating, were also presented. This information would be used in subsequent work packages to indicate how many homes would be forecasted to have heat pumps in the primary substation areas selected for the study, and which type of homes would be preferred candidates.

The technical characteristics of the latest available heat pumps were presented in the report, including different types of heat pumps (including air source and ground source heat pumps), typical heat pump arrangements, Coefficients of Performance (COPs), building suitability, sizing and design. This information was based on previous studies completed by Delta-EE, and based on discussions held with relevant equipment manufacturers. Technical characteristics of different types of thermal storage technologies were also described including how they can be used to provide flexibility. The heat pump and thermal storage characteristics would be used to develop the models in work packages 3 and 4.

Work Package 3 – Customer modelling

Work package 3 consisted of developing the model that would be used to provide load profiles at the individual house level. The aim was to determine the baseline electrical load profiles for each of the eight house archetypes developed in work package 1 if they were heated by heat pumps, and also investigate the impact that adding flexibility measures would have on these load profiles.

Originally it was intended that the model would be developed in Excel, but during the course of the project this changed to modelling in PLEXOS. It was planned to use PLEXOS in work package 4 from the outset, and using it for the individual house level modelling in work package 3 provided efficiencies when the load profiles were extended to the network level modelling. The load profile outputs from work package 3 were provided in Excel format so that they could be used by the wider WPD team.

In developing the model in PLEXOS, a house was modelled as a battery object, where the battery charge level corresponded to the temperature of the house, battery discharging represented the heat losses, and battery charging represented heat generation.

A building physics model was used to estimate the half-hourly heat losses and heat demand for each of the house archetypes, and these outputs were used to calibrate the PLEXOS model. The building physics model runs were conducted by AECOM using the IES <VE> dynamic simulation modelling suite of software. Calculations within the model were based on first-principle models of the heat transfer processes occurring within and around a building, and were driven by real weather data. The programme provided an environment for the detailed evaluation of building and system designs, allowing them to be optimised with regard to comfort criteria and energy use.

Heat loss and heat demand profiles were generated using existing AECOM housing models for the house archetypes identified in this project. These models were chosen to represent each house archetype, with the corresponding thermal mass, building fabric and window elements considered against what would typically be found in each type and age of building.

Four building physics model runs were completed in total for each house archetype covering both weather scenarios (average and 1-in-20 winter periods) and both occupancy scenarios (occupied during the daytime and unoccupied during the daytime).

To perform the calibration between the AECOM building physics model and the PLEXOS model, the heat loss values and indoor temperatures from the building physics model were used as inputs in PLEXOS and the output heat demand from PLEXOS was compared to the heat demand estimated from the building physics model. Other inputs into the PLEXOS model included the heat pump size and maximum electrical draw, outdoor air temperature, heat distribution system flow temperature (and COPs), and indoor temperature requirements. The PLEXOS model was adjusted iteratively until the half-hourly heat demand values approximately matched the results from the building physics model.

An additional "discharge efficiency" was included with the heat loss values in the PLEXOS model to reflect the impact of the thermal mass of the buildings, where heat was being transferred to the material of the building itself without increasing indoor temperature. The discharge efficiency values were also derived for each house archetype through iterative adjustments until the heat demand more closely matched the outputs from the building physics model.

Once the PLEXOS model had been calibrated, additional items, such as hot water generation, buffer tanks and electrical battery storage, were included as additional battery objects in the PLEXOS model, all sized according to the specific house archetype that was being modelled. Non-thermal electrical demand profiles were included in the model as an additional load, again dependent on house archetype.

Several scenarios were run in PLEXOS to determine the electrical demand profiles of each archetype under different conditions and with different flexibility measures applied. It was found that peak electrical demands were 3 to 6 times higher than standard peak demands after the addition of a heat pump without any flexibility measures.

Allowing more flexible heating and adding thermal and electrical storage enables load to be shifted from high price to low price periods, if suitably incentivised. Flexible heat and hot water generation could enable 10-20% of demand to be shifted from the evening peak period, depending on the archetype. The addition of a buffer tank gives a further 5-15% of peak load reduction, and an electrical battery could allow up to 100% of electrical loads to be moved outside of evening peak times.

The resultant load profiles were provided in Excel format for each of the house archetypes and flexibility scenarios modelled. The individual house model could then be scaled up to the wider distribution network as part of work package 4.

Work Package 4 – Area typology modelling

Work package 4 covered the modelling of heat flexibility solutions at the substation level. The objective was to determine how substation loads and peak demands were likely to be impacted by uptake of heat pumps, and how much these impacts could be mitigated by the use of flexibility measures such as thermal and electrical storage.

The modelling of distribution substations was undertaken in PLEXOS, building on the individual house modelling completed in work package 3. Distribution substation archetypes were created to represent the distribution substations under study across the three primary substations selected in work package 1; Bath Road, Mackworth and Newport.

The distribution substation archetypes were defined based on the number of customers connected to the substation and the mix of house archetypes on the substation.

Heat pumps were assigned to houses based on the suitability of each house archetype to having a heat pump installed. Two uptake scenarios were used to represent the level of uptake in 2030. The moderate uptake scenario forecasted between 4-12% of homes connected to a primary substation installing heat pumps (12% aligning with the primary that had the most detached / semi-detached houses connected, and 4% corresponding to the primary which had a higher proportion of flats and mid-terrace houses), a conservative assumption for the level that could be realistically achieved by 2030 that aligns with the uptake in 2025 in WPD's Consumer Transformation DFES scenario. The high uptake scenario forecasted heat pumps in 14-30% of homes connected to a primary substation, which is a more ambitious assumption that aligns with the uptake in 2030 in WPD's Consumer Transformation DFES scenario.

In order to simulate diversity across the network, PLEXOS was used to generate unique thermal and non-thermal electrical demand profiles for each individual house based on the average for its house archetype. Commercial and other non-heating domestic demands (those not modelled as part of the assessment of HP demand, including electric immersion heating) for each substation archetype were estimated based on historical substation load data and added to the modelled substation demands.

Several scenarios were run in PLEXOS to determine the impact of different weather conditions, heat pump uptake levels and flexibility measures on substation loads. The scenarios effectively assume zero or 100% uptake of flexibility measures in homes with heat pumps installed, except in the case of electrical batteries which are assumed to be installed in 50% of homes with heat pumps. This means that the results indicate the potential maximum impact of flexibility measures compared to the baseline scenarios (with no flexibility measures), and should be considered to be illustrative rather than predictive.

With no flexibility measures included, in the moderate heat pump uptake scenarios, 44 of the 234 distribution substations analysed across the three primaries were predicted to be overloaded relative to their continuous load on peak days. For the high heat pump uptake scenario, the number of overloaded substations increased to 94 out of 234.

In general across all substation archetypes it was found that allowing flexible hot water generation in all homes with heat pumps enables roughly 1% of demand to be shifted out of peak periods. This is a small amount, but can easily be achieved by programming when heat pumps can generate hot water.

Having flexible indoor temperatures (relaxing set temperature requirements by up to 1°C and allowing pre-heating of up to 21°C in the afternoon) in all homes with heat pumps has a negligible

impact (<1%) on peak demands, though this could be slightly higher if greater changes in temperature were allowed.

Use of buffer tanks in all homes with heat pumps also only reduces peaks by 1-2%, and is therefore unlikely to be a cost-effective flexibility measure. Only higher capacity thermal stores such as heat batteries can store enough heat to meaningfully reduce peak demand, and the required space is a significant factor.

Installing electrical batteries (with capacities between 5 – 13.5 kWh depending on property size) in 50% of homes with heat pumps can reduce peak demands by up to 9% in the best cases, central cases will be less. For some substations, this could be enough to avoid substations being overloaded during peak periods, however, this level of deployment is substantially greater than the DFES projections.

The resultant load profiles were provided in Excel format for each of the distribution substations archetypes and flexibility scenarios modelled.

Work Package 5 – CBA, Analysis and recommendation

WP5 of the Peak Heat project assessed the high-level cost benefit analysis (CBA) of incentivising heat flexibility solutions under several scenarios within Peak Heat. The objective was to determine the most cost-effective heat flexibility options when comparing these against the cost of traditional reinforcement of the LV network, and as such inform WPD's approach to domestic heat and flexibility. Flexibility measures were selected for cost analysis based on scenarios explored in work package 4.

The CBA utilised the outputs from work package 4 alongside costing and reinforcement assumptions. These costs and benefits were calculated for each distribution substation, under the three primary substations chosen for analysis, every year up to 2050 for each of the flexibility scenarios considered and the corresponding net present value (NPV) was derived. Where flexibility could defer or mitigate traditional substation reinforcement it was enacted in the CBA.

The NPVs for the different flexibility solutions were compared with the baseline scenario (with zero flexibility). It was found that a wide flexibility measure rollout could present a long term cost benefit to WPD based on the assumed incentives, however the majority of distribution substations would still require future reinforcement to accommodate the forecasted increase in peak loads due to the uptake of heat pumps.

6. Performance Compared to Original Aims, Objectives and Success Criteria

The performance against the project objectives is as follows:

1. **Look at the latest heat pump loads based on current strategies around heat pump operation (it should be noted that there has been significant development in controls and optimisation strategies for heat pumps in the last few years) – COMPLETED**
   Discussions were held with heat pump equipment manufacturers as part of work package 2 to understand latest heat pump loads and operational strategies. Those heat pump loads were used in development of the PLEXOS model in work package 3.

2. **Investigate the impact of heat pumps based on specific typology areas, considering the effects of clustering on our network – COMPLETED**
   Three primary substations were selected for the study. The substations chosen represented different area typologies, Newport East is a city type area, Bath Road is a town, and Mackworth is a village / rural area. The primary substations were also situated in different licence areas to provide a spread across the region.

3. **Investigate the trade-off between smart shifting of loads and cost to upgrade the network – COMPLETED**
   In work package 5, implementation of flexibility measures to shift / reduce peak loads was compared to the cost of traditional network reinforcement.

4. **Assess the impact of a peak winter (1 in 20) on the network due to both direct (e.g. poorer heat pump performance in cold conditions) and indirect (e.g. customer behaviour during these events) effects – COMPLETED**
   The heat loads were modelled for an average winter period and a 1-in-20 winter period. In the baseline scenario (with no flexibility measures included), the 1-in-20 winter peak network load in 2030 was 6.8% higher than the average winter peak network load for the S-200 distribution substation archetype (a substation with approximately 200 connected customers, comprising predominantly semi-detached homes) when a high heat pump uptake scenario was considered.

5. **Examine the potential market and role for domestic thermal storage – COMPLETED**

The work package 2 report presented information about UK market trends, focussing on heat pump uptake. Thermal storage and other flexibility solutions were also described, alongside technical characteristics of each technology and its building suitability.

The performance against the project success criteria is as follows:

1. **Creation of demand profiles that can be incorporated into main business planning tools for future network development planning and load growth modelling – COMPLETED**
   Time series demand profiles have been created for different house archetypes under different scenarios, including outdoor temperature scenarios, flexible tariff scenarios, and heat pump flexibility scenarios. This data has been provided in an Excel format that can be easily used by the wider WPD team. In addition, time series demand profiles have been provided in Excel format for each of the distribution substation archetypes, again including different flexibility scenarios, and also for different heat pump uptake scenarios.

2. **An assessment and understanding of how heat pumps operate in different types of buildings (e.g. construction, size) and regions of our network. Clarity and further understanding of the impact of factors such as building stock and climate on profiles – COMPLETED**
   Individual house heat modelling was performed in work package 3. This included modelling for different building archetypes, which indicated how heat pumps perform differently dependent on the size and thermal insulation of residential buildings. The load was modelled over a 2-month period (January and February) for average and 1-in-20 (coldest) winter periods, so a comparison of how load profiles vary based on outdoor temperature could be made.

3. **A better understanding, including profiles, of how heat pumps perform in cold weather conditions – COMPLETED**
   As per the above point, load profiles from average and 1-in-20 peak winter periods were provided for all of the building archetypes and flexibility scenarios considered in work package 3. As expected, the 1-in-20 winter profiles had higher demands than the average winter, and therefore they were used for the peak load modelling.

4. **Assessing the impact that the electrification of heat will have on different LV distribution network typologies – COMPLETED**

   To assess different LV distribution network typologies, several distribution substation archetypes were created based on the number and type/mix of building archetypes that were connected to each substation investigated.

   In order to perform the network level modelling, an assignment of the homes that would have heat pumps installed had to be created. Heat pumps were allocated to house archetypes based on which archetypes were considered most suitable for heat pump installation, for example larger houses with space for heat pumps and good insulation are better candidates for heat pumps than smaller houses with poor insulation.

   The level of heat pump uptake was adjusted based on a moderate and a high uptake scenario, in accordance with forecasted heat pump values taken from WPD's Distribution Future Energy Scenarios (DFES). The network level modelling was then performed using the PLEXOS software package. Using PLEXOS allowed for stochastic load profiles to be included in the analysis, i.e. each individual customer connected to a distribution substation archetype had their own unique load profile, this accounts for diversity between different households. This modelling provided the expected peak load on each distribution substation archetype.

   The distribution substation peak loads were also modelled based on different flexibility scenarios, similar to those investigated in work package 3. The network modelling provided an assessment of which substation archetypes were forecasted to be overloaded with the inclusion of heat pumps, and for the different flexibility and heat pump uptake scenarios.

5. **An understanding of how and when heat load can be shifted to manage network loading whilst maintaining the required customer service – COMPLETED**

   Different flexibility solutions have been modelled in work packages 3 and 4 to provide an indication of the amount of peak load reduction and load shifting that can be achieved through adoption of each solution. The flexibility solutions considered included hot water flexibility (allowing the heat pump to generate hot water at flexible times), temperature flexibility (where heat pump users have more flexible temperature settings during the day), installing buffer tanks, installing electrical batteries, and various combinations of the aforementioned solutions. At the individual house level the modelling found that, depending on the flexibility solution applied, there could be a tendency to shift the load to different times during the day rather than to reduce the overall load.

6. **An overview of the sources of flexibility and how thermal storage stacks up as an enabler of flexibility. This includes assessing the overall economic case for these sources versus upgrading the network – COMPLETED**

   An assessment of flexibility was performed in the network level modelling. The results from the network level modelling led to the development of a cost benefit analysis (CBA), and this CBA includes a comparison of the costs to implement flexibility solutions versus the cost of traditional substation reinforcement.

7. Required Modifications to the Planned Approach during the Course of the Project

Modifications to the planned project approach are detailed below:

- The work package 3 modelling was planned to be completed in Excel, but this was later changed to modelling in PLEXOS. It was planned to use PLEXOS in work package 4 from the outset, and using it for the individual house level modelling in work package 3 provided efficiencies when the load profiles were extended to the network level modelling. The load profile outputs from work package 3 were still provided in Excel format so that they can be used by the wider WPD team.

- The scope for work package 4 included development of LV feeder archetypes for the purposes of modelling the system, however during the course of the project this changed to development of distribution substation archetypes. Detail on the number and type of customers (e.g. detached houses, flats etc.) connected to each LV feeder was not available for this study, but this information was available at the distribution substation level. Hence substation archetypes could be created based on the number of customers and the representative mix of house archetypes connected to each substation. In total, 16 distribution substation archetypes were created for the work package 4 modelling.

8. Project Costs

Table 8-1: Project Spend

Activity	Budget	Actual
WPD Internal Costs	£20,136.00	£908.09
Consultancy Costs	£215,152.00	£215,152.00

9. Lessons Learnt for Future Projects and outcomes

A number of lessons have been learnt on the project to date. These are summarised for each work package below.

Work Package 1 – Archetype creation:

- Split sites (sites with split 11kV busbars) need careful consideration since the demand headroom information for these sites can be misinterpreted. The headroom should be confirmed with reference to the information presented in the Long Term Development Statement.

Work Package 2 – Heat market landscaping

- Heat pump manufacturers were consulted to determine the most appropriate hot water generation strategy for heat pumps. Several different approaches can be adopted, with some manufacturers recommending two one-hour generation periods ahead of the morning and evening demands and others recommending charging the cylinder in the middle of the day when outdoor temperatures are highest. For customers on a cheaper overnight tariff, hot water can be generated in these periods to reduce costs. Heat pumps can also be set up to recharge the cylinder whenever the temperature falls to 10°C below the set temperature. The difference between the actual temperature and the set temperature will determine what capacity the heat pump operates at, and hence how much current it draws. Because hot water can be stored efficiently for several hours, hot water generation is an important source of flexibility. However, it can also be a source of peaks on the network, if many homes have heat pumps set to generate hot water in the same short window each day.

Work Package 3 – Customer modelling

- It was found that the analysis that was planned to be completed in Excel for work package 3 (modelling the house using inputs from AECOM) can be undertaken successfully in PLEXOS. As such, the PLEXOS model was prepared to represent the house as a heat battery, optimise heat pump space heating demand, including non-electric heating demand, and hot water / thermal storage use according to price optimisation, ensuring temperature does not drop below a certain limit.

- Initial results from modelling by AECOM of heat demand profiles for homes showed slightly unrealistic ramp up times and assumptions around heating capacity. Model reruns were made to include dynamic set-point adjustment to cater for extreme cold periods and heating capacity limits, and adjustment of the heating capacity limits based on heat loss calculations.

- Differences between profiles produced by the AECOM building physics model and profiles produced in PLEXOS (underestimation of heat demand in PLEXOS model on coldest days) was explained by the initial absence of modelling the effect of thermal mass of buildings in PLEXOS. The PLEXOS profiles were brought in line with AECOM profiles by applying a factor representing the effect of this thermal mass variable.

- At the individual house level on a variable tariff it was found that peaks were shifted from evening periods to morning periods, rather than reduced. Peaks were higher in scenarios with electrical batteries, as these are an additional load. However, by applying limits to total electricity demand, loads could be spread more evenly across the day, and peaks could be reduced with the addition of storage. This illustrates the importance of having the right market signals to incentivise the use of storage in a way that is most beneficial to the network.

- The heat demand modelling assumes that the heat pump would be able to deliver all of a property's heat demand (i.e. additional heating through other electrical / resistive heating is not required). This assumption was based on guidance from heat pump manufacturers. Further study could include investigating the demand in existing properties with heat pumps installed, and assessing whether the heat pump alone provides sufficient thermal input to meet the demand.

Work Package 4 – Area typology modelling

- At the network level it was found that, with high levels of heat pump uptake, the introduction of flexibility measures shifted peak demands from high price to low price periods on an Agile-type tariff, rather than reducing peaks. Rather than introducing electricity supply limits to counter this, the ToU price was adjusted to try to encourage peak shaving rather than peak shifting. It was determined that a tariff with low overnight rates, high peak rates, and a linear change in prices between the two had the desired effect.

- Preliminary results from the network level modelling suggest that electrical batteries (50% uptake among homes with heat pumps) and flexible hot water generation are the most effective measures for reducing peak loads. Flexible hot water generation should be relatively easy to incentivise for households. However, batteries are expensive investments, and it is possible that the costs might outweigh the benefits. Temperature flexibility and buffer tanks were found to be less effective.

Work Package 5 – CBA, Analysis and recommendation

- Assumptions for battery uptake used in the Peak Heat project are illustrative only. In work package 4 it was found that there is not a great deal of additional benefit (in terms of reduction in peak loads) when uptake of batteries exceeds 50% of homes with heat pumps. However, it is noted that battery uptake is forecasted to be much lower in practice. DFES indicates that only around 2% of all WPD customers will have heat pumps in 2030, in the Consumer Transformation scenario. The 50% uptake has been taken as the illustrative scenario for the Peak Heat project to provide an indication of the maximum amount of flexibility that batteries could offer if a wide rollout took place.

- The CBA model confirmed that pre-emptive transformer replacements, i.e. avoiding multiple upgrades of the same substation, result in improved net present value benefits compared with multiple incremental upgrades to the next size up.

The key learnings from the project are detailed below:

- At the individual property level, electricity peak demands could be between 4 to 6 times higher (dependent on the property archetype) than peak non-thermal demands if a property switches from gas/oil/LPG heating to electrically driven heat pumps. Total electricity demands were higher in larger homes with poor insulation.

- Under cold conditions, many of the flexibility measures investigated had a minimal impact on peak demands, and often resulted in peak-shifting rather than peak reduction at the individual house level.

- At the network level, the study found that for a 1-in-20 winter period, a high heat pump uptake, and no flexibility measures, approximately 44% of the distribution substations in the areas investigated would require reinforcement by 2030, and this would increase to 72% by 2040.

- Flexibility measures were found to have a negligible or very low impact on peak demand reduction at the network level during a 1-in-20 winter period. Flexible hot water generation resulted in approximately 1% reduction in peak load, and the use of buffer tanks reduced peaks by 1-2%. Temperature flexibility had less than 1% impact on peak load reduction, and also has a higher incentive cost compared to the other measures considered, so is less cost effective. Inclusion of electrical batteries in half of homes with heat pumps provided the greatest level of peak demand reduction, at up to 9%, but the number of batteries in homes is likely to be limited based on DFES projections.

- Outdoor temperature has a significant impact on the peak heat demand. Taking the S-200 substation archetype as an example, the half hourly peak heat demand in a 1-in-20 winter (on a day with an average temperature of -4°C) is approximately two times higher than in an average winter (on a day with an average temperature of 4°C).

Updates on the project have been disseminated to the wider WPD team in a virtual workshop (21 September 2021), and to interested industry stakeholders in the WPD Innovation Showcase Event (06 December 2021).

10. The Outcomes of the Project

The following list gives a summary of the project's outcomes:

- Work Package 1 report – detailing the selection of the primary substations for the study and methodology / development of the customer archetypes.

- Work Package 2 report – outlining the different types of heat pump technologies and flexibility solutions available. This report also includes commentary on forecasted market trends for heat pump uptake.

- Work Package 3 report – describing the methodology behind the individual house archetype load modelling, including presentation of the different flexibility scenarios considered and results from the modelling.

- Work Package 4 report – takes the outputs from work package 3 and scales them up to network level modelling. The report presents the development of the distribution substation archetypes alongside the assumptions used, and the results from the modelling are presented.

- Work Package 5 report – presenting the cost assumptions that were used to develop the cost benefit analysis and the corresponding net present values. It compares the various flexibility scenarios against the traditional substation reinforcement scenario.

In addition to the above, the demand profile data from the individual house level modelling, and network level modelling, has been provided in an Excel format for use by the wider-WPD team.

Recommendations from the study include:

- In the near-term, focus on incentivising flexibility measures which have the most impact and are lowest cost to implement, this includes flexible hot water generation and use of electrical batteries.

- Explore the potential offered by different types of electricity tariff structures, these could be used to mitigate risks of heat pumps all operating concurrently and could optimise battery discharge profiles.

- Explore how flexibility incentives for battery storage and larger thermal storage (such as phase change material batteries) can be reduced.

- Support policy and regulatory development in heating controls arena. Including supporting diversification of load shifting in order to avoid creating

- Engage with heating engineers / installers and standard setting for heating controls with the aim of driving changes in standard control configuration to support flexibility (e.g. flexible hot water generation).

- Investigate other methods of relieving capacity in the networks using network-side flexibility approaches.

11. Data Access Details

The up-to-date outputs from the project can be found on the dedicated project website here. The website contains the relevant documentation and information that has been generated by the project team along with the latest progress summary.

Further details can be requested by contacting the National Grid's Innovation Team (Nged.innovation@nationalgrid.co.uk).

12. Foreground IPR

No foreground IPR has been generated

13. Planned Implementation

The average and 1-in-20 winter period peak load profiles have been provided in an Excel format that can be utilised by the wider-WPD for network planning purposes. The data can also be used for future innovation projects relating to heat electrifications, such as the Equinox project.

14. Contact

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

Email:

Nged.innovation@nationalgrid.co.uk

Postal:

Innovation Team

National Grid

Pegasus Business Park

Herald Way

Castle Donington

Derbyshire DE74 2TU

Glossary

Abbreviation	Term
CBA	Cost Benefit Analysis
COP	Coefficient of Performance
DFES	Distribution Future Energy Scenarios
DNO	Distribution Network Operator
EPC	Energy Performance Certificate
kWh	Kilowatt-hour
LV	Low Voltage
MV	Medium Voltage
NPV	Net Present Value
HP	Heat Pump
RIIO-ED2	Ofgem Electricity Distribution price control 2 period (2023-2028)
TOU	Time of Use (tariff)