NIA ENWL024
Smart Heat

Closedown Report

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GLOSSARY

Term	Description
ADMD	After Diversity Maximum Demand
BAU	Business as Usual
CBA	Cost Benefit Analysis
HP	Heat Pump
HV	High Voltage
LCT	Low Carbon Technology
LV	Low Voltage
NIA	Network Innovation Allowance
NIC	Network Innovation Competition

1 EXECUTIVE SUMMARY

1.1 Aims

This research project improved the understanding of future heating markets, the impact they will have on the electricity network and the opportunities for mitigating the impacts using demand side flexibility and smart network management via variable thermal rating.

1.2 Methodology

Our project partners, Delta-EE and Ricardo, used desktop modelling techniques to assess the network impact from the installation of Heat Pumps (HPs). Once the impact was understood they then investigated how smart solutions such as variable ratings and heat flexibility could be used to mitigate the increase in demand. They also carried out some customer research to understand customer's attitudes to providing heat flexibility.

1.3 Outcomes

The outputs showed that the Electricity North West network is likely to accommodate a low level of HP uptake without requiring intervention but if HPs are deployed at a higher rate reinforcement or an alternative would be required.

The application of variable ratings to distribution transformers could release significant capacity to help mitigate the increased demand but the thermal ratings of other associated equipment should be taken into account when applying variable ratings.

Many customers said it would be acceptable to provide a small level of heat flexibility as long as they retained a level of control and were suitably incentivised.

The use of heat flexibility measures could reduce the peak demand by 1-15% during 1 in 20 winter conditions and the combination of heat flexibility and variable ratings offers further benefits.

1.4 Key learning

There is likely sufficient existing network capacity to accommodate a low uptake of HPs.

The use of variable ratings could enable the uptake of higher numbers of HPs, but additional research and demonstration is required to build up confidence in the method.

Heat flexibility measures enable relatively small reductions in peak demand**.** Many customers would be willing to provide heat flexibility provided they have override control and are suitably compensated. An appropriate flexibility mechanism requires further development.

1.5 Conclusions

This desktop research project has provided a methodology to quantify the problem and conducted initial investigations into appropriate interventions. Further research and development is required fully develop the interventions into Business as Usual (BAU) solutions.

1.6 Closedown reporting

This project was compliant with Network Innovation Allowance (NIA) governance and this report has been structured in accordance with those requirements.

This report and the associated documents are available via the Energy Networks Association's Smarter Networks learning portal at www.smarternetworks.org or via the Electricity North West website.

2 PROJECT FUNDAMENTALS

Title	Smart Heat
Project reference	NIA_ENWL024
Funding licensee(s)	Electricity North West Limited
Project start date	April 2021
Project duration	1 year
Nominated project contact(s)	InnovationTeam@enwl.co.uk

3 PROJECT BACKGROUND

The UK has a target of achieving net zero greenhouse gas emissions by 2050 and in the North West local leaders have set more challenging targets. In order to meet these targets significant decarbonisation will need to take place in the heating sector which is likely to result in the future residential heating market looking very different from the current gas-dominated market. Under a range of future heating scenarios, it is likely that electrification of heat will result in a significant increase in load on the electricity network with little apparent diversity which will trigger significant network reinforcement unless alternative solutions are identified.

This small-scale research project will investigate the impact of heat on Electricity North West's network by drawing on the analysis from other work (e.g. the WPD Peak Heat project) and combining this with customer engagement to explore the motivations and connection considerations around heat pumps and further testing the acceptability of different methods for network management and flexibility.

The project will use the learning from ENWL's Celsius and Smart Street projects to assess how smart network management can exploit existing network capacity, for example, by using variable thermal ratings, voltage control and demand flexibility, and will produce a CBA of methods to manage and mitigate the impacts of electrical heating demand, including variable rating and flexibility.

4 PROJECT SCOPE

This project is a desktop research and analysis piece based around the following tasks:

- Future low carbon heating market scenarios and network impacts
- Best practice in understanding, connections and managing heat pumps
- Characterising heat flexibility
- Assessing customer impact
- Investigating the use of enhanced variable ratings
- Cost benefit analysis
- Recommendations for future work

5 OBJECTIVES

This research project will help to improve understanding of future heating markets, the impact these will have on the electricity network and the opportunities for mitigating those impacts using demand side flexibility and smart network management via variable thermal rating.

6 SUCCESS CRITERIA

Production of a report detailing:

- Future heat landscape scenarios
- Best practice for the connection and management of electric heating technologies
- The impact of low carbon electric heating on network assets, and the potential of leveraging variable thermal ratings
- The likely availability of flexibility from heat
- An understanding of customer needs around heating
- An assessment of the costs and benefits of approaches to mitigate the impact of electric heating load on networks
- Recommendations for further work

7 PERFORMANCE COMPARED TO THE ORIGINAL PROJECT AIMS, OBJECTIVES AND SUCCESS CRITERIA

The full methodology for this work is detailed in the “Smart Heat final report” and “MS4 Customer Research Findings” report produced by our partners, Ricardo and Delta-EE and issued alongside this report.

7.1 Future heat landscape scenarios

To estimate the additional demand from HPs, the homes connected to Electricity North West’s network were classified into a limited number of archetypes for which half hourly HP load profiles were estimated.

Distribution transformers were also classified into archetypes were based on the number and mix of housing connected to them.

Representative HP uptake scenarios were selected and translated into uptake scenarios for each transformer based on the mix of houses connected with HPs assigned to each house archetype based on their suitability for having HPs installed.

New load forecasts were generated for each transformer archetype based on the number of HPs installed in each scenario with data from the Celsius Network Innovation Competition (NIC) project providing the baseline load. The load forecasts were generated on a half hourly basis over a two-month winter period in which 1 in 20 weather conditions occur.

This new load forecast for was then be compared to the transformer rating to understand the impact.

7.2 Best practice for the connection and management of electric heating technologies

This objective looked to identify best practice in understanding, connecting, and managing HPs on Electricity North West's distribution network via the following tasks:

- Review of Electricity North West's current processes for the connection of HPs.
- Review of UK and international projects that investigate methods to manage HP demand.
- Identification of an initial long list of potential mitigations and best practice.
- Identification of any gaps in research and data for the implementation of best practice, and how to fill them.
- Recommendations of measures to implement best practice procedures, which can support the connection of HPs on a large scale.

7.3 The impact of low carbon electric heating on network assets, and the potential of leveraging variable thermal ratings

The variable ratings were calculated using the characteristic equations developed as part of the Celsius NIC project and involved the following steps:

1. Identify the transformers thermal behaviour equations.
2. Determine the ambient temperature for the transformer.
3. Calculate the half hourly variable ratings for each transformer.

Half hourly is adequate as the operating temperature does not change more quickly than this due to the transformer thermal mass. The half hourly ratings could then be used to find ratings at lower frequencies, such as six hourly and daily ratings by taking the lowest, or 'worst case' ratings within the time period, i.e. a daily rating will be equal to the lowest half hourly rating within the day.

The capacity released by variable rating (i.e. the variable rating minus the nameplate rating) is then compared with the forecasted heat demand (i.e. ignoring any non-heat demand). This demonstrated whether the capacity released by variable rating could meet the forecasted heat demand while discounting all other non-heat demand, as well as understanding the benefits and suitability to specifically support heating load.

This section discusses likely network pinch points that could be encountered on network equipment at HV and LV level following the adoption and implementation of variable ratings of distribution transformers. The analysis in this section is a high-level conceptual view of current installation practice only; actual pinch points present, particularly as part of historic installation arrangements will be different for each substation, and specific pinch point studies should be undertaken when considering adoption of variable rating.

To ensure the application of variable ratings did not cause other unintended consequence a "pinch point" analysis was carried out. This analysis investigated the maximum permissible transformer overload taking into account the thermal limits of network equipment and protection components on the HV and LV side of distribution transformers.

7.4 An understanding of customer needs around heating

A multi-stage programme of quantitative and qualitative research was undertaken with Electricity North West customers with the following objectives:

- To understand customers' motivations for adopting Low Carbon Technologies (LCTs), particularly electric heating.
- To understand the acceptability of flexibility measures related to heating such as flexibility of heating regimes or adopting storage technologies.
- To understand the barriers to adoption of flexibility measures and how to mitigate them, including incentives.
- To understand the acceptability towards, and impact of, flexibility approaches for customers in vulnerable circumstances
- Identify the key features that customers think a heat flexibility mechanism would need to provide.

To meet these objectives, three streams of research were conducted.

1. A quantitative survey of 562 customers in the North West of England.
2. Engaged Customer Panels with 30 customers across the North West of England and UK: 15 with a regular heating system and 15 with a HP installed in their home.
3. In-depth interviews with 6 customers in the North West of England in vulnerable circumstances.

7.5 The likely availability of flexibility from heat

Six scenarios were created to test the impact of various demand side heat flexibility measures on substation loads. The scenarios were combinations of the following:

- *Water heating:* the model determined the most cost-effective times to generate hot water. Hot water flexibility is applied in all scenarios as this measure would be relatively easy to implement in practice.
- *Indoor temperature:* temperature scenarios were tested, allowing for lower temperatures (by 1°C, 2°C or 3°C) during occupied periods and overheating (to 23°C, 24°C or 25°C) in the afternoons and evenings. The model determined the most cost-effective indoor temperature profile within these constraints. Overheating was not allowed in the mornings, as preliminary customer research findings suggested this was unacceptable to most households.
- *Storage:* a store equivalent to a small electrical battery or large thermal store was included in 50% of the homes with a HP.
- *Electricity tariff:* A variable electricity tariff with higher morning and evening charges was applied to incentivise houses to shift demand outside of these periods.

The six heat flexibility scenarios were run for each transformer under the three different levels of HP uptake. The two-month modelled period from included both average and 1 in 20 winter weather conditions. The impact on substation loading considering the number and types of housing connected to the substations was assessed.

This work was then extended to demonstrate the effectiveness of the variable ratings developed in section 7.3 in combination with the heat flexibility measures.

7.6 An assessment of the costs and benefits of approaches to mitigate the impact of electric heating load on networks

Two Cost Benefit Analyses (CBA) were carried out to estimate the benefits and costs of the solutions being proposed in Smart Heat; an initial CBA to provide early insight into likely benefits, and a full CBA carried out at the end of the project which incorporates all the learning from Smart Heat.

The Smart Heat CBA model quantified the potential financial, capacity and carbon benefits of developing and implementing the Smart Heat solutions by comparing the following cases:

- *Traditional Reinforcement Case:* assumes only traditional network reinforcement solutions are available and are deployed wherever the network load exceeds the nominal rating of the equipment.

- *Smart Base Case:* includes both traditional reinforcement and any innovative solutions that are expected to become available in BAU over the modelling period.

- *Smart Heat Project Case:* represents the approaches and solutions that will be possible if the solutions explored in this project are developed, demonstrated, and implemented into BAU. This case also includes the solutions included in the Smart Base Case. As a last resort, traditional reinforcement will be deployed if lower cost options have been exhausted.

The CBA model then assessed the most appropriate solution for a given substation in a given year for each case. The selection of the most appropriate solution depended on transformer nominal rating, substation building type, forecasted load, and any solutions already applied to that site. The cost for the selected solutions for each case were then aggregated and compared to determine the benefits.

8 THE OUTCOME OF THE PROJECT

The full results for this work is detailed in the "Smart Heat final report" and "MS4 Customer Research Findings" report produced by our partners, Ricardo and Delta-EE and issued alongside this report.

8.1 Future heat landscape scenarios

The results of the load assessment showed that for a low HP uptake just over half of the transformers would not be overloaded even during peak periods, whereas for a high HP uptake only 10% of transformers would never be overloaded and over two thirds will be consistently overloaded.

8.2 Best practice for the connection and management of electric heating technologies

The recommendations for improved best practice in the connections, planning and operations processes in Electricity North West are:

- *Connections:* Improvements can potentially be made in linking HP connection logs with operation and planning activities. Connection assessments should be updated based on findings from monitoring and innovation projects. After Diversity Maximum Demand (ADMD) assumptions should also be updated as new information becomes available. In order to minimise costs and barriers, it is preferred to use a 'fit and inform' approach as often as possible, which will require Electricity North West to react to changing loads quickly and cost-effectively.

- *Planning:* HP load forecasts should be updated based on actual HP uptake rates. Load profiles could be improved using actual ambient temperatures rather than assumed monthly averages. Smart solutions should also be included in load forecasts where appropriate.

- *Operations:* Active network management solutions such as those considered in this project should be implemented to manage additional loads from HPs.

8.3 The impact of low carbon electric heating on network assets, and the potential of leveraging variable thermal ratings

For low HP uptake the capacity released through the application of variable ratings is sufficient to meet the forecasted heat demand for 96% of transformers. For medium HP uptake this figure reduces to 70% but for high HP uptake, the capacity released would be insufficient to meet the heat demand for more than 80% of transformers.

The results also showed that 99% and 88% of the studied transformers will be overloaded for less than 10% of the time in the low and medium HP uptakes respectively, implying that capacity released by variable rating would be sufficient to meet the heat demand 90% of the time under these scenarios.

As stated previously the thermal pinch points of other network equipment could impact the capacity released and the transformer environment impacts these pinch points. The analysis showed that for indoor substations variable ratings up to 53% above nameplate rating could be achieved whilst for outdoor substations this increased to 96% above nameplate rating.

The analysis indicates that a significant number of transformers may be able to adopt variable ratings without any concern for potential pinch points but a site specific study should be carried out before implementing them.

8.4 An understanding of customer needs around heating

Key findings from the customer research are:

- Factors such as price, performance and quality are the key drivers when choosing a heating system. Those with HPs are more likely to take environmental impact and sustainability into account.

- 33% of respondents said it would be acceptable for changes to be made to the level of heating in their home in general, with 24% saying it would be unacceptable.

- When specifically asked about a reduction in their heating during the peak evening period, only 21% would not be willing to have their heating reduced at all, indicating (as long as this is kept within certain parameters) that many customers would be willing to accept reduced temperatures.

- Younger customers seemed to find changes most acceptable, along with those that live in a city location.

- Customers would be more likely to accept a change if it was a small reduction in temperature, rather than a small increase, as turning up heating was seen as a waste.

- The majority of customers liked the idea of electric batteries, especially if they were used alongside other LCTs, such as solar panels. They also reacted positively to buffer tanks and hot water cylinders but were less convinced of a need for them.

- Some respondents not having to make the temperature changes themselves and suggested that they may not notice a small change without being told. Others preferred to make the changes themselves as that ensured they had control. Respondents felt it was important to have a manual override and the ability to set limits within which temperature changes would be made.

- Respondents would prefer to be communicated with by the supplier as they already have a relationship with them. They were less keen on third party involvement as this would be less cost-effective.
- The key barrier identified for allowing the DNO to change their heating was that they would be losing control. Some were concerned that they would be too cold in their own home as a result of the changes.
- The most appealing incentives were financial rewards, either in the form of a reduction in bill, or an annual payment. Respondents also liked the idea of personalised advice, which would mean they could reduce their bill themselves, through reduced usage.
- Other incentives that respondents suggested included knowing they were doing the right thing for the environment and helping those that need heating more than they do.
- Customers in vulnerable circumstances have similar needs to other customers, though they typically placed a slightly higher importance on their heating level.
- Overall, similarly to all other customers, customers in vulnerable circumstances would like to retain a level of control themselves and would also be happy with a financial reward as an incentive.

A heat flexibility mechanism should then include the following:

- *Choice:* the ability for customers to choose an approach that suits them best.
- *Personalisation:* the ability to tailor the approach according to customers' own needs.
- *Flexibility:* allowing customers to 'opt out' if their circumstances change.
- *Incentives:* a financial reward will be the most effective, but advice is also valued.
- *Information:* ensuring customers are informed of the benefits of their actions.

8.5 The likely availability of flexibility from heat

Looking at the half hourly load profile for one distribution transformer with a moderate level of HP uptake the baseline load (with no flexibility measures) peaks in the evening at just over 800kW – more than 60% above its 500kW nameplate rating.

Shifting hot water generation to off-peak times reduces peak demand by about 3%. Allowing some over or under-heating in homes reduces the peak by an additional ~1% for every 1°C change. Changing indoor temperatures by a few degrees might have an appreciable impact on demand on an average winter day, but it has little impact during 1 in 20 weather conditions.

The most effective flexibility measure for reducing peak demand is storage, either electrical or thermal, which can be charged during off-peak times and discharged during peak times. Together with flexible hot water generation this reduces the peak demand by about 11%.

The exact impact of the different heat flexibility measures varies based on weather conditions, house mix and level of HP uptake on a substation. Overall, these measures could be expected reduce the peak demand by 1-15% during 1 in 20 winter conditions. High levels of uptake of flexibility measures, could delay transformer upgrades by a few years.

Combining variable rating with heat flexibility

For high HP uptake more than 90% of transformers would be overloaded and require reinforcement if no additional measures are taken. Adopting variable ratings reduced the percentage of overloaded transformers to 65%. Combining this with heat flexibility measures reduces this further to 58%.

For low HP uptake adding heating flexibility to variable ratings has no additional effect as there is less flexibility available.

8.6 An assessment of the costs and benefits of approaches to mitigate the impact of electric heating load on networks

A CBA indicates that the Smart Heat solutions could deliver significant financial, carbon and capacity release benefits over alternative approaches, including traditional reinforcement and other smart solutions.

For the high HP uptake, the 2050 benefit is £1,554m when compared to traditional reinforcement and £395m when compared to the Smart Base Case for a GB-scale rollout.

The solutions could also provide 2050 carbon benefits of up to 114ktCO_2e at GB scale.

9 REQUIRED MODIFICATIONS TO THE PLANNED APPROACH DURING THE COURSE OF THE PROJECT

There were no modifications required to the planned approach during the project.

10 PROJECT COSTS

Item	Category	Estimated costs (£k)	Final costs £k	Variance
1	Project Management	£100,000	£104,615	-£4,615
2	Research and Development	£392,670	£392.637	£33
	Total	**£492,670**	**£497,252**	**-£4,582**

11 LESSONS LEARNED FOR FUTURE PROJECTS

There is likely sufficient existing network capacity to accommodate a low uptake of HPs, but with high levels the majority of substations would be heavily overloaded and require intervention.

DNOs should consider integrating HP connection data into other business processes, reviewing ADMD assumptions as new information becomes available, making more use of existing monitoring to inform connection assessments and including smart solutions in intervention assessment as they become available.

The use of variable ratings could enable the uptake of HPs whilst causing minimal disruption to customers, but additional research and demonstration is required to build up confidence in the method. If variable ratings are being considered an assessment of network pinch points should be carried out and any mitigation required taken into account in the intervention decision.

Heat flexibility measures such as shifting hot water generation, use of storage, pre-heating homes ahead of peak times or reducing indoor temperatures during peak periods enable relatively small reductions in peak demand**.** Many customers would be willing to provide heat flexibility provided they have override control and are suitably compensated. To enable this solution an appropriate flexibility mechanism will need to be developed.

There is a clear business case for the deployment of variable ratings as a solution to release capacity for the adoption of HPs across distribution networks, whereas the benefits from heat flexibility are marginal.

12 PLANNED IMPLEMENTATION

This desktop research project has demonstrated the benefits of various solutions to manage the increased demand associated with the electrification of heating.

These solutions require further development before implementation and it is likely that Electricity North West will carry out further research into the application of variable ratings for distribution transformers. The creation of a heat flexibility mechanism is being investigated by another DNO.

13 DATA ACCESS

There was no data gathered as part of this project as it was a desktop research project and used data available from the Celsius project.

Electricity North West's innovation data sharing policy can be found on our website.

14 FOREGROUND IPR

The default IPR position has been applied to this project, and there has been no relevant foreground IPR registered as part of this project.

15 FACILITATE REPLICATION.

As this was a research project there is no solution to replicate. However, there are some recommendations on best practice for connections which DNOs may wish to consider for their own business processes.

16 OTHER COMMENTS

None.