PROJECT DEFENDER WORKSTREAM 1

D1.5-1 – Cost-Benefit Analysis

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Published in the UK: 2023

Revision History

Name	Notes	Reviewer	Date
1.0	DRAFT	Laura Glover - Manager	15/02/22
1.1	DRAFT	Laura Glover - Manager	27/02/22
1.2	FINAL	Laura Glover - Manager	08/03/23

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Definitions

Name	Acronym	Description
Distribution Future Energy Scenarios	DFES	Forecasts for a range of customer demand and generation metrics up to 2050, completed by NGED.
Distribution Network Options Assessment	DNOA	A process by which investment decisions are made by NGED in order to deal with constraints across their network
Energy Performance Certificate	EPC	A record of energy performance criteria for an address containing information on building fabric, heating system, and performance. Approx. 60% UK coverage.
Archetype	-	Primary categorisation of addresses by construction age, type, and form factor
Sub-archetype	-	Secondary categorisation of addresses by the level of insulation
National Grid Electricity Distribution	NGED	Formerly known as WPD
Heat Thermal Coefficient	HTC	Heat flow rate divided by indoor and outdoor temperature difference (W/K)
U-value	-	Heat flow rate divided by indoor and outdoor temperature difference and surface area (W/m^{2}K)
Unique Property Reference Number	UPRN	Unique identifier for all UK addresses
Geographic Information System	GIS	Mapping software used to do analysis
Net Present Value	NPV	Financial metric used to assess attractiveness of an investment over its lifetime

Executive Summary

One of the overarching questions that the DEFENDER project aims to address is what to identify the potential for domestic energy efficiency interventions to defer or avoid network reinforcement costs. This WP5 report brings together outputs from work-packages 1 to 4 to complete cost benefit analysis (CBA) for individual and combinations of energy efficiency interventions at both the individual house-level and the network level.

The house-level CBA categorises the existing 100 most prevalent house sub-archetypes in NGED area into low, medium and high energy efficiency categories, based on the current levels of thermal energy efficiency measures installed. Across the population of homes that falls within these 100 sub-archetypes, almost half the homes are classed as ‘medium’ thermal efficiency. A further 37% of homes are of a low energy efficiency standard, with only very limited levels of insulation present. Only 15% of homes have high levels of building fabric, largely consisting of new-build homes and a small number of retrofits.

The most cost-effective interventions for upgrading low efficiency homes to either medium or high categories and existing medium homes to high levels of energy efficiency were identified for each house archetype. House archetypes classified as “high” were assumed to have no further efficiency measures installed and were removed from the analysis.

Three main conclusions can be drawn from our analysis to inform the types of homes that should be the focus of any retrofit schemes being considered by NGED:

- Loft insulation, cavity wall insulation, and double glazing are the most cost-effective measures for reducing peak loads on the network on a £Capex per kW reduction in peak load basis
- The effect on house-level peak loads as a result of upgrading from low to medium thermal efficiency has a maximum of 600W reduction per house. This is a similar impact as upgrading from medium to high thermal efficiency, which has a maximum of 750W peak load reduction, but the latter comes at much higher capital cost. Therefore, low to medium retrofits should be prioritised.
- The highest load reductions at a house level can be achieved through upgrading a detached or semi-detached house from low to high thermal efficiency. They include more than one fabric measure and can achieve up to 2200W reduction in peak load. However, these measures come at significant capital cost, often involving measures such as solid wall insulation and may not be the most cost-effective option for NGED to manage network reinforcement costs.

From the homeowner perspective, 30% of all homes in NGED’s licence areas have a retrofit option with a positive net present value. The breakdown in terms of payback time as a percentage of homes in the license area is:

    - 5% have a discounted payback time of under 5 years
    - 11% have a discounted payback time of 5-10 years
    - 9% have a discounted payback time of 10-20 years
    - 5% have a discounted payback time of 20-30 years

The homes with shortest payback tend to be for upgrades of low thermal efficiency homes to medium thermal efficiency homes. These upgrades tend to payback in under 10 years and are therefore likely to occur in the absence of additional funding by NGED.

Benefits to the network operator of installing energy efficiency are very location specific as they are highly dependent on the exact mix of properties in the building stock connected, the existing utilisation of the network assets and the cost to upgrade the network asset. Therefore, it is not possible to attribute specific cost savings to each sub-archetype. To identify the impacts of energy efficiency interventions on network reinforcement timing and costs, three case study areas were investigated. These were Axbridge, Mackworth and Withycombe Raleigh, selected based on their forecasted high proportion of domestic buildings, high uptake of heat pumps, good and good network, weather and EPC data availability. The building stock in each of these areas was categorised into the sub-archetypes developed earlier in the DEFENDER project and heat pump and energy efficiency uptake scenarios were applied to project out the network loads to 2030 and 2050. In all cases, heat pump deployment was tied to the DFES Consumer Transformation assumptions, with energy efficiency measures falling into either no, low, medium or high levels.
The following rules for the scenarios were applied in each case:

- The **No Energy Efficiency scenario** is a counterfactual scenario that just looks at the profiles of existing homes installing a heat pump.

- In the **Low scenario**, all 'low thermal efficiency' buildings move to medium, and all 'medium' and 'high' thermal efficiency buildings remain the same. This scenario represents the minimum fabric requirements to ensure 'low' thermal efficiency buildings are heat pump ready.
- The **Medium scenario** has been set to match the Committee on Climate Change's (CCC) Balanced Pathway in their 6th Carbon Budget[1].
- In the **High scenario**, all 'low thermal efficiency' buildings move to high, and all 'medium thermal efficiency' buildings move to high. This scenario represents the maximum levels of energy efficiency that can be installed in homes.

Across these scenarios, the results showed typically a maximum difference in peak load of 5.4% in 2050. This limited reduction is mainly due to the high efficiency of a heat pump in converting electrical energy input into thermal output, effectively reducing heat demand by a factor of 3, meaning that the impact of any reduction in heat demand as a result of energy efficiency measures is observed significantly less on electrical load than if the demand was being met by direct electric or natural gas. Consequently, electricity base load remains a much higher proportion of the overall electricity consumption, and is not affected by energy efficiency measures. This low reduction in peak load is exacerbated in the three case study areas investigated, due to the relatively high thermal efficiency in the existing building stock reducing the potential for energy efficiency measures to reduce load.

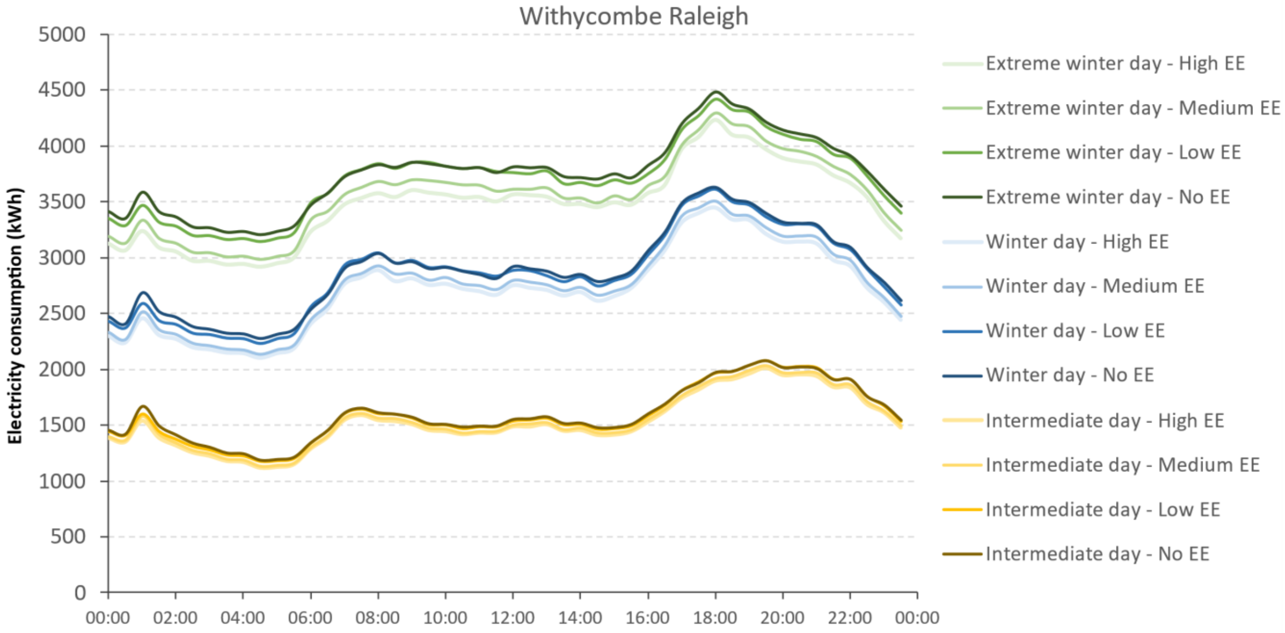

Figure A: 2050 daily profiles for three representative weather days and four energy efficiency scenarios in Withycombe Raleigh feeder area

For each of the three case study areas, the low and high energy efficiency scenarios were used in network flow modelling to identify the impact that energy efficiency interventions have on deferring or avoiding network reinforcement. The low scenario was used as a base case instead of the no energy efficiency scenario based on the findings in the house-level CBA that most low energy efficiency interventions pay back within timescales attractive to homeowners and are unlikely to require additional funding.

The results of this network modelling showed that high energy efficiency deployment does not tend to result in complete avoidance of reinforcement and instead defers investment by typically under two years, resulting in limited network cost savings and less attractive NPVs than investing only in the network reinforcement. This is due to the cables and transformers that require reinforcements being those that are already close to their threshold load and the increase in load resulting from installing a heat pump is significant compared to the only minimal peak load saving achieved from energy efficiency measures. Additionally, the network

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[1] Committee on Climate Change's (CCC) 6th Carbon Budget
CCC Balanced Pathway projects the number of wall, floor and roof insulations out to 2050 which was used to calibrate the medium energy efficiency scenario – roughly a third of low thermal efficiency homes move to high, and two thirds to medium; two thirds of medium thermal efficiency homes move to high, and a third remain as medium.

infrastructure that required reinforcement in the three case studies investigated was relatively low cost to upgrade, consisting of overhead lines and ground mounted LV transformers. Further assessment is needed to understand if this finding remains the case in dense urban areas with largely underground cables or if higher cost 33kV/11kV transformers are overloaded. DEFENDER Workstream 2 considers this in more detail.

In summary, this study concludes that there is very limited benefit for NGED to invest in energy efficiency measures as a method for reducing network reinforcement costs based on the modelling completed. The scope of this project was limited to the impacts of thermal energy efficiency on the low voltage distribution network as heat pump deployment increases. However, this change will not happen in isolation and the findings will be affected by wider system dynamics. It has been well shown at the GB system level that energy efficiency is very beneficial in reducing costs. We recommend that further modelling in two main areas:

- Identification of the wider impact of energy efficiency deployment on individual stakeholders across the sector to identify where greatest benefits are seen and hence which organisation outside of the DNOs should be engaged in pushing forward deployment of thermal energy efficiency retrofits.
- Interactions between energy efficiency deployment and the flexible operation of heat pumps and batteries on the investment case for these assets and their impact on the distribution network.

In addition to further modelling, we recommend that NGED:

- Engaging with other stakeholders with an interest in deployment of energy efficiency measures for non-network benefits, such as local authorities, on how best NGED can support based on location specific network characteristics. This may involve identification of network areas with high-cost reinforcement requirements and high density of low thermal efficiency homes and providing targeted support only in these specific locations, ensuring that the low to medium upgrades occur as anticipated and high cost upgrades are considered on a case by case basis.
- Track the deployment of energy efficiency measures to improve the DFES forecasting process and DNOA decision making.

1 House-Level Cost-Benefit Analysis of Energy Efficiency Measures

1.1 Objectives of House-Level Cost-Benefit Analysis

- To characterise the housing stock connected to NGED's network using EPC data and a predefined list of sub-archetypes to identify the thermal fabric in each building.
- To carry out an in-depth analysis on applying energy efficiency measures to the most common sub-archetypes connected to NGED's network.
- To provide an assessment of the factors affecting the financial case for installation of energy efficiency measures alongside heat pumps e.g. what types of measures in what types of homes
- To provide recommendations as to where additional DNO funding into energy efficiency could provide most benefits to the electricity grid, in the context of widespread heat pump deployment.

1.2 Methodology

The approach to completing a CBA analysis is described below. It utilises previously developed frameworks and models created as part of this project, further details of which can be found in deliverables for WP1.1 through to WP1.4.

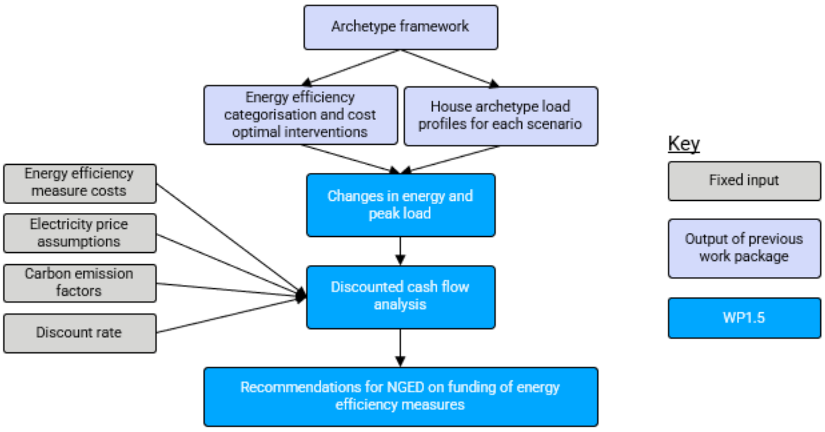


Figure 1 Inputs and approach to CBA

1.2.1 Archetype framework

All domestic dwellings are categorised into a numbered list of archetypes based on the following parameters:

- Property type and built form (e.g. Detached house, top floor flat)
- Construction age (before/after 1930)
- Floor type and insulation
- Roof type and insulation
- Wall type and insulation
- Window glazing

All combinations of the above parameters generate 2,905 possible sub-archetypes, most of which are non-existent on NGED's network and can therefore be excluded from analysis. A detailed list of the top 100 most common sub-archetypes on NGED’s network is shown in appendix 3.1, covering approximately 88% of all homes on NGED’s network

1.2.2 High, medium and low categorisation of thermal efficiency

Determining whether each archetype’s thermal efficiency is low, medium or high was done by applying thresholds to heat transfer coefficients (HTC) using the insulation parameters for walls, windows, floor and roof as indicators. The following principles describe how these archetypes were assigned:

- Typically, low thermal efficiency was assigned to sub-archetypes with higher HTC than that of the sub-archetype with double glazing, roof insulation, and no insulation on the walls or floor. This combination of insulation parameters was selected as it is close to the lower third of sub-archetype HTCs and is a common combination across all house archetypes.
- Medium thermal efficiency was assigned to the middle bracket of sub-archetypes, which have lower HTC than the ‘low thermal efficiency’ category but could feasibly install more measures to upgrade to ‘high thermal efficiency’.
- High thermal efficiency was assigned to sub-archetypes that typically wouldn’t install any additional energy efficiency measures i.e. buildings with nearly maximum levels of insulation.

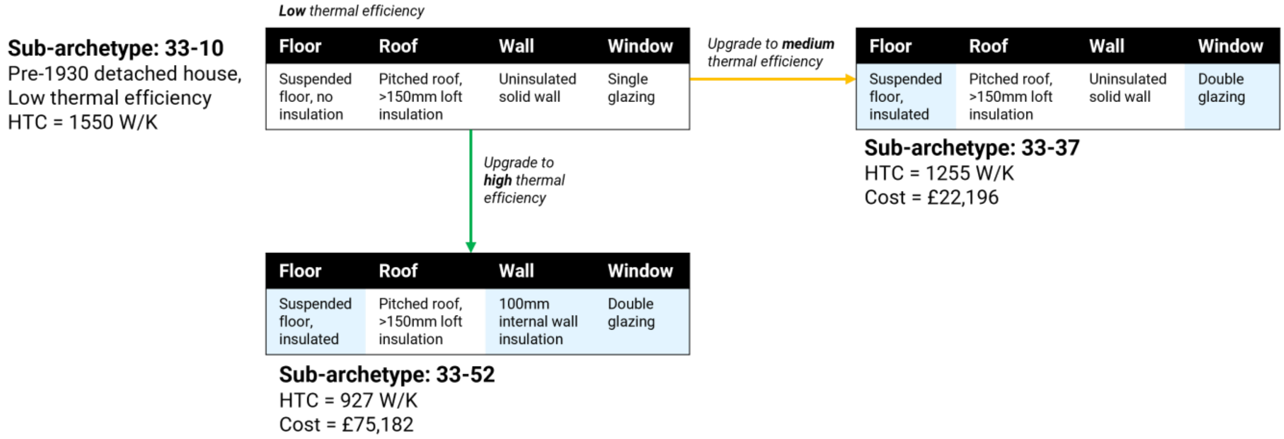
  Insulation thresholds are consistent between archetypes, but HTC values are not due to the large variance between property types. This means that low, medium and high are relative within an archetype, or in other words, buildings on the efficient end of ‘low thermal efficiency’ could in theory have a lower HTC than a building classed as having ‘medium thermal efficiency’ from another archetype.

1.2.3 Cost optimal packages of measures

To determine the fabric measures needed to change the thermal efficiency of an archetype, a cost optimisation module was created that selects the most cost-effective measure, or combination of measures, that upgrades the thermal efficiency of an archetype from:

- Low to medium
- Low to high
- Medium to high

It is assumed that sub-archetypes classed as having ‘high’ thermal efficiency will not install any additional fabric measures. For example, archetype 33 describes a pre-1930 detached house with a pitched roof, solid walls and a suspended floor, and sub-archetype 33-10 has >150mm loft insulation, no wall or floor insulation, and has single glazing, and is therefore classed as having low efficiency. The cheapest way to upgrade this property to medium thermal efficiency is to install double glazing and floor insulation (assumed easy access) which has a cost of £22,196. These measures move the sub-archetype from 33-10 to 33-37. The cost-optimal way to upgrade to high efficiency would be to upgrade to medium, plus add 100mm internal wall insulation. This is shown in Figure 2.



Sub-archetype: 33-10
Pre-1930 detached house,
Low thermal efficiency
HTC = 1550 W/K

Floor	Roof	Wall	Window
Suspended floor, no insulation	Pitched roof, >150mm loft insulation	Uninsulated solid wall	Single glazing

Floor	Roof	Wall	Window
Suspended floor, insulated	Pitched roof, >150mm loft insulation	Uninsulated solid wall	Double glazing

Sub-archetype: 33-37
HTC = 1255 W/K
Cost = £22,196

Floor	Roof	Wall	Window
Suspended floor, insulated	Pitched roof, >150mm loft insulation	100mm internal wall insulation	Double glazing

Sub-archetype: 33-52
HTC = 927 W/K
Cost = £75,182

Figure 2. Diagram showing the cost optimal interventions required to move sub-archetype 33-10 (low thermal efficiency) to medium and high thermal efficiency

1.2.4 Workstream 1 profiling tool

The profiling tool can be used to generate an annual electricity profile for each sub-archetype, allowing the effect of installing fabric measures can be assessed. Outputs from the profiling tool are used to calculate the change in annual electricity consumption and peak load for each house installing a cost-optimal package of fabric measures.

1.2.5 Discounted cashflow analysis

A discounted cashflow analysis was completed for the top 100 most common house sub-archetypes connected to NGED's network, representing approximately 88% of all homes on NGED's network. Each upgrade assessed in the analysis included the following outputs:

- Change in annual electricity consumption (kWh)
- Change in peak load (kW)
- Average annual operating cost saving (£/annum)
- 30-year Net Present Value (NPV) (£)
- Discounted payback period (years)
- Lifetime carbon savings (tCO_2)

1.3 Assumptions

This section details the assumptions used in the analysis.

1.3.1 Energy efficiency cost optimisation model

- The energy efficiency cost data is Carbon Trust proprietary data, incorporating a combination of inputs including Spon's Architects' and builders' price book 2021[2], in-house market research and published construction market data.
- The Spon's Architects' and builders' price book data was converted into a usable format using EPC building dimensions for the cost optimisation
- The following assumptions were made to inform the application of the cost data to specific property types:
    - Pitched loft insulation happens at the joists (270mm)
    - Insulation on suspended floors is assumed to be "easy access"
    - Filled cavities are assumed to be fully insulated
    - Unfilled or partially filled cavities receive cavity wall insulation
    - Pre-1930s solid walls receive 100mm internal wall insulation
    - Post-1930s solid walls receive 200mm external wall insulation, with a higher rate for flats.
- Pitched roofs include properties with roof rooms which account for a small percentage (<10%) of pitched roofs. Roof rooms are more challenging to insulate as it is more disruptive for the occupant – additional costs have not been considered in this analysis

1.3.2 Cost benefit analysis

The cost benefit analysis included the following assumptions:

- Energy efficiency measures are only installed alongside the installation of an air-source heat pump, or in properties with a heat pump already installed. The cost and viability of installing a heat pump has not been assessed – it is assumed that all sub-archetypes can install one allowing a comparison

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[2] Spon's Architects' and builders' price book is a paid-for dataset

to be made between a property with and without energy efficiency measures.

- The heat demand profile used in the analysis is based on 2018 weather conditions. Three individual profiles representing an intermediate day, a winter day, and an extreme winter day (Beast from the East) were applied across the whole year to generate annual energy consumption profiles.
- The average lifetime of the packages of energy efficiency measures being installed is assumed to be 30 years.
- Annual energy costs were charged on a fixed p/kWh basis, with no time of use of elements or flexibility actions considered. Standing charges have not been included in the calculation of energy costs.
- A base 2022 domestic electricity retail price of 67p/kWh, the current energy price cap, has been assumed[3].
- Energy prices are currently unusually high and would give a potentially inaccurate view of the annual cost savings expected over the 30-year period being considered. Therefore, the annual percentage change figures calculated from the reference scenario of the BEIS Energy and Emission Projections 2022[4] have been applied. Beyond 2040, prices are assumed to be constant in the absence of other underlying data points to justify a change.
- A 3.5% discount rate has been used, taken from HM Treasury Green Book 2022[5].
- Inflation is excluded from this analysis. All prices are in 2022 values.
- Average grid carbon emission factors and carbon prices have been sourced from Greenhouse gas reporting: conversion factors, 2021, Table 1: Electricity Emission Factors to 2100[6]

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[3] Latest energy price cap announced by Ofgem | Ofgem

[4] Energy and emissions projections: 2021 to 2040 - GOV.UK (www.gov.uk), Annex M

[5] HM Treasury Green book 2022, p46

[6] Greenhouse gas reporting: conversion factors 2021 - GOV.UK (www.gov.uk)

1.4 Current State of Thermal Fabric in Homes on NGED's Network

A database of one million homes from across the NGED license area was compiled to provide a representative sample on which to base the analysis. There are approximately 7.3 million homes connected to the network, meaning this sample housing data of one million homes represents 14% of homes on NGED's network.

This section provides details on:

- The distribution of dwellings by energy efficiency category
- Details on the types of roof, wall, floor and glazing currently present in the NGED building stock

1.4.1 Medium and low efficiency homes are dominant in NGEDs license area

Based on the categorisation approach described in section **Error! Reference source not found.**, 85% of homes in the NGED license area have potential for additional improvements to building fabric that could lead to a reduction peak heat demand.

Almost half the homes are classed as 'medium' thermal efficiency (Figure 3). This means they have lower or equal HTC to an equivalent version of the property with double glazing, roof insulation, and no floor or wall insulation, and could benefit from more fabric improvements. A further 37% of homes are of a low energy efficiency standard, with only very limited levels of insulation present. Only 15% of homes have high levels of building fabric, largely consisting of new-build homes and a small number of retrofits.

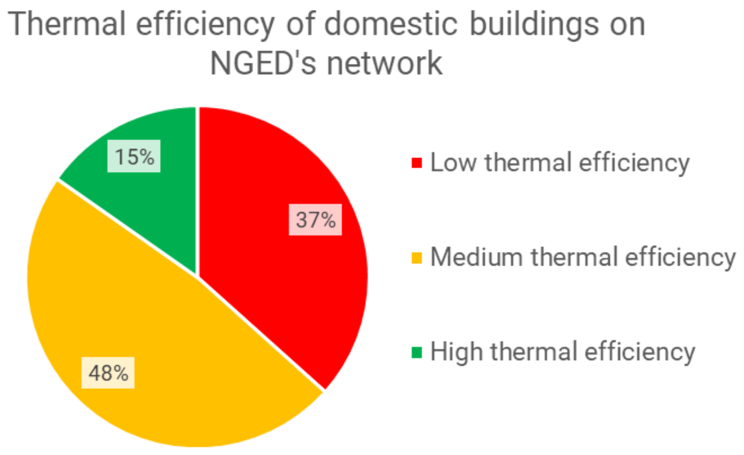

Figure 3 Distribution of dwellings connected to NGEDs network by thermal efficiency category

1.4.2 Roof types and current insulation levels

98% of dwellings in NGED’s license area have pitched roofs, making loft insulation the most suitable type of roof insulation to considered. The remaining dwellings have flat or thatched roofs and upgrades to these have not been considered further due to their very low frequency reducing the impact that any improvements could have on network loads.

Year of update to building regulation	Depth of loft insulation recommended
1965	25mm
1975	60mm
1985	100mm
1990	150mm
1995	200mm
2002	250mm
2003	270mm

Table 1. Depth of loft insulation recommended by Building Regulations

Loft insulation is present in properties in the sample building stock to a wide variety of depths as building regulations and industry recommendations have evolved over time, with thicker levels of insulation resulting in reduced heat loss (Table 1). To account for this variation in our analysis, the amount of loft insulation has been separated into three depths: below 50mm, 50-100mm, and above 100mm. These bands have been chosen for the following reasons:

- In NGED’s license area, dwellings are weighted to older age bands and hence typically lower depths of loft insulation
- The addition of insulation to properties below 50mm has the greatest impact on heat loss per mm installed
- Beyond 100mm, the proportional reduction in heat loss diminishes, reducing the cost effectiveness of improvements

In NGEDs license area, only 16% have below 50 mm of loft insulation and a further 40% have between 50-100mm, showing there is still significant potential for further improvements to be made (Figure 4).

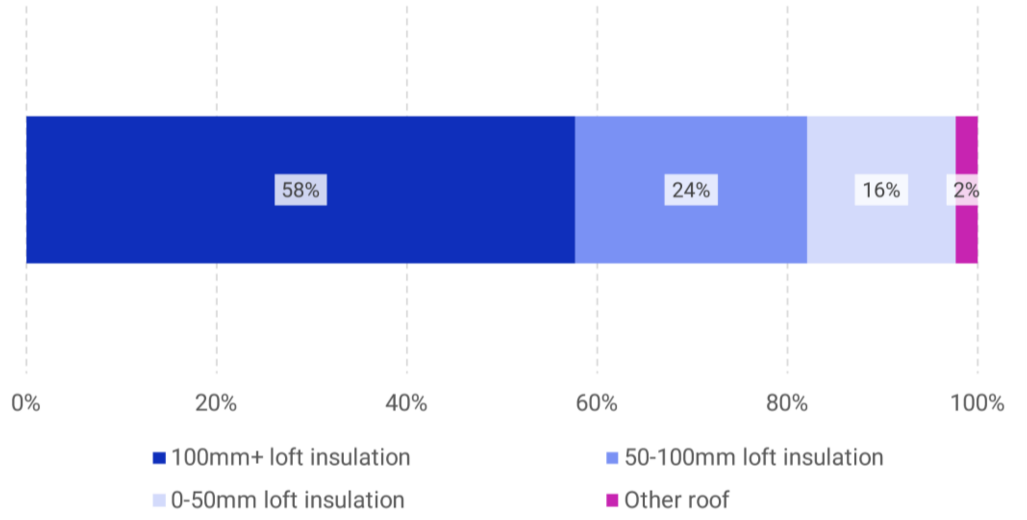

Figure 4. Summary of roof types and level of loft insulation on homes connected to NGED’s network

1.4.3 Wall types and current insulation levels

The walls of a dwelling often have the largest area of all the other insulation categories and therefore more heat is lost through walls as a result. The two main categories of wall are solid wall, typically made from sandstone, granite, timber, or brick, and cavity wall, normally made from two layers of brick or concrete blocks.

The types of wall insulation that can be applied vary between the two categories, with different costs and installation barriers associated with each. For example, uninsulated solid walls are on average 20 times more expensive to insulate than cavity walls and often is associated with either loss of floor area or the external aesthetic of the property.

In NGED's licence areas, there is roughly an even split between properties with cavity walls and properties solid walls, with solid walls predominantly found in homes built before 1930. Due to the challenges associated with insulating solid walls, only 19% of the solid wall properties have been insulated, compared to 80% of cavity wall properties (Figure 5). This means that there is still a large number of homes where insulation could be added to reduce heat demand and hence network load. However, these are typically the harder to treat homes.

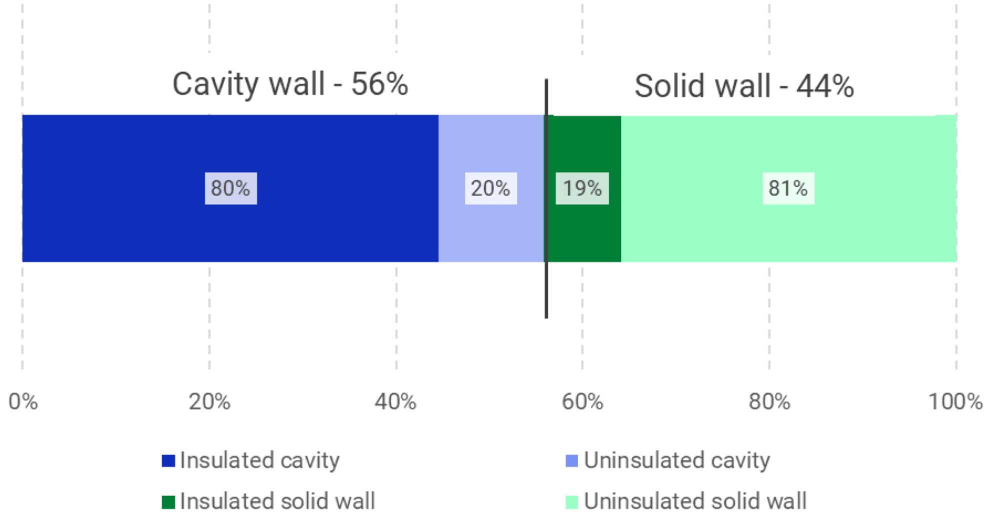

Figure 5. Summary of wall types and level of wall insulation in homes connected to NGED's network

1.4.4 Floor types and insulation

The two main categories of floor type are solid and suspended, with installation of insulation resulting in a similar reduction in heat loss in both of these categories. However, suspended floors are typically easier to access and hence cheaper and less disruptive for insulation to be installed.

In NGED's license area, there is a roughly even split of solid and suspended floors them amongst the housing stock, with similar levels of insulation present in each floor type. Across the housing stock, 89% of homes have uninsulated floors, resulting in significant opportunity for improvements to be made (Figure 6).

The following assumptions have been made:

- Top and mid- floor flats not included in totals for floor insulation as they are above heated spaces
- Floor type and insulation refers to the bottom floor of a property as higher floors are assumed to be above heated spaces

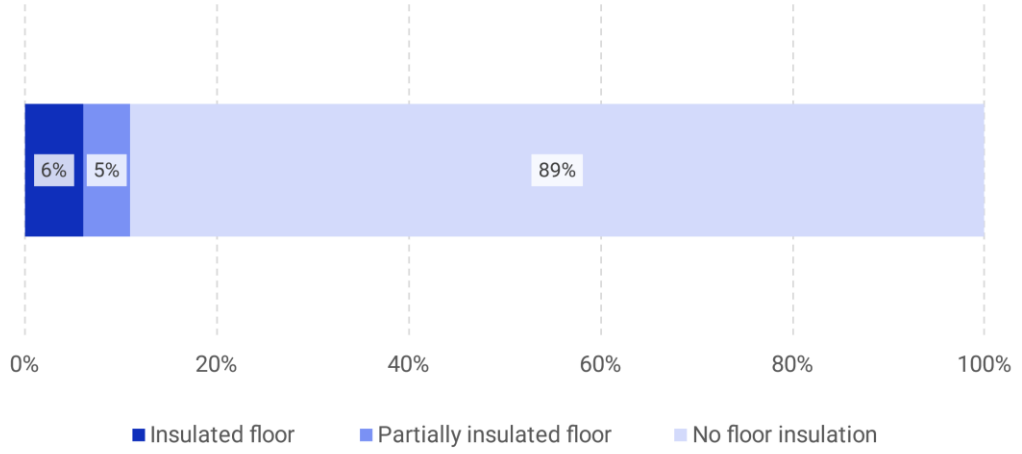

Figure 6. Summary of floor insulation in homes connected to NGED's network

1.4.5 Window glazing

There are three key types of window glazing: single, double and triple. There are large differences in heat loss between single and double glazing, leading to this upgrade being perceived as a low regrets option for homeowners due to the relatively low cost for improved comfort levels. However, there is a smaller improvement between double glazing and triple glazing, leading to a low retrofit of double glazing to triple glazing unless windows need to be replaced for non-performance related reasons.

These trends are consistent with those found in the NGED license area, where 95% of homes have double glazing, 4% have single glazing and less than 1% have triple glazing. Due to the high prevalence of double glazing already in the building stock, there is low opportunity for cost-effective improvements in this area to reduce heat demand.

1.5 CBA Results for Applying Energy Efficiency Measures at a Household Level

The next section of this report examines the costs and benefits of applying energy efficiency measures to the most common house archetypes connected to NGED's network. Benefits to the network operator are very location specific as they are highly dependent on the exact building stock connected, the existing utilisation of the network assets and the cost to upgrade the network asset. Therefore, it is not possible to attribute specific cost savings to each sub-archetype. Instead, this house-level analysis aims to inform NGED on:

1. Where there is significant potential to reduce the electrical load from specific sub-archetypes during peak times
2. The prevalence of each sub-archetypes connected to NGED's network
3. The relative cost effectiveness of different individual and combination of measures in reducing peak loads on a £capex per kW reduction basis
4. The payback period and NPV for homeowners in making the investment in different levels of energy efficiency measures, which will provide an indication of the levels of energy efficiency investment NGED should expect in the absence of further interventions.

Network specific savings for three case study areas will be assessed in Section 2.

The house-level CBA was completed on the top 100 most common sub-archetypes. Details of these archetypes are shown in full in Appendix 3.1. To analyse the cost-optimal fabric measures for each of the top 100 sub-archetypes, a total of 116 possible upgrades have been assessed, which include:

- The cost-optimal route to upgrade a property with 'low' thermal efficiency to both 'high' and 'medium', included as two separate packages of measures
- The cost-optimal route to upgrade a property with 'medium' thermal efficiency to 'high', included as a single package measure
- Properties with 'high' thermal efficiency were omitted as they are assumed to not require any additional upgrades

We summarise findings for the top ten sub-archetypes by prevalence and top ten sub-archetypes for upgrade by cost effectiveness in reducing peak loads. When considering the financial viability of upgrades, we consider the following costs and benefits:

- Costs
  - CAPEX of energy efficiency measures (£)
- Benefits
  - Reduction in peak load per house ((£capex)/(kW reduction in peak load from sub-archetype))
  - Electricity bill savings (£/annum)
  - Carbon savings[7]

Conclusions on financial viability for homeowners to invest in EE measures have been made based on the payback period and the NPV of the investment over the 30-year lifetime. According to English Housing

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[7] Annual projected carbon prices sourced from: Greenhouse gas reporting: conversion factors 2021 - GOV.UK (www.gov.uk)

Survey[8], homeowners live in their home for an average of 17.8 years. Given that homeowners could currently be any number of years into their ownership, a cautious assumption is that payback times of under half the ownership period would be feasible for the average homeowner, especially as energy efficiency investments add value to the property. Therefore, in general we can assume that:

- Payback times below 5 years are affordable for a homeowner
- Payback times between 5 and 20 years would require a subsidy or grant to make it attractive for a homeowner, given the disruption of installation
- Payback times higher than 20 years are difficult to implement

The NPV is a metric used to identify and compare the attractiveness of different investments by looking at all the financial savings or revenue you expect to make from an investment and translating those returns into the pound value of the present day. The analysis takes into account the variability in returns over the lifetime of the project, as energy prices and carbon prices vary and the inherent time value of money, the concept that financial costs and benefits are worth more now than the promise of costs or benefits in the future. A positive NPV indicates an attractive investment.

1.5.1 Loft insulation is the single most cost-effective measure for reducing house peak loads

Loft insulation, cavity wall insulation, and double glazing are the most cost-effective measures in reducing heat loss, all costing under £7 per Watt reduction in heat loss for a typical semi-detached building (Table 2). Whilst this figure will vary for different house types, the hierarchy of measures remains consistent. Buildings where these measures are not already present should therefore be a priority for upgrade and relevant sub-archetypes in the NGED license area. However, on NGED's network the opportunities for further installation of these measures is limited, where only 16% of domestic dwellings have loft insulation below 50mm, 11% have unfilled cavity walls, and 4% are single glazed. Other more expensive measures also need to be considered to in more prevalence sub-archetypes on the NGED network.

Table 2. Table of average cost and impact on building performance for each type of energy efficiency measure applied to a semi-detached house. *Temperature assumptions: 19°C room temperature, -1.8°C lowest winter temperature, 10.8°C average ambient temperature

Rank	Energy Efficiency Measure	Property age	Average cost	Cost / reduction in heat loss £/ (W/K)	Cost / reduction in heat loss £/ W *
1	Loft insulation	after 1930	£964	£20.99	£1.01
2	Loft insulation	before 1930	£1,111	£22.64	£1.09
3	Cavity wall insulation	after 1930	£1,363	£40.41	£1.94
4	Double glazing	after 1930	£10,696	£96.69	£4.65
5	Double glazing	before 1930	£14,758	£127.37	£6.12
6	Solid wall insulation	before 1930	£30,692	£180.45	£8.68
7	Suspended floor insulation	before 1930	£3,804	£87.02	£10.61
8	Solid floor insulation	before 1930	£5,114	£121.81	£14.86
9	Triple glazing	before 1930	£20,380	£319.81	£15.38
10	Suspended floor insulation	after 1930	£3,134	£152.50	£18.60
11	Solid wall insulation	after 1930	£26,857	£497.74	£23.93

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[8] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/817623/EHS_2017-18_Home_ownership_report.pdf

12	Triple glazing	after 1930	£14,771	£578.61	£27.82
13	Solid floor insulation	after 1930	£4,445	£236.68	£28.86

1.5.2 Larger dwellings have greatest potential for peak load reduction

Larger homes cost more to upgrade to higher levels of thermal efficiency but do have the potential for yielding higher reductions in network load per pound spent. All sub-archetypes where peak load reductions of greater than 1kW are possible as a result of installation of energy efficiency measures are detached or semi-detached homes. To achieve these savings, a combination of measures is likely to be required.

The exact financial benefit of peak load savings for the network operator is highly location specific and cannot be specified for individual house sub-archetypes.

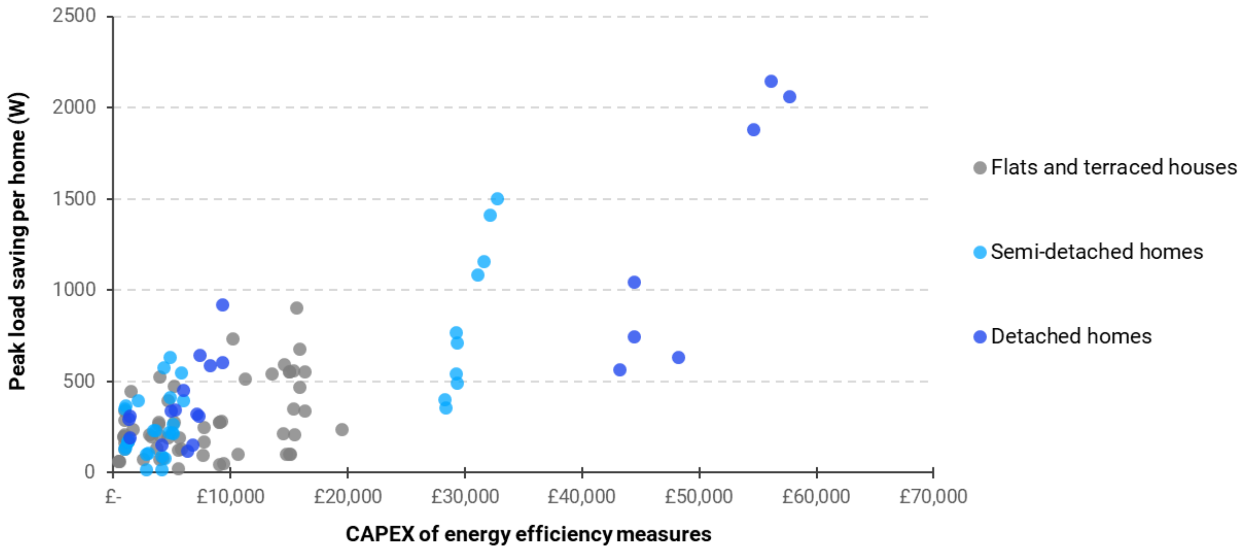


Figure 7. Peak load saving per home for the 116 retrofit options on homes connected to NGED's network, highlighting detached and semi-detached homes

1.5.3 High levels of peak load reduction are achieved through combinations of measures being installed

There is a strong correlation between the type of insulation measure and the impact on peak load. Single measures achieve a maximum reduction in peak load of 500W per home, and multiple measures can achieve up to 2,000W per home. Packages of measures that include solid wall insulation achieve the highest peak load savings, especially on larger properties as walls cover a larger area and have more of an impact on building heat loss. However, these measures come at high cost, with solid wall insulation alone costing between £10,000 and £30,000 depending on the size of home and type of façade. This measure is relevant for 36% of homes on NGED's network, indicating the size of capital required for widespread uptake.

The large spread of CAPEX for packages of measures that include solid wall and floor insulation is due to the complexity of installing these measures in different types of property. Suspended floors and internal solid wall insulation on smaller properties are cheaper than solid floor and external solid wall insulation on larger properties or flats with complex façades.

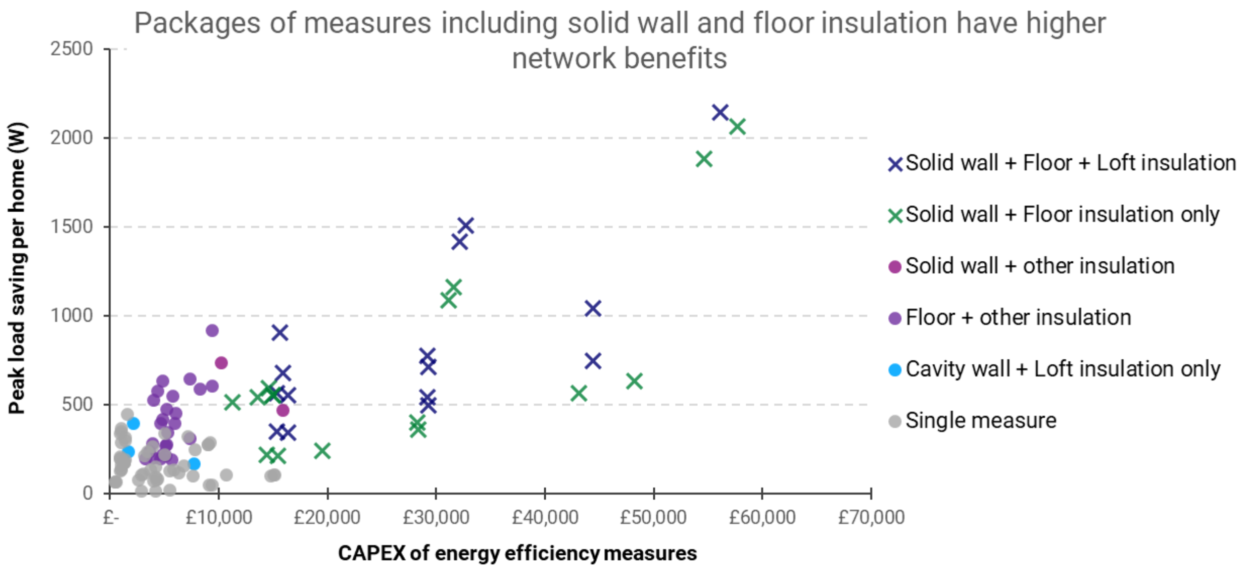


Figure 8. Peak load saving per home for the 116 retrofit options on homes connected to NGED's network, highlighting the most impactful types of energy efficiency measure

1.5.4 Financial viability analysis for the 100 most common sub-archetypes connected to NGED's network

Using the 100 most common sub-archetype (which represent 88% of homes connected to NGED's network) as a proxy to represent all homes, we can estimate the total number of sub-archetypes that have a retrofit option with a positive 30-year NPV. 34% of the top 100 sub-archetypes have a positive NPV and a positive payback, which corresponds to 30% of all homes in NGED's licence areas. The breakdown in terms of payback time is as follows:

- 5% have a discounted payback time of under **5 years** – a viable investment for homeowners
- 11% have a discounted payback time of **5-10 years** – a viable investment for homeowners with a grant/subsidy, or for wealthy homeowners
- 9% have a discounted payback time of **10-20 years** – a viable investment for homeowners with a grant/subsidy
- 5% have a discounted payback time of **20-30 years** – difficult investment for homeowners, would likely need an additional funding source stacked with a grant/subsidy
- The remaining 70% of homes have a discounted payback time of **over 30 years –** not a viable investment, however, this analysis looks at packages of measures that vastly improve the performance of a building and not small bespoke efficiency improvements, so other options are available for these properties.

Financial viability is highest for upgrades including loft insulation and lowest for solid wall insulation

When these findings are broken down by measure, almost all cost-optimal fabric improvements with a positive 30-year NPV are found to include loft insulation. Loft insulation upgrades are divided into two types:

- Adding insulation to lofts with under 50mm of insulation
- Adding insulation to lofts with between 50-100mm of insulation

According to the EPC records, 40% of homes in the one million homes sample have below 100mm loft insulation. Generally, the upgrades with better 30-year NPV currently have loft insulation below 50mm, as the higher improvement in building performance leads to lower consumer bills.

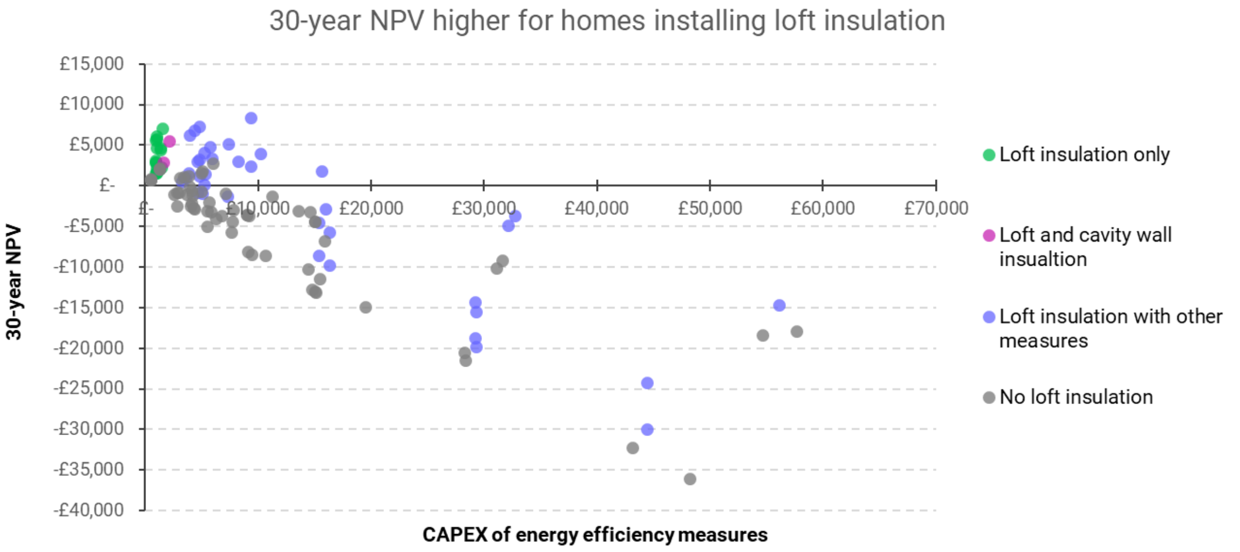


Figure 9. 30-year NPV for the 116 retrofit options on homes connected to NGED's network, highlighting measures that include loft insulation

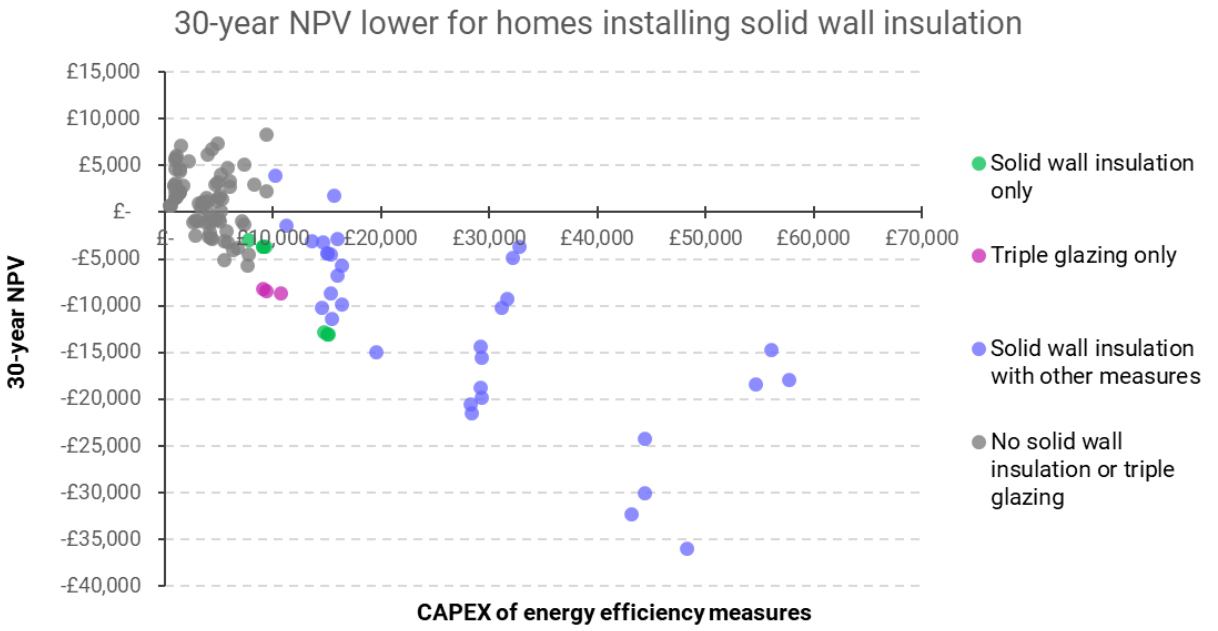


Figure 10. 30-year NPV for the 116 retrofit options on homes connected to NGED's network, highlighting measures that include solid wall insulation and triple glazing

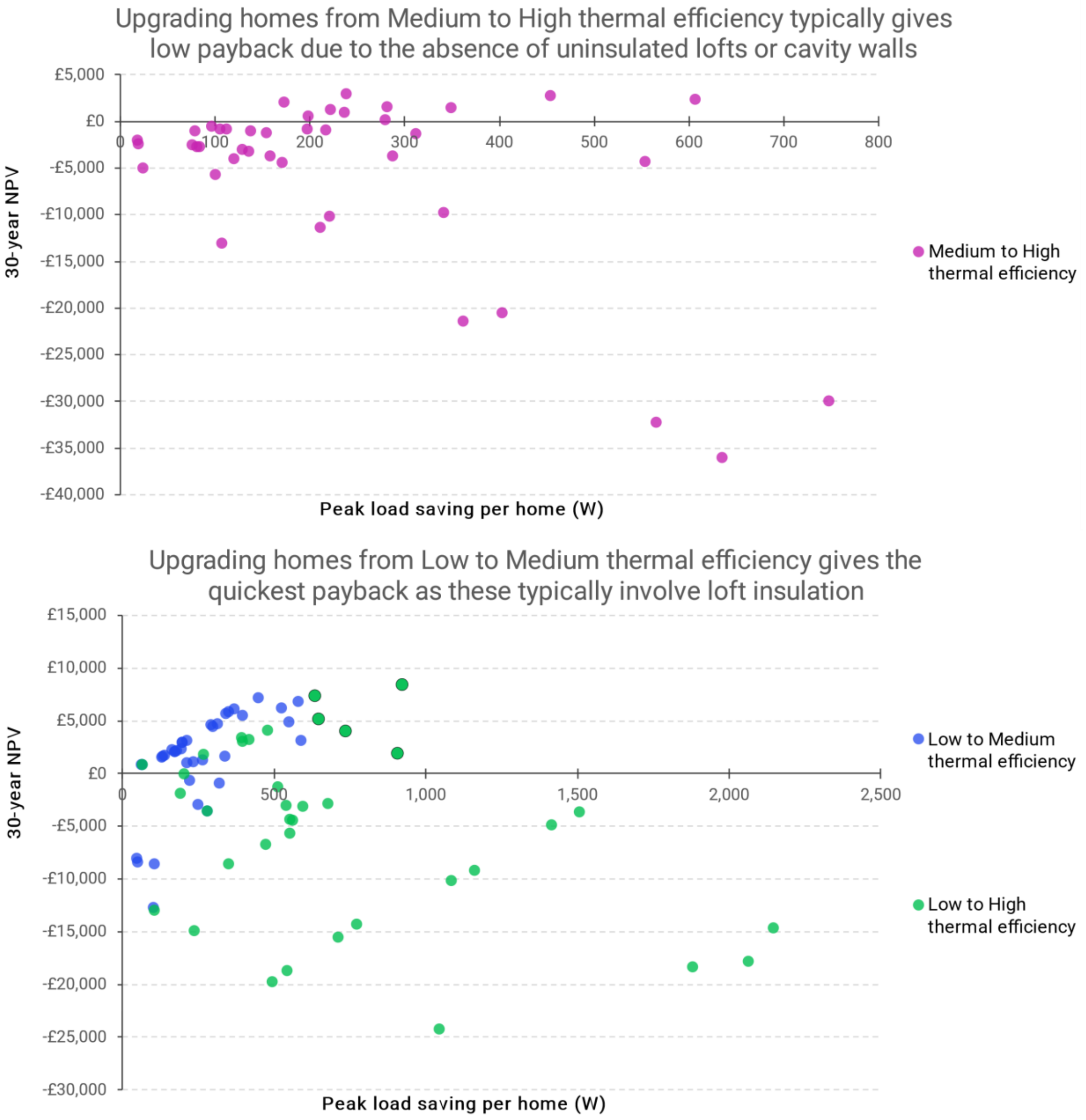
Conversely, almost all cost-optimal fabric improvements with a 30-year NPV less than -£5,000 include solid wall insulation. Solid wall insulations have a significant effect on building performance but are by far the most expensive intervention – all packages of measures above £15,000 involve solid wall insulation.

Triple glazing comes out as more favourable than solid wall insulation only in some mid-floor flats (pink dots) as solid wall insulation for individual flats is more complex and incurs a higher cost. However, this analysis does not consider measures applied to whole blocks of flats, which may make solid wall insulation a more viable option than triple glazing in these cases.

There are fewer financially viable solutions when upgrading homes from medium to high thermal efficiency

Homes classed as having ‘medium’ thermal efficiency typically have the lowest capex measures already installed, such as cavity wall and loft insulation. Therefore the 30-year NPV for these properties tends to be low, with a maximum payback of £3,000 and a minimum of -£35,000. Conversely, the cost optimal packages of measures available for properties with low thermal efficiency tend to have greater finanical viability, with NPVs ranging between -£25,000 and £8,000.

Figure 11 compares interventions on the same subset of sub-archetypes. Properties with low thermal efficiency typically have more uninsulated lofts and unfilled cavity walls. Insulation of these components are a cost-effective measure and tends to have a positive payback. Going further to insulate solid walls or floor worsens the business case but increases the peak load saving per home.


Upgrading homes from Medium to High thermal efficiency typically gives low payback due to the absence of uninsulated lofts or cavity walls

Upgrading homes from Low to Medium thermal efficiency gives the quickest payback as these typically involve loft insulation

Figure 11. Two scatter charts that show the difference in terms of CAPEX and network benefits for packages measures that (top) upgrade a home from medium to high thermal efficiency; (bottom) upgrade a home from low to medium thermal efficiency and from low to high thermal efficiency

The effect on peak load as a result of upgrading from low to medium thermal efficiency has a maximum of 600W reduction per house, which has a similar network impact as upgrading from medium to high thermal efficiency, which has a maximum of 750W peak load reduction.

Upgrading from low to high thermal efficiency has a much greater peak load reduction on average (up to 2.2 kW). There are five cases in the 100 most common sub-archetypes where upgrading from low to high thermal efficiency has a positive 30-year NPV while delivering above 500W peak load reduction per home. These are summarised in Table 3 below. In these cases, there is possibly a business case for DNO investment into additional, more costly fabric improvements for homeowners that want to insulate their homes, which are unlikely to occur in the absence of additional funding. However, this is highly dependent on the type of home and the area of network it is connected to. Additionally, the sub-archetypes relevent to these cases represent under 5% of the housing stock connected to NGED's network. High densities of these homes in specific locations would be required.

Table 3. Table of the five best low to high thermal efficiency upgrades in terms of 30-year NPV and peak load saving

Sub-archetype	Archetype description	% Of homes on NGED network	Cost optimal EE packages of measures	CAPEX	Peak load saving per house (W)	30-year NPV	Discounted payback years
46-8	Detached house, after 1930	0.2%	Solid floor, loft and cavity wall insulation	£9,319	920	£8,435	11
17-2	Mid-terrace House, before 1930	3.0%	Suspended floor, loft and solid wall insulation	£15,591	906	£1,879	25
49-2	Top floor flat, before 1930	0.7%	Loft and solid wall insulation	£10,176	735	£3,997	18
45-30	Detached house, after 1930	0.3%	Suspended floor, loft and cavity wall insulation	£7,340	648	£5,149	13
13-8	Semi-detached house, after 1930	0.4%	Suspended floor, loft and cavity wall insulation	£4,823	633	£7,381	6

1.5.5 Financial viability of cost-optimal upgrades to the ten most common sub-archetypes connected to NGED's network

Table 4. Table of cost-optimal packages of energy efficiency measures and their financial viability applied to the top 10 most frequently occurring sub-archetypes connected to NGED's network. Note that the 3rd and 8th most common sub-archetypes are 'high' thermal efficiency and are therefore omitted from the table, and that the 4th and 5th most common sub-archetypes are 'low' thermal efficiency and have two rows for upgrading to 'medium' and 'high' efficiency.

Rank	Sub-archetype	% Of homes on NGED network	Thermal category change	Cost optimal EE package of measures	CAPEX	Peak load reduction per house (W)	CAPEX / Peak load saving(£/W)	Discounted payback years	Payback years using current day price
1	14-45	7.20%	Medium to High	Solid floor insulation	£4,104	728	5.6	30+	23
2	46-45	4.49%	Medium to High	Solid floor insulation	£6,293	474	13.3	30+	30+
4	17-2	3.02%	Low to Medium	Suspended floor and loft insulation	£3,932	2,083	1.9	6	6
4	17-2	3.02%	Low to High	Suspended floor, loft and solid wall insulation	£15,591	3,594	4.3	25	18
5	17-26	2.86%	Low to Medium	Suspended floor insulation	£3,093	847	3.7	19	15
5	17-26	2.86%	Low to High	Suspended floor and solid wall insulation	£14,598	2,359	6.2	30+	25
6	14-33	2.83%	Medium to High	Solid floor and loft insulation	£4,762	1,227	3.9	21	16
7	68-9	2.80%	Medium to High	Solid floor insulation	£5,487	507	10.8	30+	30+
9	30-45	2.55%	Medium to High	Solid floor insulation	£3,981	298	13.3	30+	30+
10	13-45	2.54%	Medium to High	Suspended floor insulation	£2,820	415	6.8	30+	28

Many of the most common house sub-archetypes have negative 30-year NPV, making the case for investment difficult. The two common sub-archetypes with 'low' thermal efficiency (17-2 & 17-26) have viable economic cases for upgrading. In particular, upgrading 17-2 (3% of housing stock) to medium thermal efficiency has a large 30-year NPV of £6,000 while a peak load saving of 2kW and upgrading to high thermal efficiency pays back less (£1,900) but has better network benefits (3.5kW peak load saving).

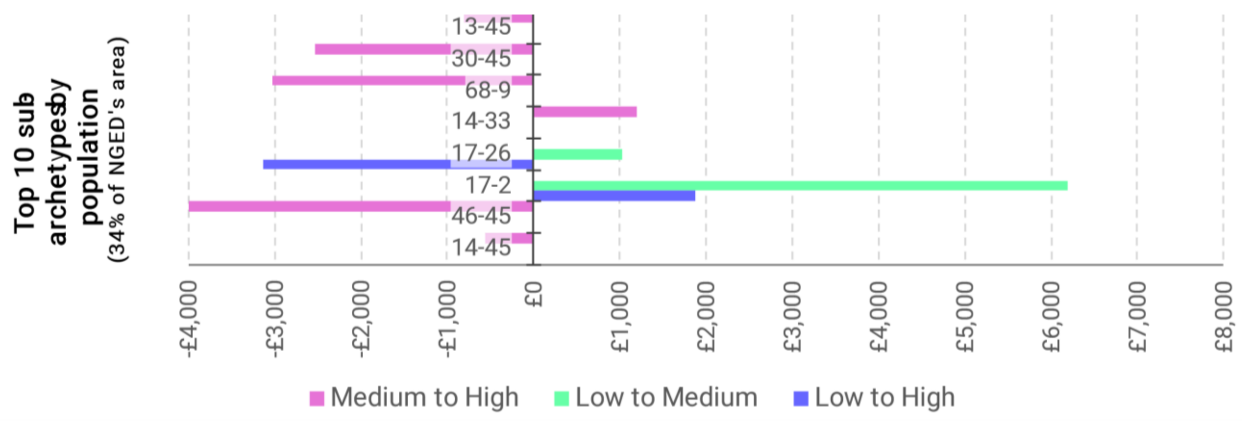


Figure 12 NPV of top ten sub-archetypes by prevalence

1.5.6 Identification of the ten most cost-effective sub-archetypes to upgrade

Table 5 shows the ten sub-archetypes where the upgrades identified have the greatest impact on network loads per pound spent. In all cases, these sub-archetypes are currently of low thermal efficiency. They are roughly evenly split between semi-detached, detached and terraced houses and are typically built after 1930. Collectively, they equate to approximately 5% of the homes connected to NGED's network, which is approximately the same as the 2nd most prevalent sub-archetype individually in terms of scale.

They are most cost-effectively upgraded to medium efficiency through the installation of loft insulation. Loft insulation is a relatively cheap intervention that offers between 200 and 500 Watts reduction in peak load per house when installed in properties with less than 50mm of loft insulation currently in place. Installing additional loft insulation in these properties has a payback of between 1 and 3 years and is therefore considered a very low regrets measure. Homeowners would not need additional support to fund this as they benefit from cheaper bills to justify the investment.

Approximately 16% of homes connected to NGED's network can achieve a payback of under 3 years from installing loft insulation, which equates to approx. one million homes on NGED's network. This could result in a combined peak load saving of between 200 and 500 MW across NGED's network.

In general, a fabric improvement CAPEX per Watt of peak load saved less than £20/Watt will pay back within the average 30 year lifetime of these measures. Therefore, a package of measures that includes more cost optimal interventions e.g. loft or cavity wall insulation, will likely be much lower than £20/Watt.

Table 5. Table of cost-optimal packages of energy efficiency measures and their financial viability applied to the top 10 most cost-effective sub-archetypes to upgrade based on network impact

Rank	Sub-archetype	% Of homes on NGED network	Category change	Cost optimal EE packages of measures	CAPEX	Peak load saving per house (W)	CAPEX / Peak load saving (£/W)	Discounted payback years
1	25-7	0.36%	Low to Medium	Loft insulation	£942	343	2.75	1.27
2	10-7	0.42%	Low to Medium	Loft insulation	£969	353	2.75	1.27
3	9-8	1.12%	Low to Medium	Loft insulation	£1,020	371	2.75	1.27
4	18-2	1.09%	Low to Medium	Loft insulation	£977	291	3.35	1.83
5	49-2	0.67%	Low to Medium	Loft insulation	£1,505	448	3.36	1.84
6	30-7	0.18%	Low to Medium	Loft insulation	£881	199	4.42	2.52
7	41-9	0.18%	Low to Medium	Loft insulation	£1,317	298	4.42	2.52
8	26-7	0.19%	Low to Medium	Loft insulation	£939	212	4.43	2.52
9	46-8	0.16%	Low to Medium	Loft insulation	£1,393	315	4.43	2.53
10	30-9	0.19%	Low to Medium	Loft insulation	£881	199	4.43	2.53

The top 10 most cost-effective upgrades on a £/kW load reduction basis, can achieve NPVs of between £3,000 and £7,000 over 30 years, indicating an attractive investment in all cases.

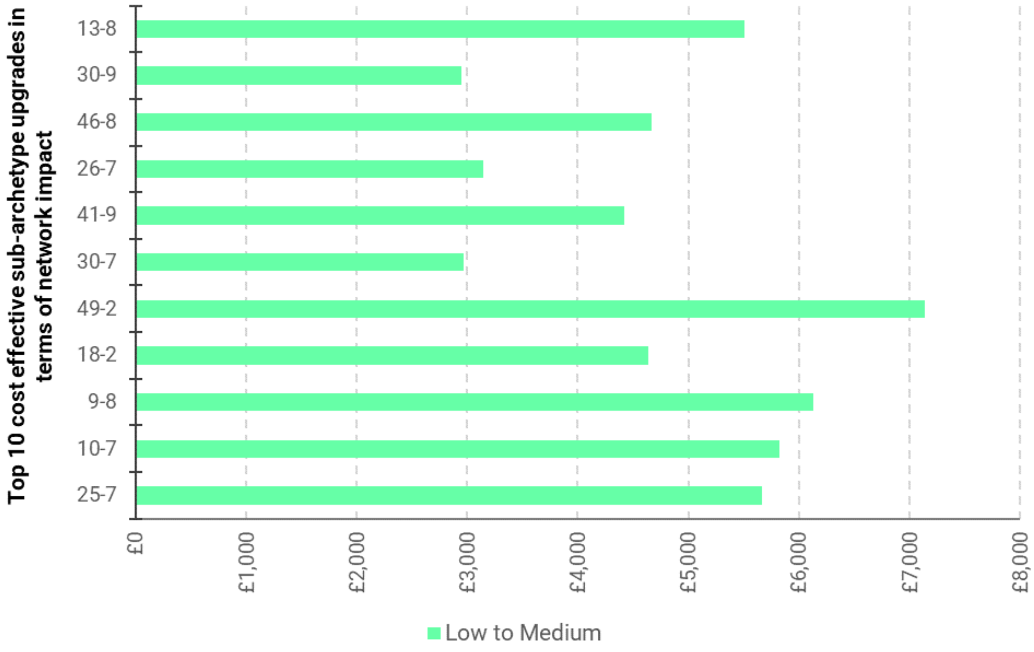


Figure 13. 30-year NPV for the top 10 most cost-effective sub-archetypes to upgrade

1.6 Conclusions and Limitations

Conclusions

Three main conclusions can be drawn from our analysis to inform the types of homes that should be the focus of any retrofit schemes being considered by NGED:

- Loft insulation, cavity wall insulation, and double glazing are the most cost-effective measures for reducing peak loads on the network on a £capex per kW reduction in peak load basis, and should be the focus of any retrofit scheme being considered by NGED.
- The effect on house-level peak loads as a result of upgrading from low to medium thermal efficiency has a maximum of 600W reduction per house. This is a similar impact as upgrading from medium to high thermal efficiency, which has a maximum of 750W peak load reduction, but the latter comes at much higher capital cost.
- The highest load reductions can be achieved through upgrading a detached or semi-detached house from low to high thermal efficiency. They include more than one fabric measure and can achieve up to 2200W reduction in peak load. However, these measures come at significant capital cost, often involving measures such as solid wall insulation.

The type of support required for incentivising homeowners to upgrade their properties will vary based on the types of upgrade required. For example, loft insulation is a relatively cheap fabric measure that offers a 200 – 500W reduction in peak load per house with for properties that currently have less than 50mm of loft insulation. Installing additional loft insulation in these properties has a payback of between one and three years, low enough that additional capital funding should not be required to incentivise uptake. Therefore, an awareness campaign may be a more suitable intervention of NGED or other stakeholders in this case.

30% of all homes in NGED's licence areas have a cost optimal retrofit option with a positive net present value. The breakdown in terms of payback time as a percentage of homes in the license area is:

  - 5% have a discounted payback time of under 5 years
  - 11% have a discounted payback time of 5-10 years
  - 9% have a discounted payback time of 10-20 years
  - 5% have a discounted payback time of 20-30 years

These results are sensitive to the wholesale cost of electricity. When comparing BEIS price projections to current day prices, payback times of 20-25 years are brought down to 15-20 years.

Limitations to this analysis

- The package options assessed in this report are the cost optimal routes to upgrade the most common house types on NGED’s network to a lower HTC band defined by the high, medium and low classification of thermal efficiency. In reality, other solutions are possible for the types of homes assessed.
- The scenario model selects the cost optimal combination of measures to upgrade an archetype, irrespective of the heat technology installed. It is possible that in a few cases, the type of new or existing heat technology will influence the optimal energy efficiency measures being installed e.g. if pipework needs upgrading in a wall or floor then the property owner may choose to insulate as well.
- The EPC records used to characterise the building stock on NGED’s network are not may not always be accurate for the following reasons:
    - EPC records have been collected since 2008. Properties are not required to update their EPC if they install fabric improvements, but sometimes do. EPCs are only required when a property is sold
    - Surveyor errors – it is known that due to access restrictions, surveyors will not always check some features of a building e.g. the loft, so will make an assumption instead

2 Network-Level Cost-Benefit Analysis of Energy Efficiency Measures

2.1 Objectives of the Network-Level Cost-Benefit Analysis

- To apply the cost-optimal energy efficiency measures examined in section 1 of this report to three pre-selected case study areas on NGED's network. Aggregating house profiles to substation and feeder areas enables the investigation of network impacts by overlaying future changes in electricity profiles (as a result of heat pumps and energy efficiency) with cable load thresholds.

- To produce four energy efficiency scenarios for two benchmark years (2030 and 2050) in each of the case study areas. The four scenarios are linked to DFES rates of heat pump installations to ensure consistency with other NGED studies on future energy scenarios. The scenarios include two extreme cases (no energy efficiency and maximum energy efficiency (high)) and two more realistic middle cases (low and medium uptake of energy efficiency):
    - No energy efficiency
    - Low uptake of energy efficiency
    - Medium uptake of energy efficiency
    - High uptake of energy efficiency

- To analyse the costs and benefits to the network in the three case study areas as a result of energy efficiency measures. The analysis focuses on network reinforcement costs at the Low Voltage (LV) level (i.e. 11kV and 6.6kV). Spending more on energy efficiency in homes can defer network reinforcement costs which could benefit the DNO.

- To provide recommendations to NGED about how best the DNO should be involved with energy efficiency schemes. This was done by assessing the impact of investing in energy efficiency on network costs and whether unsubsidised homeowner investments can alone have an impact.

2.2 Methodology

2.2.1 Case study area selection

In the initial scoping phase of the project, the project partners agreed on three case study areas on NGED's network to test the profile and scenario models. The three feeder areas were selected based on the following:

- High proportion of domestic buildings
- High DFES heat pump projection
- Availability of network data
- Good EPC coverage
- Proximity to a weather station

Primary substation / ESA	Feeder name	Number of secondary substations	Number of dwellings
Axbridge	180017/0001	2	252
Mackworth	870038/0010	17	3,362
Withycombe Raleigh	310037/0024	13	1,843

For each of the 32 substations, polygons were drawn around the boundaries of their cable files using GIS which enabled address UPRNs to be mapped using a proximity-based analysis.

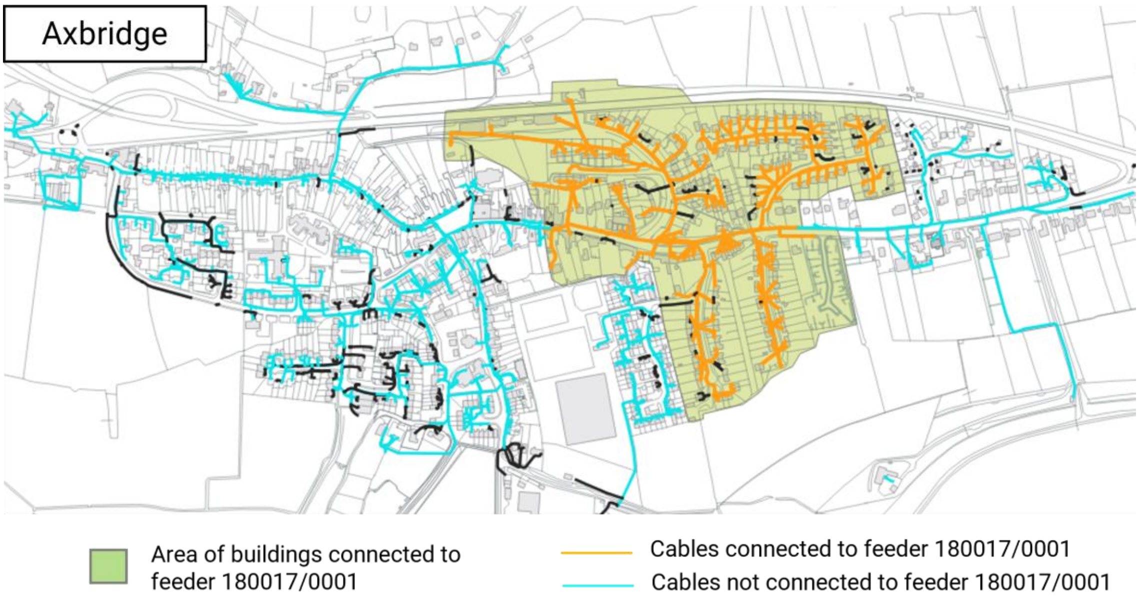


Figure 14. Image of GIS proximity analysis showing how network cable files were used to draw polygons (shown in green) to map buildings connected to feeder 180017/0001

We used GIS to allocate a secondary substation to each building in the building stock database through a proximity-based analysis of network cable files. GHD provided Carbon Trust with the number of MPANs in each substation area which was used to verify the results of this analysis.

2.2.2 Energy Efficiency scenarios

Rates of installations

The rate of fabric retrofit installations was determined by linking the rate of interventions to the distribution future energy scenarios (DFES) rates of heat pump installations. This top-down approach ties the energy efficiency scenarios to the DFES scenarios to achieve one of the core objectives of this modelling exercise – to update the DFES scenario assumptions on demand reduction from energy efficiency in domestic homes.

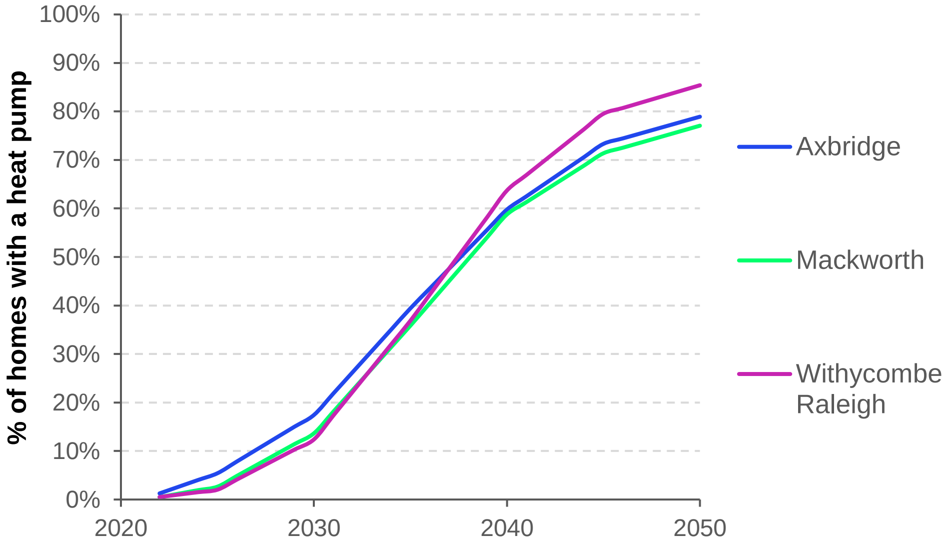


Figure 15. DFES Consumer Transformation, primary substation areas

Given that >85% of properties in NGED's licence areas are fossil fuel heated, we can assume that energy efficiency measures are installed at any time between the baseline year and the year of heat pump installation as the demand reduction is only observed on the grid when the heat technology is electrified.

We have used one DFES scenario – Consumer Transformation – as this represents the most ambitious rate of heat pump deployment and hence the most extreme increase on electricity network loads. The other two Net Zero compliant DFES scenarios (System Transformation and Leading the Way) have relatively high proportions of hybrid heat pumps, hydrogen heating, and district heat networks. For this study, we are not considering energy efficiency measures in these properties for the following reasons:

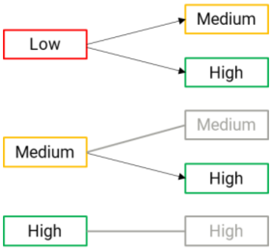
- Operating profiles of hybrid heating still largely unknown as no economic case currently
- High levels of uncertainty around hydrogen deployment
- District heating likely to require separate grid connection process
- Suitability of the three areas for heat networks is likely to be low as they are largely residential with no large non-domestic loads. More detailed heat network zoning is out of scope for this project.

The Falling Short scenario has low heat pump deployment and does not reach Net Zero 2050 – we considered running energy efficiency scenarios for the Falling Short DFES scenario as a base case, however, due to the time it takes to run the model for all the substations and the limited additional value, we have moved this task to 'Further Work'.

Types of installations

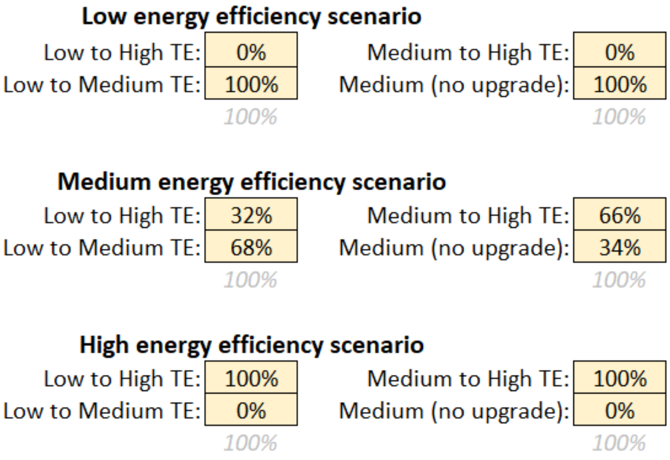
The cost optimisation module selects the most cost-effective route to upgrade each sub-archetype, and the scenarios project movements in sub-archetype populations as a result of the energy efficiency measures. We developed high, medium and low energy efficiency scenarios separated by the proportion of homes installing a heat pump in a given year that changes thermal efficiency from:

- Low[9] to medium
- Low to high
- Medium to high
- Stays as medium
- Stays as high



Buildings that have high thermal efficiency do not install additional fabric upgrades in any scenario.

The scenario model generates four energy efficiency scenarios – High, Medium, Low and No Energy Efficiency. The parameter settings for the different scenarios are the percentage of homes that change thermal efficiency from low to medium, low to high, and medium to high. The following rules for the scenarios were applied:



Low energy efficiency scenario

Low to High TE:	0%	Medium to High TE:	0%
Low to Medium TE:	100%	Medium (no upgrade):	100%
	100%		*100%*

Medium energy efficiency scenario

Low to High TE:	32%	Medium to High TE:	66%
Low to Medium TE:	68%	Medium (no upgrade):	34%
	100%		*100%*

High energy efficiency scenario

Low to High TE:	100%	Medium to High TE:	100%
Low to Medium TE:	0%	Medium (no upgrade):	0%
	100%		*100%*

- The **No Energy Efficiency scenario** is a counterfactual scenario that just looks at the profiles of existing homes installing a heat pump.
- In the **Low scenario**, all ‘low thermal efficiency’ buildings move to medium, and all ‘medium’ and ‘high’ thermal efficiency buildings remain the same. This scenario represents the minimum fabric requirements to ensure ‘low’ thermal efficiency buildings are heat pump ready.
- The **Medium scenario** has been set to match the Committee on Climate Change’s (CCC) Balanced Pathway in their 6th Carbon Budget[10].
- In the **High scenario**, all ‘low thermal efficiency’ buildings move to high, and all ‘medium thermal efficiency’ buildings move to high. This scenario represents the maximum levels of energy efficiency that can be installed in homes.

It is important to note, the results for the high medium and low energy efficiency scenarios are largely influenced by both the thermal efficiency that exists in the baseline housing stock, and the rate of heat pump penetration in DFES, which is consistent across all scenarios.

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[9] Broadly, homes classed as having low thermal efficiency are less likely to install a heat pump due to the limited capacity of a standard air-source heat pump. High-temperature heat pumps have been ruled out due to high running costs making them unaffordable at a domestic scale. Therefore, we have assumed in the model that homes with low thermal efficiency must move to either medium or high before installing a heat pump.

[10] Committee on Climate Change’s (CCC) 6th Carbon Budget
CCC Balanced Pathway projects the number of wall, floor and roof insulations out to 2050 which was used to calibrate the medium energy efficiency scenario – roughly a third of low thermal efficiency homes move to high, and two thirds to medium; two thirds of medium thermal efficiency homes move to high, and a third remain as medium

2.3 Assumptions

2.3.1 Energy efficiency scenarios

- The model results show the fabric improvements at the point of heat pump installation, whereas in actual fact, the fabric improvements can be made between the baseline year up until the year of heat pump installation without being observed by the electricity network
- Dwellings classed as having high thermal efficiency will not make any additional fabric improvements
- High and low scenarios represent the extreme cases, whereas the medium scenario reflects the CCC's Balanced Pathway in their 6th Carbon Budget
- Heat pump installations each year are evenly split between low, medium and high thermal efficiency (i.e. no weighting towards currently more efficient homes)
- Detached and semi-detached homes are the early adopters of heat pumps, while flats adopt heat pumps later in the scenario period. As the DFES heat pump penetration does not reach 100% in 2050 in the most ambitious scenario, some flats will not change from the baseline heat technology and thermal properties
- When there is a mix of heating technologies in the baseline for a single archetype, the model assumes that fossil fuel-heated homes are converted to heat pumps first, then direct electric, and finally, night storage heaters last. This was done to phase out gas heated homes in order to align the 2050 heat technology portfolio with DFES Consumer Transformation scenario.
- The analysis has been completed for existing homes only. New developments have not been considered in this study.

2.3.2 Cost benefit analysis

- The heat demand profile used in the analysis is based on 2018 weather conditions. Three individual profiles representing an intermediate day, a winter day, and an extreme winter day (Beast from the East) were applied across the whole year to generate annual energy consumption profiles. Annual energy costs were charged on a fixed p/kWh basis, with no time of use of elements or flexibility actions considered. Standing charges have not been included in the calculation of energy costs.
- A base 2022 domestic electricity retail price of 67p/kWh, the current energy price cap, has been assumed[11].
- Energy prices are currently unusually high and would give a potentially inaccurate view of the annual cost savings expected over the 30-year period being considered. Therefore, the annual percentage change figures calculated from the reference scenario of the BEIS Energy and Emission Projections 2022[12] have been applied. Beyond 2040, prices are assumed to be constant in the absence of other underlying data points to justify a change.
- A 3.5% discount rate has been used, taken from HM Treasury Green Book 2022[13].
- Inflation is excluded from this analysis. All prices are in 2022 values.
- Low to Medium thermal efficiency upgrades are assumed to be sufficiently attractive for homeowners to cover the cost of these measures. All other types of energy efficiency upgrades require a level of third-party funding.

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[11] Latest energy price cap announced by Ofgem | Ofgem

[12] Energy and emissions projections: 2021 to 2040 - GOV.UK (www.gov.uk), Annex M

[13] HM Treasury Green book 2022, p46

2.4 Current State of Thermal Fabric of Homes in Case Study Areas

Using the same categorisation of a buildings' thermal efficiency detailed in section 1.2.2., a summary of the distribution of energy efficiency categories for the three case study areas is shown in Figure 16.

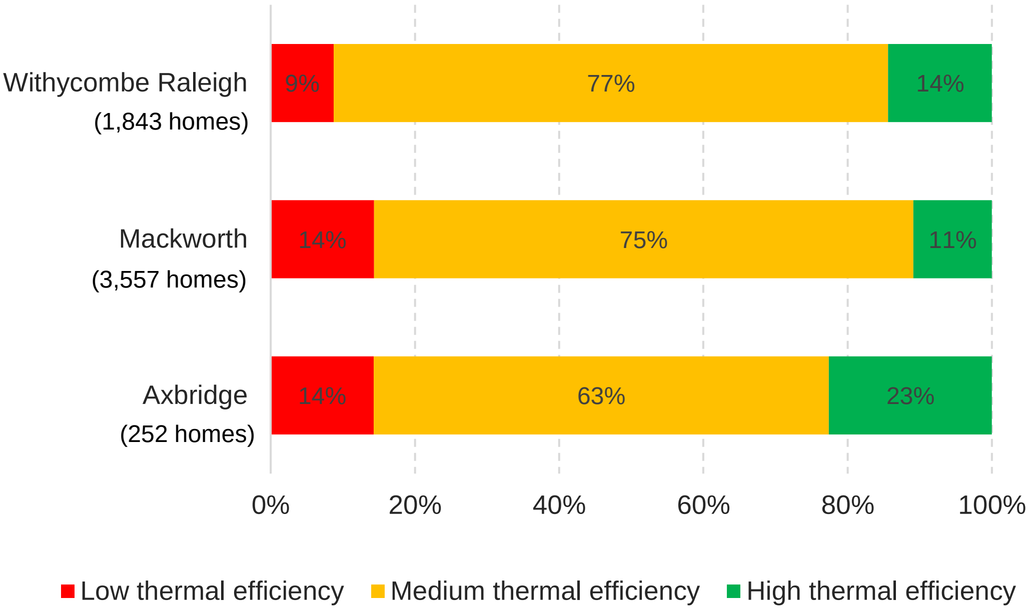

Figure 16. Distribution of dwellings connected to NGEDs network by thermal efficiency category

The three case study areas (Axbridge, Mackworth, Withycombe Raleigh) all have a more thermally efficient building stock on average than the overall NGED building stock. Figure 3 shows that 37% of homes connected to NGED's network are classed as having low thermal efficiency. The three case study areas contain less than 15% of buildings with low thermal efficiency, less than half the NGED average.

Axbridge in particular has a relatively efficient building stock, with almost a quarter of homes classed as having high thermal efficiency and therefore will not install any additional measures under any scenario in the period to 2050. The effect this has on the result is that less is spent overall on energy efficiency and the difference in energy profiles between the four scenarios is reduced as there is limited scope for additional improvements.

Note that the following sections on roof, floor, wall and window insulation only compare construction types and insulation of the three feeder areas with the overall NGED picture. For more detail about how the categories were choses, see section 1.4.

2.4.1 Roof type and insulation in the case study areas

98% of dwellings in NGED's license area have pitched roofs, which is reflected in the three case study areas. In all case study areas, over two thirds of buildings have above 100mm loft insulation. This is above the NGED total (58%) meaning there are fewer buildings on average that can benefit from loft insulation in the case study areas than in other areas of NGED's network.

Table 2 shows that loft insulation is the most cost-effective measure to install in homes. Therefore, measures installed in the case study areas will generally be less cost-effective compared to other more typical areas on NGED's network.

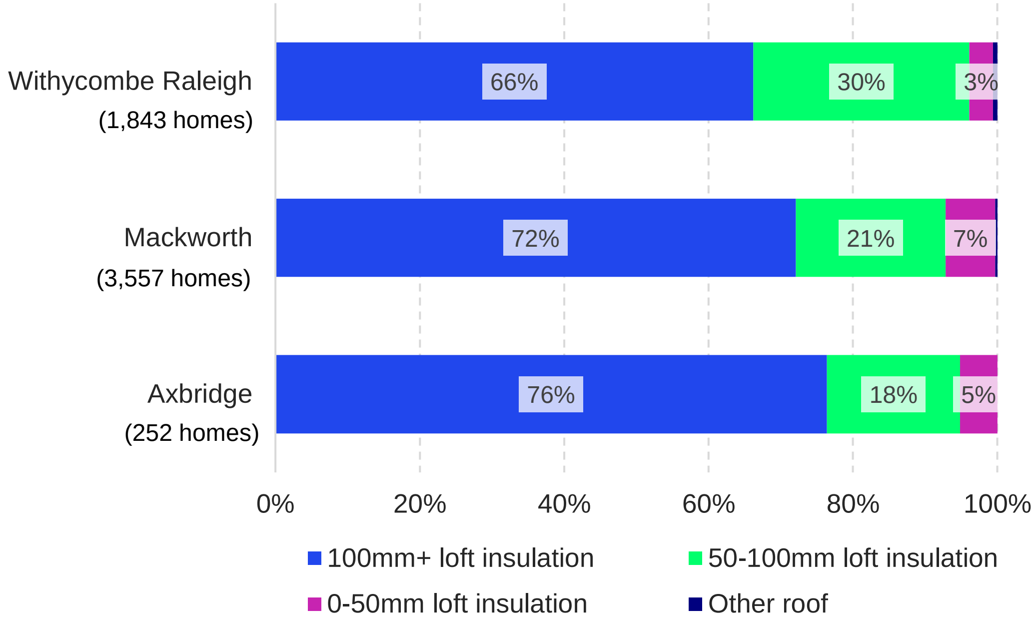

Figure 17. Summary of roof type and insulation in each of the three case study areas

2.4.2 Wall type and insulation in the case study areas

In NGED's licence areas, there is roughly an even split between properties with cavity walls and properties solid walls, with solid walls predominantly found in homes built before 1930, with most solid walls having no insulation, and most cavity walls having insulation (Figure 5).

The housing stock in the three case study areas are more modern than the average NGED house construction age. This is shown in Figure 18 where there is a much higher proportion of cavity walls. Approximately 80% of homes in the case study areas have filled cavity walls, compared to an NGED average of 45%. Cavity wall insulation is another relatively cost-effective measure whose potential is limited in the case study areas.

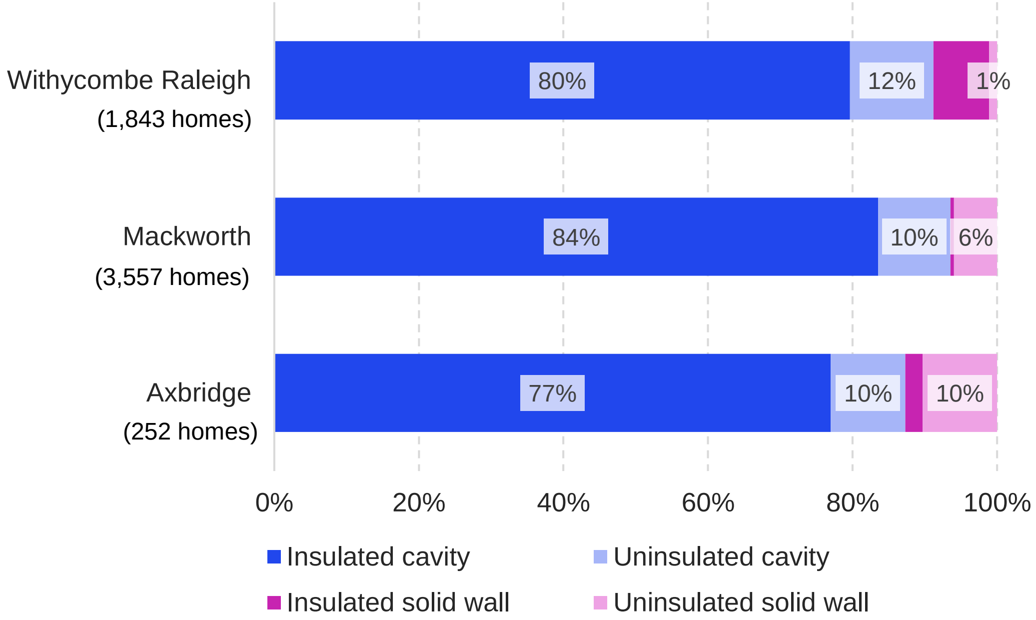

Figure 18. Summary of wall type and insulation in each of the three case study areas

2.4.3 Floor insulation in the case study areas

Across the NGED housing stock, 89% of homes have uninsulated floors. Mackworth has similarly high rates of uninsulated floors resulting in significant opportunity for improvements to be made (Figure 6).

Both Axbridge and Withycombe Raleigh have relatively high proportions of insulated, or partially insulated floors. Note that partially insulated floors can still receive additional insulation in the model but the decrease in U-value (heat loss) is less making the insulation of partially insulated floors less cost-effective.

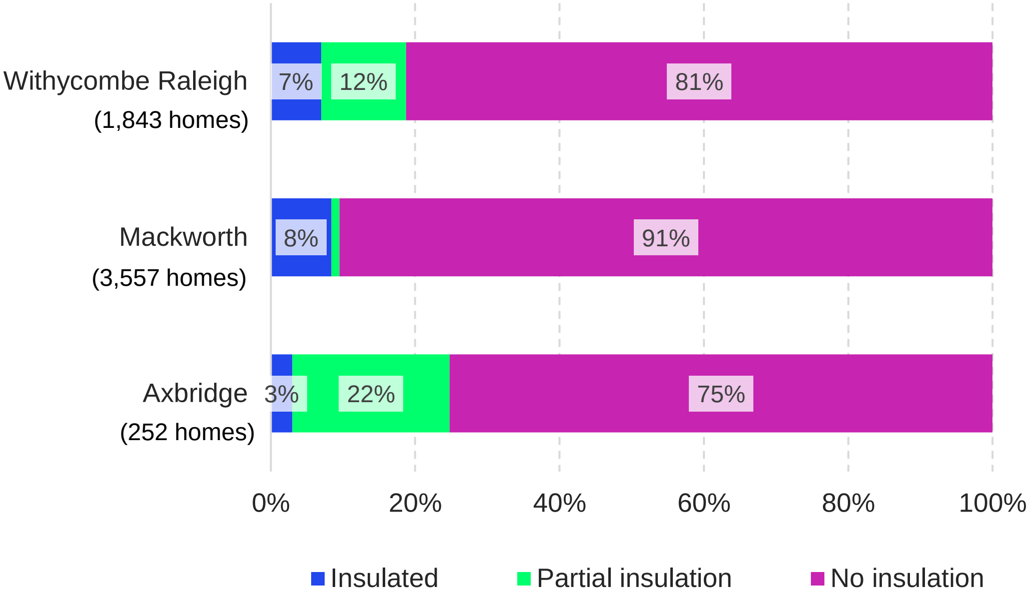

Figure 19. Summary of floor insulation in each of the three case study areas

2.4.4 Window glazing in the case study areas

Window glazing in the case study areas reflects the overall NGED picture, with over 93% of homes with double glazing already installed. This means that there is limited opportunity in this area.

2.5 CBA Results for Applying Energy Efficiency Measures at a Feeder Level

The method for producing energy efficiency scenarios is outlined in report D1.4-2 – Forecast Scenario Methodology and summarised in section 2.2. in this report.

The scenario model projects changes in sub-archetype population based on energy efficiency assumptions and generates results for two benchmark years – 2030 and 2050. The following outputs were produced in the model and used for the cost benefit analysis:

- New sub-archetype portfolios (building characterisation): this was inputted into the profiling tool to generate annual electricity profiles and peak electricity demand statistics for each substation
- Number of installations of floor, roof, wall and window insulations across the building stock
- Total CAPEX of energy efficiency measures
- Breakdown of heat technologies (inc. heat pumps, electric storage heaters, direct electric, and fossil fuel)

The cost-benefit analysis features additional network-level attributes that enables us to investigate the time and cost of network cable and transformer upgrades based on the following load threshold assumptions:

- Overhead (OH) and underground (UG) cables are replaced when line loading exceeds 50%. Overloaded cables are upgraded to 300 sq.mm Aluminium conductor.
- 11kV/LV ground mount transformers that reach a threshold of 80% loading are replaced, which is used as a conservative/proactive planning criterion (higher thresholds would delay the upgrades)

2.5.1 Energy efficiency scenarios in case study areas

Raising the level of energy efficiency in existing buildings becomes increasingly costly per kW peak load reduction. This effect can be seen for each feeder area in Table 6. Note that:

- Peak load refers to the 6pm peak on a 1-in-20 winter day
- All feeder areas track the DFES rate of heat pump installation for the primary substation area under the Consumer Transformation scenario

Table 6. Summary of scenario results for each feeder area in terms of CAPEX of energy efficiency measures, number of heat pumps, and effect on the electricity grid

Feeder area	Energy efficiency scenario	Number of heat pumps in 2050 (Consumer Transformation)	Cost of energy efficiency measures	Annual electricity consumption (MWh)	Peak demand (kW)
Axbridge	No EE	200 (78.9% of homes)	£0	3,257	613.1
	Low EE		£128,480	3,225	602.6
	Medium EE		£712,785	3,152	585.9
	High EE		£1,163,067	3,092	573.0
Mackworth	No EE	2,578 (77.1% of homes)	£0	43,310	8,249.1
	Low EE		£1,808,313	42,886	8,168.3
	Medium EE		£10,852,169	42,685	8,133.0
	High EE		£18,926,472	41,973	7,911.4
Withycombe Raleigh	No EE	1,593 (85.4% of homes)	£0	24,294	4,482.1
	Low EE		£368,957	24,061	4,423.1
	Medium EE		£3,998,904	23,348	4,294.2
	High EE		£6,809,844	23,018	4,235.2

As the level of energy efficiency is raised across the scenarios, individual household measures become more expensive. The low EE scenario targets interventions at low thermally efficient properties that likely do not have existing loft or cavity wall insulation. There are not many properties that fit this criterion in the case study areas (section 2.4) meaning fewer interventions in total. The medium and high scenarios include more costly measures. Therefore, as the level of energy efficiency is raised for an area, the interventions become less cost-effective in terms of reducing peak network loads.

The impact of energy efficiency scenarios on network load is further illustrated by looking at the modelled daily profiles for a feeder area (Figure 20). The profiling tool runs the four scenarios (No EE, Low EE, Medium EE, High EE) for three representative weather days:

- Extreme winter day: 1-in-20 winter day, using temperature profile from the Beast from the East (1st March 2018)
- Winter day: temperature profile from an average winter day (15th January 2018)
- Intermediate day: temperature profile from an average intermediate day (15th October 2018)

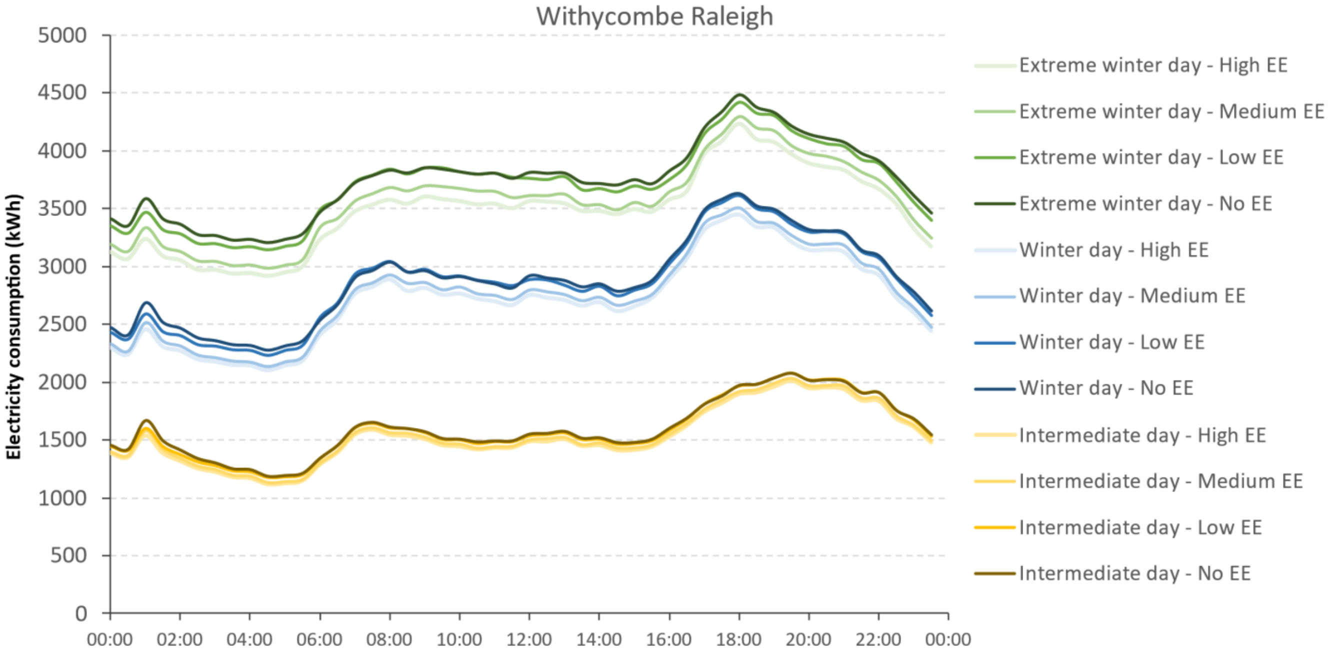

Figure 20. 2050 daily profiles for three representative weather days and four energy efficiency scenarios in Withycombe Raleigh feeder area.

The feeder area Withycombe Raleigh is used as an example in Figure 20. It primarily shows that temperature has a much more significant effect on daily electricity consumption than the effect of energy efficiency measures. This is because energy efficiency only influences the heating portion of electricity consumption profile. The efficiency of a heat pump (assumed COP of 2.8) effectively divides the heating demand by three making base electricity load a more significant portion of the total electricity consumption. The overall demand on energy networks (gas and electricity collectively) goes down as a result despite electricity demand increasing slightly.

Upgrading homes from low thermal efficiency to high thermal efficiency can achieve up to a maximum of 50% reduction in heat loss according to the SAP modelling. However, given the mix of thermal efficiencies in Withycombe Raleigh and the low impact thermal efficiency has on electricity demand for homes with a heat pump, the following peak load savings are observed:

- Extreme winter day – 5.4% difference between No EE and High EE
- Winter day – 4.1% difference between No EE and High EE
- Intermediate day – 2.6% difference between No EE and High EE

Similar results are observed for the other two case study areas.

2.5.2 Network reinforcement costs in case study areas

The network implications of applying the DFES Consumer Transformation rate of heat pump installations under different energy efficiency scenarios in the case study areas was assessed using the following loading thresholds to determine when reinforcement is requires: (see Assumptions for more detail)

- Above 50% line loading for underground and overground cables
- Above 80% transformer loading for secondary substation transformers

Table 7. Summary of network upgrades required by 2050 in each of the three case study areas as a proportion of the total network infrastructure. The table shows results for the high and low energy efficiency scenarios assuming extreme winter peak load conditions.

Feeder area	Length of cables (m)	Number of transformers	Scenario	% Cables replaced by 2050	% Transformers replaced by 2050	Cost (£)
Axbridge	641.3	2	Low EE	0%	0%	£0
			High EE	0%	0%	£0
Mackworth	9594.3	16	Low EE	31.3%	68.8%	£428,328
			High EE	31.3%	68.8%	£428,328
Withycombe Raleigh	5883.5	13	Low EE	0.06%	53.8%	£56,449
			High EE	0.06%	53.8%	£56,449

The amount of reinforcement needed between the high and low energy efficiency scenarios is the same in 2050 for all the feeder areas if networks are reinforced to meet demand for the extreme winter day conditions. The network upgrades in the 'No Energy Efficiency' scenario was not assessed due to the additional modelling time to produce the scenarios – however it is evident that varying levels of energy efficiency has little impact on the required reinforcements based on the difference in peak load between a 'No EE' scenario and a 'High EE' scenario. The low scenario is the scenario the lowest thermal performance that ensures homes are heat pump ready before installing a heat pump.

Table 7 also demonstrates that the need for network reinforcements strongly depends on the current baseline level of loading on a cable or transformer. A higher proportion of Mackworth's cables and transformers were close to the threshold loading factor than in the other feeder areas. This means that network reinforcement requirements are location specific assuming the relatively uniform DFES rates for uptake of heat pumps and electric vehicles across NGED's network. There may be other locations on the network where energy efficiency may have a larger effect on network reinforcement needs.

If network reinforcement is deployed to allow the network to meet the demands of an extreme winter day (1-in-20 winter), significantly higher levels of network reinforcement are required compared to modelling future network loads assuming a typical winter day. Figure 21 shows that network reinforcement costs are between 1.3 – 1.4 times higher when modelling an extreme winter day in 2050 compared to a typical winter day where network reinforcements are required in the modelled areas (i.e. in Mackworth and Withycombe Raleigh).

The effect low and high energy efficiency deployment on network reinforcement deferral can also be seen in Figure 21. Irrespective of extreme winter peak or typical winter peak temperatures, a high energy efficiency scenario will defer network reinforcement needs by typically only 1 to 3 years over a low energy efficiency scenario. The low energy efficiency scenario was selected for comparison over the No EE scenario as it is unlikely there will be no fabric upgrades in the scenario period.

Out of the three case study areas studied, only average winter peak conditions in Withycombe Raleigh showed a difference in the number of assets needing upgrading between the different energy efficiency scenarios by 2050 – as this upgrade was deferred to 2051. Further information on the variability of network reinforcement requirements more generally across NGED's network can be found in DEFENDER Workstream 2 Analysis and Insights Report.

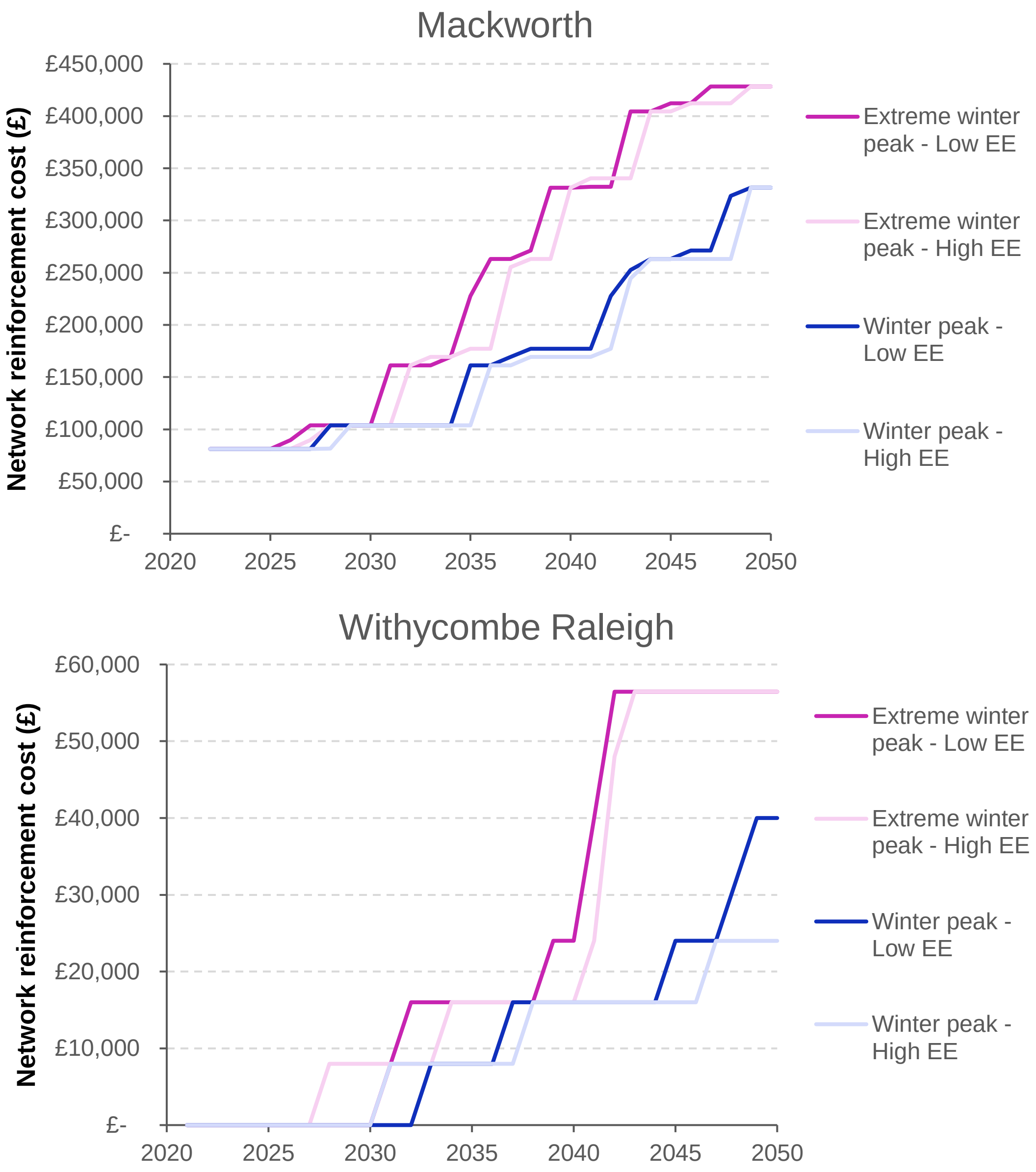

Figure 21. Network reinforcement costs over time for the high and low energy efficiency scenarios and for two weather condition assumptions (extreme winter peak and typical winter peak). Top = Mackworth; Bottom = Withycombe Raleigh.

2.5.3 Cost implications for NGED

Discounted cash flow analysis was completed to assess the benefits to NGED of funding energy efficiency measures to defer network reinforcement costs in each of the three case study areas. Discounted cash flow analysis was chosen due to its ability to take into account for the time value of money: the concept that a pound that you have today is worth more than a pound that you receive tomorrow because it can be invested in other projects or conversely, that a pound spent today is given a higher value than a pound spent in the future.

The NPV is the key metric from the discounted cash flow analysis used to compare the cost effectiveness of each investment option, with more positive values representing better investment cases. Input assumptions for this analysis can be found in Section 2.3.2.

This section presents two cases:

- NGED investment case: the benefits to NGED of investing in energy efficiency measures

- Homeowners’ investment case: the investment case for the homeowners in the case study area in investing in energy efficiency measures

This approach allows for identification of who is best placed to make an investment and where savings flow between stakeholders.

NGED investment case

Table 8 shows that energy efficiency investment adds significant cost to NGED with very little financial benefit from deferring reinforcement, under all investment options considered and both winter temperature conditions. This is largely due to the lack of avoidance of any reinforcement costs and limited duration of deferral as a result of the energy efficiency measures, as shown in Section 2.5.2.

The analysis was completed for three investment cases. Firstly, for the low energy efficiency scenario where it is assumed that homeowners will invest in the energy efficiency measures, leaving NGED to only cover the cost network reinforcement. This is the lowest cost option for NGED and the most likely outcome providing homeowners make sufficient energy bill savings to justify this cost. The second scenario looks at the counterfactual to this, with NGED covering the cost of the low EE scenario energy efficiency interventions. This adds significant additional cost in all scenarios, typically reducing the NPV by an order of magnitude. Under a high EE scenario, with NGED covering the cost of EE upgrades, the NPV reduces by another order of magnitude. This strongly indicates that funding these measures is not a cost-effective option for NGED in any of the three case study areas investigated.

Table 8. NGED NPV including all energy efficiency measure costs and reinforcement costs

Scenario	Mackworth		Withycombe Raleigh		Axbridge	
	2030	2050	2030	2050	2030	2050
Average winter peak – Low EE; EE costs covered by homeowners	-£ 99,510	-£ 216,122	£ -	-£ 20,312	£ -	£ -
Average winter peak – Low EE; EE costs covered by NGED	-£ 610,321	-£1,387,712	-£111,893	-£ 262,295	-£ 37,992	-£ 83,892
Average winter peak – High EE; EE costs covered by NGED	-£5,024,205	-£12,312,428	-£956,839	-£4,055,456	-£358,240	-£ 764,920
Extreme winter peak – Low EE; EE costs covered by homeowners	-£ 100,403	-£ 291,206	£ -	-£ 32,588	£ -	£ -
Extreme winter peak – Low EE; EE costs covered by NGED	-£ 611,214	-£ 1,462,796	-£ 111,893	-£ 274,571	-£37,992	-£ 83,892
Extreme winter peak – High EE; EE costs covered by NGED	-£5,025,054	-£12,384,441	-£963,347	-£ 4,073,715	-£358,240	-£764,920

Homeowners’ investment case

As a counterfactual to the NGED investment case, we present the investment case for the aggregate of the homeowners in each case study area who have energy efficiency measures installed in the low and high EE scenarios.

Positive investment cases were found in the low energy efficiency scenarios across the three case studies. The value that could be generated from the energy efficiency interventions installed varied across the three areas, due to the exact mix of house types present and the cost of installing upgrades in these types. The most positive case was seen in Mackworth, with a discounted payback time across the housing stock of 8.7 years and an NPV by 2050 of £3.7 million. Conversely, the investment case for Axbridge is more tenuous, with a discounted payback time of 27 years and an NPV of just £9,200.

These results validate the assumption above that at least in some locations, homeowners do have a financial case to invest in energy efficiency measures equivalent to those in the low EE scenario rather than NGED. However, in other locations, additional funding from another source may be required to trigger this investment, assuming there is sufficient wider system benefit for these upgrades to occur.

Across all three case study areas, investment in energy efficiency measures specified in the High EE scenario do not result in a positive NPV and there is a very low likelihood of investment by homeowners of these measures. This is consistent with findings in the House-level CBA analysis completed for each house archetype.

Table 9. NPV and discounted payback time of investing in energy efficiency measures for customers in the case study areas. These figures do not account for any network reinforcement costs.

Scenario	Mackworth		Withycombe Raleigh		Axbridge	
	2030	2050	2030	2050	2030	2050
Low EE - NPV	£ 12,837	£ 3,693,002	-£ 85,045	£ 406,887	-£ 33,102	£ 9,220
Discounted payback time	8.7 years		18.0 years		27.4 years	
High EE - NPV	-£ 4,401,654	-£ 7,236,374	-£ 701,345	-£ 58,840	-£ 299,943	-£ 183,057
Discounted payback time	Does not payback		Does not payback		Does not payback	

2.6 Conclusions

The CBA results show very limited benefit for NGED to invest in energy efficiency measures as a method for reducing network reinforcement costs in any of the three case study areas assessed. This is due to four main reasons:

1. **There is only a marginal reduction in peak load on network infrastructure between the high and low energy efficiency scenarios.**
   On an extreme (1-in-20) winter day in a feeder area with ~80% heat pump coverage in domestic dwellings, the difference in peak load between a scenario with No Energy Efficiency and a High Energy Efficiency scenario is only 5.4%. This is mainly due to the efficiency of a heat pump, effectively reducing heat demand by a factor of 3, meaning electricity base load constitutes a much higher proportion of the overall electricity consumption, and base load is not affected by energy efficiency measures. This low reduction in peak load is especially apparent in the three case study areas investigated, due to the relatively high thermal efficiency in the existing building stock. Higher reduction in peak load may be expected in areas of the network with lower thermal efficiency in the building stock and higher numbers of direct electric heating. However, this is likely to be highly location specific on NGED's network based on the results of the building stock analysis.

2. **High energy efficiency deployment does not tend to result in complete avoidance of reinforcement and instead defers investment by typically under two years, resulting in limited network cost savings.**
   The difference between the time it takes for a cable or transformer to exceed its threshold load in a high energy efficiency scenario versus a low energy efficiency scenario is always between 1 and 3 years, irrespective of the representative weather day or feeder area. This is due to the cables and transformers that require reinforcements being those that are already close to their threshold load and the increase in load resulting from installing a heat pump is significant compared to the minimal peak load saving achieved from energy efficiency measures. This effect is likely to be exacerbated if EV load is also included in the analysis.

3. **The cost to upgrade overhead lines and ground mounted LV transformers is low.**
   The case study areas modelled have a high proportion of overhead lines and ground mounted low voltage transformers, both of which are relatively low cost to upgrade. The cost-effectiveness of energy efficiency investment is therefore comparatively poor in these areas. Cost-effectiveness may be greater in dense urban areas with largely underground cables or if higher cost 33kV/11kV transformers are overloaded. DEFENDER Workstream 2 considers this in more detail.

4. **There is a positive investment case for homeowners to invest in energy efficiency measures equivalent to those in the low energy efficiency scenario, indicating that other non-NGED funded routes may be more suitable.**
   In the low energy efficiency scenario, most house archetypes benefit from positive NPV as lower cost, high impact energy efficiency measures such as loft and cavity wall insulation are deployed, resulting in net positive financial case due to energy bill savings. This is one of the key conclusions in the house-level CBA (section 1.6.) and supports the assumption that some homeowners will install energy efficiency measures without NGED support due to the benefits it provides them. However, there is limited investment case for either NGED or homeowners to fund fabric measures in a high energy efficiency scenario as this only defers network reinforcement by a maximum of three years and does not usually reduce consumer bills sufficiently to payback in under 30 years.

Additionally, benefits to the wider energy system such as reduced generation capacity requirements, generation operation cost, carbon costs and higher voltage network infrastructure investment have not been considered. Other stakeholders across the energy system may benefit to a larger extent than NGED and be better placed to lead on an energy efficiency retrofit programme if these higher cost energy efficiency measures are beneficial to them. Alternatively, social benefits such as health benefits from warmer homes may lead to local authorities prioritising these interventions.

It should be noted that this analysis did not investigate the interactions between more flexible heat pump usage and thermal energy efficiency deployment, as well as other changes expected on the low voltage network, such as deployment of EV's, solar PV and batteries. When considered in this context, energy efficiency may:

- Provide greater network benefits through improving the viability and business case for investing in these other technologies, such as a smaller battery that allows the heat pump to be run off battery power rather than grid electricity during peak times and improve self-consumption of solar PV.
- Energy efficiency may allow more flexible operation of the heat pump, allowing it to be turned off during peak hours without the home dropping to un-comfortable temperatures. The model currently assumes continuous running of the heat pump.

Furthermore, the deployment of these other technologies will significantly affect the need for and timing of reinforcement, which could alter the NPVs calculated in this study.

Recommendations

The scope of this project was limited to the impacts of thermal energy efficiency on the low voltage distribution network as heat pump deployment increases. However, this change will not happen in isolation and the findings will be affected by wider system dynamics. It has been well shown at the GB system level that energy efficiency is very beneficial in reducing costs. We recommend that further modelling in two main areas:

- Identification of the wider impact of energy efficiency deployment on individual stakeholders across the sector to identify where greatest benefits are seen and hence which organisation outside of the DNOs should be engaged in pushing forward deployment of thermal energy efficiency retrofits.
- Interactions between energy efficiency deployment and the flexible operation of heat pumps and batteries on the distribution network.

In addition to further modelling, we recommend that NGED:

- Engage with other stakeholders with an interest in deployment of energy efficiency measures for non-network benefits, such as local authorities, on how best NGED can support based on location specific network characteristics. This may involve identification of network areas with high-cost reinforcement requirements and high density of low thermal efficiency homes and providing targeted support only in these specific locations.
- Track the deployment of energy efficiency measures to improve the DFES forecasting process and DNOA decision making.

3 Appendix

3.1 Top 100 sub-archetypes on NGED's network

Rank	Sub-archetype	Thermal efficiency	Percent of NGED homes	Built form	Construction age band	Wall type and insulation	Floor type and insulation	Roof type and insulation	Window glazing
1	14-45	Medium	7.2%	Semi-detached house	after 1930	Cavity, insulated	Solid, uninsulated	Pitched, insulated	Double glazing
2	46-45	Medium	4.5%	Detached house	after 1930	Cavity, insulated	Solid, uninsulated	Pitched, insulated	Double glazing
3	55-17	High	3.1%	Top floor flat	after 1930	Cavity, insulated	-	Pitched, insulated	Double glazing
4	17-2	Low	3.0%	Mid-terrace house	before 1930	Solid, uninsulated	Suspended, uninsulated	Pitched, uninsulated	Double glazing
5	17-26	Low	2.9%	Mid-terrace house	before 1930	Solid, uninsulated	Suspended, uninsulated	Pitched, insulated	Double glazing
6	14-33	Medium	2.8%	Semi-detached house	after 1930	Cavity, insulated	Solid, uninsulated	Pitched, partial insulation	Double glazing
7	68-9	Medium	2.8%	Bottom floor flat	after 1930	Cavity, insulated	Solid, uninsulated	-	Double glazing
8	60-5	High	2.6%	Mid floor flat	after 1930	Cavity, insulated	-	-	Double glazing
9	30-45	Medium	2.6%	Mid-terrace house	after 1930	Cavity, insulated	Solid, uninsulated	Pitched, insulated	Double glazing
10	13-45	Medium	2.5%	Semi-detached house	after 1930	Cavity, insulated	Suspended, uninsulated	Pitched, insulated	Double glazing
11	9-39	Medium	2.49%	Semi-detached house	after 1930	Solid, uninsulated	Suspended, uninsulated	Pitched, insulated	Double glazing
12	59-5	High	1.86%	Mid floor flat	after 1930	Solid, insulated	-	-	Double glazing
13	46-34	Medium	1.69%	Detached house	after 1930	Cavity, insulated	Solid, uninsulated	Pitched, partial insulation	Double glazing
14	1-25	Low	1.64%	Semi-detached house	before 1930	Solid, uninsulated	Suspended, uninsulated	Pitched, insulated	Double glazing
15	10-39	Medium	1.42%	Semi-detached house	after 1930	Solid, uninsulated	Solid, uninsulated	Pitched, insulated	Double glazing
16	45-45	Medium	1.41%	Detached house	after 1930	Cavity, insulated	Suspended, uninsulated	Pitched, insulated	Double glazing
17	9-29	Low	1.35%	Semi-detached house	after 1930	Solid, uninsulated	Suspended, uninsulated	Pitched, partial insulation	Double glazing
18	1-5	Low	1.28%	Semi-detached house	before 1930	Solid, uninsulated	Suspended, uninsulated	Pitched, uninsulated	Double glazing
19	18-26	Medium	1.27%	Mid-terrace house	before 1930	Solid, uninsulated	Solid, uninsulated	Pitched, insulated	Double glazing

20	14-41	Low	1.16%	Semi-detached house	after 1930	Cavity, uninsulated	Solid, uninsulated	Pitched, insulated	Double glazing
21	2-25	Low	1.13%	Semi-detached house	before 1930	Solid, uninsulated	Solid, uninsulated	Pitched, insulated	Double glazing
22	9-8	Low	1.12%	Semi-detached house	after 1930	Solid, uninsulated	Suspended, uninsulated	Pitched, uninsulated	Double glazing
23	46-49	High	1.10%	Detached house	after 1930	Cavity, insulated	Solid, partial insulation	Pitched, insulated	Double glazing
24	18-2	Low	1.09%	Mid-terrace house	before 1930	Solid, uninsulated	Solid, uninsulated	Pitched, uninsulated	Double glazing
25	14-29	Low	1.07%	Semi-detached house	after 1930	Cavity, uninsulated	Solid, uninsulated	Pitched, partial insulation	Double glazing
26	30-29	Medium	1.06%	Mid-terrace house	after 1930	Cavity, insulated	Solid, uninsulated	Pitched, partial insulation	Double glazing
27	10-47	Medium	1.02%	Semi-detached house	after 1930	Solid, insulated	Solid, uninsulated	Pitched, insulated	Double glazing
28	55-11	Medium	0.98%	Top floor flat	after 1930	Cavity, insulated	-	Pitched, partial insulation	Double glazing
29	14-52	High	0.90%	Semi-detached house	after 1930	Cavity, insulated	Solid, insulated	Pitched, insulated	Double glazing
30	13-33	Medium	0.90%	Semi-detached house	after 1930	Cavity, insulated	Suspended, uninsulated	Pitched, partial insulation	Double glazing
31	57-2	Low	0.85%	Mid floor flat	before 1930	Solid, uninsulated	-	-	Double glazing
32	59-3	Low	0.85%	Mid floor flat	after 1930	Solid, uninsulated	-	-	Double glazing
33	46-52	High	0.80%	Detached house	after 1930	Cavity, insulated	Solid, insulated	Pitched, insulated	Double glazing
34	14-50	Medium	0.77%	Semi-detached house	after 1930	Cavity, insulated	Solid, partial insulation	Pitched, insulated	Double glazing
35	34-25	Low	0.76%	Detached house	before 1930	Solid, uninsulated	Solid, uninsulated	Pitched, insulated	Double glazing
36	29-45	Medium	0.74%	Mid-terrace house	after 1930	Cavity, insulated	Suspended, uninsulated	Pitched, insulated	Double glazing
37	13-29	Low	0.74%	Semi-detached house	after 1930	Cavity, uninsulated	Suspended, uninsulated	Pitched, partial insulation	Double glazing
38	18-9	Low	0.70%	Mid-terrace house	before 1930	Solid, uninsulated	Solid, uninsulated	Pitched, partial insulation	Double glazing
39	49-2	Low	0.67%	Top floor flat	before 1930	Solid, uninsulated	-	Pitched, uninsulated	Double glazing
40	49-14	Medium	0.66%	Top floor flat	before 1930	Solid, uninsulated	-	Pitched, insulated	Double glazing
41	68-7	Low	0.66%	Bottom floor flat	after 1930	Cavity, uninsulated	Solid, uninsulated	-	Double glazing
42	53-17	High	0.64%	Top floor flat	after 1930	Solid, insulated	-	Pitched, insulated	Double glazing
43	2-5	Low	0.63%	Semi-detached house	before 1930	Solid, uninsulated	Solid, uninsulated	Pitched, uninsulated	Double glazing
44	10-29	Low	0.62%	Semi-detached house	after 1930	Solid, uninsulated	Solid, uninsulated	Pitched, partial insulation	Double glazing
45	61-2	Low	0.61%	Bottom floor flat	before 1930	Solid, uninsulated	Suspended, uninsulated	-	Double glazing

46	68-16	High	0.60%	Bottom floor flat	after 1930	Cavity, insulated	Solid, insulated	-	Double glazing
47	26-45	Medium	0.59%	Mid-terrace house	after 1930	Solid, insulated	Solid, uninsulated	Pitched, insulated	Double glazing
48	26-41	Medium	0.58%	Mid-terrace house	after 1930	Solid, uninsulated	Solid, uninsulated	Pitched, insulated	Double glazing
49	62-2	Low	0.56%	Bottom floor flat	before 1930	Solid, uninsulated	Solid, uninsulated	-	Double glazing
50	25-41	Medium	0.56%	Mid-terrace house	after 1930	Solid, uninsulated	Suspended, uninsulated	Pitched, insulated	Double glazing
51	45-34	Medium	0.54%	Detached house	after 1930	Cavity, insulated	Suspended, uninsulated	Pitched, partial insulation	Double glazing
52	57-1	Low	0.52%	Mid floor flat	before 1930	Solid, uninsulated	-	-	Single glazing
53	60-3	Low	0.50%	Mid floor flat	after 1930	Cavity, uninsulated	-	-	Double glazing
54	30-52	High	0.48%	Mid-terrace house	after 1930	Cavity, insulated	Solid, insulated	Pitched, insulated	Double glazing
55	41-37	Medium	0.45%	Detached house	after 1930	Solid, uninsulated	Suspended, uninsulated	Pitched, insulated	Double glazing
56	46-30	Medium	0.45%	Detached house	after 1930	Cavity, uninsulated	Solid, uninsulated	Pitched, partial insulation	Double glazing
57	30-26	Medium	0.45%	Mid-terrace house	after 1930	Cavity, uninsulated	Solid, uninsulated	Pitched, partial insulation	Double glazing
58	10-7	Low	0.42%	Semi-detached house	after 1930	Solid, uninsulated	Solid, uninsulated	Pitched, uninsulated	Double glazing
59	13-8	Low	0.39%	Semi-detached house	after 1930	Cavity, uninsulated	Suspended, uninsulated	Pitched, uninsulated	Double glazing
60	67-9	Medium	0.38%	Bottom floor flat	after 1930	Cavity, insulated	Suspended, uninsulated	-	Double glazing
61	25-7	Low	0.36%	Mid-terrace house	after 1930	Solid, uninsulated	Suspended, uninsulated	Pitched, uninsulated	Double glazing
62	33-25	Low	0.36%	Detached house	before 1930	Solid, uninsulated	Suspended, uninsulated	Pitched, insulated	Double glazing
63	55-15	High	0.36%	Top floor flat	after 1930	Cavity, uninsulated	-	Pitched, insulated	Double glazing
64	45-39	Medium	0.35%	Detached house	after 1930	Cavity, uninsulated	Suspended, uninsulated	Pitched, insulated	Double glazing
65	13-52	High	0.33%	Semi-detached house	after 1930	Cavity, insulated	Suspended, insulated	Pitched, insulated	Double glazing
66	45-49	High	0.32%	Detached house	after 1930	Cavity, insulated	Suspended, partial insulation	Pitched, insulated	Double glazing
67	55-9	Medium	0.32%	Top floor flat	after 1930	Cavity, uninsulated	-	Pitched, partial insulation	Double glazing
68	66-9	Medium	0.32%	Bottom floor flat	after 1930	Solid, insulated	Solid, uninsulated	-	Double glazing
69	25-26	Low	0.31%	Mid-terrace house	after 1930	Solid, uninsulated	Suspended, uninsulated	Pitched, partial insulation	Double glazing
70	30-50	High	0.30%	Mid-terrace house	after 1930	Cavity, insulated	Solid, partial insulation	Pitched, insulated	Double glazing
71	34-12	Low	0.30%	Detached house	before 1930	Solid, uninsulated	Solid, uninsulated	Pitched, partial insulation	Double glazing
72	10-35	Medium	0.29%	Semi-detached house	after 1930	Solid, insulated	Solid, uninsulated	Pitched, partial insulation	Double glazing

73	60-6	High	0.29%	Mid floor flat	after 1930	Cavity, insulated	-	-	Triple glazing
74	66-6	Low	0.28%	Bottom floor flat	after 1930	Solid, uninsulated	Solid, uninsulated	-	Double glazing
75	68-14	Medium	0.28%	Bottom floor flat	after 1930	Cavity, insulated	Solid, partial insulation	-	Double glazing
76	26-26	Medium	0.28%	Mid-terrace house	after 1930	Solid, uninsulated	Solid, uninsulated	Pitched, partial insulation	Double glazing
77	45-30	Low	0.28%	Detached house	after 1930	Cavity, uninsulated	Suspended, uninsulated	Pitched, partial insulation	Double glazing
78	45-52	High	0.28%	Detached house	after 1930	Cavity, insulated	Suspended, insulated	Pitched, insulated	Double glazing
79	67-16	High	0.26%	Bottom floor flat	after 1930	Cavity, insulated	Suspended, insulated	-	Double glazing
80	54-17	High	0.26%	Top floor flat	after 1930	Solid, insulated	-	Flat, insulated	Double glazing
81	29-29	Medium	0.24%	Mid-terrace house	after 1930	Cavity, insulated	Suspended, uninsulated	Pitched, partial insulation	Double glazing
82	13-50	Medium	0.24%	Semi-detached house	after 1930	Cavity, insulated	Suspended, partial insulation	Pitched, insulated	Double glazing
83	53-15	Medium	0.22%	Top floor flat	after 1930	Solid, uninsulated	-	Pitched, insulated	Double glazing
84	9-47	Medium	0.22%	Semi-detached house	after 1930	Solid, insulated	Suspended, uninsulated	Pitched, insulated	Double glazing
85	42-37	Medium	0.21%	Detached house	after 1930	Solid, uninsulated	Solid, uninsulated	Pitched, insulated	Double glazing
86	56-17	High	0.20%	Top floor flat	after 1930	Cavity, insulated	-	Flat, insulated	Double glazing
87	29-26	Medium	0.20%	Mid-terrace house	after 1930	Cavity, uninsulated	Suspended, uninsulated	Pitched, partial insulation	Double glazing
88	56-13	Medium	0.20%	Top floor flat	after 1930	Cavity, insulated	-	Flat, partial insulation	Double glazing
89	41-27	Medium	0.19%	Detached house	after 1930	Solid, uninsulated	Suspended, uninsulated	Pitched, partial insulation	Double glazing
90	30-9	Low	0.19%	Mid-terrace house	after 1930	Cavity, insulated	Solid, uninsulated	Pitched, uninsulated	Double glazing
91	26-7	Low	0.19%	Mid-terrace house	after 1930	Solid, uninsulated	Solid, uninsulated	Pitched, uninsulated	Double glazing
92	29-52	High	0.18%	Mid-terrace house	after 1930	Cavity, insulated	Suspended, insulated	Pitched, insulated	Double glazing
93	30-7	Low	0.18%	Mid-terrace house	after 1930	Cavity, uninsulated	Solid, uninsulated	Pitched, uninsulated	Double glazing
94	41-9	Low	0.18%	Detached house	after 1930	Solid, uninsulated	Suspended, uninsulated	Pitched, uninsulated	Double glazing
95	42-46	Medium	0.16%	Detached house	after 1930	Solid, insulated	Solid, uninsulated	Pitched, insulated	Double glazing
96	46-8	Low	0.16%	Detached house	after 1930	Cavity, uninsulated	Solid, uninsulated	Pitched, uninsulated	Double glazing
97	67-7	Low	0.15%	Bottom floor flat	after 1930	Cavity, uninsulated	Suspended, uninsulated	-	Double glazing
98	10-52	High	0.15%	Semi-detached house	after 1930	Solid, insulated	Solid, insulated	Pitched, insulated	Double glazing
99	56-11	Medium	0.14%	Top floor flat	after 1930	Cavity, uninsulated	-	Flat, partial insulation	Double glazing
100	66-16	High	0.14%	Bottom floor flat	after 1930	Solid, insulated	Solid, insulated	-	Double glazing