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Analysis Work to Refine Fabric Energy Efficiency Assumptions for use in Developing the Sixth Carbon Budget

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Executive Summary

The Committee on Climate Change (CCC) has published its recommendation on the level of the sixth carbon budget, as required under the Climate Change Act, to provide ministers with advice on the volume of greenhouse gases the UK can emit during the period 2033-2037. It will set the path to the UK's new net-zero emissions target in 2050, as the first carbon budget to be set into law following that commitment.

Today, the existing UK residential building stock consists of approximately 29 million dwellings and accounts for about a fifth of the UK's greenhouse gas emissions. To support the significant step-change in carbon reduction needed for the residential sector, robust analysis of the impact and technical potential of retrofitting energy efficiency measures in these homes is critical.

To inform this, the following report has been prepared by University College London to review and update the CCC's energy efficiency assumptions for the sixth carbon budget through the development of a fully updated set of cost and energy saving assumptions for **fabric energy efficiency measures** across the UK housing stock, which reflects the latest evidence (including in-use performance), where ***fabric energy efficiency measures*** are generally defined as measures that seek to improve the insulation performance and/or restrict uncontrolled air movement through the building envelope.

A robust approach

Methods that are used to inform advice and policy-making in this area must be robust and transparent, supporting the ***replicability*** and ***reproducibility*** of the work which they underpin. To achieve this, the assumptions generated in this report were based on a mixed methods framework incorporating an extensive evidence-base and case study review, dynamic modelling and stakeholder engagement and feedback analysis, where relevant data sources and underlying calculations have been documented.

Main Findings

Revising the scope of fabric energy efficiency measures

A revised list of fabric energy efficiency measures, referred to as 'sixth carbon budget measures', was defined for this work. This consolidates previously used categories for clarity and certainty in the production of assumptions, and extends coverage to several measures not previously included that better reflect available evidence. These new measures reflect evolving technologies and aim to cover both heritage properties and higher energy saving/high performance retrofit approaches (e.g. Passivhaus/EnerPHit) not previously considered. In recognition of climate change and the unintended consequences associated with retrofit, measures targeting overheating risk such as ventilation and shading variants were also considered. This range of measures can be summarised as:

- Insulation measures: External, internal and thin internal solid wall insulation, cavity wall insulation including treatments for Hard to Treat and partial fill cavities, loft insulation categories and insulation for both solid and suspended floors.
- Glazing measures: In addition to standard double glazing, secondary, slim profile and triple glazing were also considered.
- Other measures: A scope of 'easier to implement' measures including draught proofing, reduction of infiltration and tank insulation
- Overheating mitigation measures: This focused on the provision of standard ventilation and fixed, as well as internal and shutter typologies for shading.

Reflecting real-world contexts

The updated assumptions have aimed to incorporate in-use measured data from the National Energy Efficiency Data Framework (NEED) dataset (BEIS, 2019a) and the most up-to-date assumptions from the Cambridge Architectural Research (CAR) dataset for costings, which is based on extensive research that incorporated wide-ranging feedback from contractors (CAR, 2017). This was further strengthened through the comparison against, and where necessary inclusion of, field trial and case study data.

To provide a more in-depth understanding of factors that impact both achievable energy savings and estimated costings for fabric energy efficiency measures, an extensive analysis of 'adjustment factors' such as the performance gap, take back factor, opportunities for cost efficiencies, cost variations and uncertainties were incorporated. The impact of these factors can contribute to up to 40% variation in achieved savings and over 200% in cost variation, when uncertainties relating to aspects such as contractor disputes are considered.

Updated savings and costs

Across various archetypes, insulation measures in general tend to account for the most significant energy savings and involve the highest cost outlays (for the total cost of installation) compared to other measures. Despite achieving variable energy savings, costs associated with glazing measures are in some cases comparable to those for the most expensive insulation measures. In archetypes with typically smaller floor areas, the total installation cost of some glazing measures exceeds those associated with some wall insulation measures such as internal and cavity wall insulation. While relatively easier to implement, measures such as reduced infiltration and tank insulation can collectively achieve considerable savings, comparable to some types of glazing upgrades, when combined and implemented properly.

Understanding the heritage domestic stock

There are a wide range of buildings that face additional challenges in decarbonising, including those formally recognised as having some form of heritage value (namely listed homes and homes in conservation areas) as well as traditional buildings more widely – generally considered to be those built prior to 1919.

The CCC routinely advises on the costs and savings expected to be associated with decarbonisation, in order to support effective policy-making. In light of the additional challenges faced by buildings with heritage value, this study aims to establish an improved understanding of those measures which are currently considered more applicable than others in domestic buildings of heritage value or located in conservation areas. The findings are based on feedback from heritage professionals, engaged in both policy making and retrofit. The outputs include a more comprehensive 'measure suitability matrix', and an assessment of the potential cost uplifts associated with installing measures in heritage buildings than that included in the previously published 'Analysis on abating direct emissions from 'hard-to-decarbonise' homes' report (Element Energy, UCL, 2019).

For homes categorised as having heritage value (as well as traditional buildings more broadly), fabric energy efficiency measures are viewed by some to pose additional risks for these buildings as a result of unintended consequences associated with such impacts as moisture build up. In the case of heritage homes and homes in conservation areas, this can manifest in more onerous planning restrictions. However, it is also recognised that sympathetic and appropriate application of these measures better enables the ongoing use of these buildings as assets and some practitioners are increasingly championing investment in better technical equipment, more usable control systems and efficient low carbon energy supplies.

The outputs in this report are not intended to act as guidance, but rather as a means to reflect the additional challenges these buildings can face in decarbonising. In practice, while the variability in the heritage sector necessitates that every building is considered on a case-by case basis and would generally require a bespoke assessment and recommendations, the matrix and cost assessment provide a framework by which to structure more generalised assumptions that may be needed when modelling the building stock as a whole. The assessment provided here represents an early step and this remains an area for future work and evidence gathering.

Study Limitations

The main limitations that should be considered when interpreting the assumptions contained in this report include:

- *Data vs. Assumptions:* While a comprehensive review of available sources and datasets was carried out, the main available statistical releases on which this work is based (the NEED dataset and the CAR costings), had inherent limitations in regards to the coverage of the data (in relation to archetypes, the measures covered and data availability and variability for Devolved Administrations). NEED is based on specific schemes and may not capture all retrofit work undertaken in the UK, the data therefore is not necessarily indicative of energy savings that would be achieved where measures are installed in the wider stock. The CAR cost dataset is based on comparatively small sample sizes for some measures and there are uncertainties regarding the materials specifications for the measures covered. To address this, certain assumptions had to be made to enable the extrapolation of data where it was found to be missing. The cases in which these assumptions have been used were nonetheless explicitly recorded to ensure transparency.
- *Modelling vs. Reality*: To address further evidence gaps, a modelling exercise was undertaken to inform our understanding of the impact of combining measures. While modelling aims to represent a complex system, it cannot precisely replicate it, especially in the case of occupant behaviour and this remains an important evidence gap.
- *Real homes vs. Archetypes:* The archetypes around which the assumptions were structured, were developed to be to be broadly representative of the housing stock and to enable close mapping to the available evidence. As with all archetypes, they are however idealized representations of typologies within the UK stock. Real homes, and their occupants, will deviate from these assumptions that are inherent to these archetypes.
- *Case Studies:* Due to the inherent nature of case study-based research, the ability to generalise findings is often limited and attempts to transfer this learning or key lessons for wider application can present a challenge (Yin, 2011).

To address these limitations and provide the knowledge base required to address the main data 'gaps', more consistent information regarding the real-world performance of fabric energy efficiency measures should be provided. In particular, future field trials should be commissioned and more strategically designed to allow for the disaggregation of the impacts of a wider range of measures both individually and in combination. While the NEED dataset provided an invaluable source of information, the current format requires expansion beyond the current scope of fabric measures and should incorporate more detailed data on the impact of measures across archetypes that are currently not included such as flat typologies.

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List of Abbreviations and Terms

BEIS	Department of Business, Energy & Industrial Strategy
CCC	Committee on Climate Change
CWI	Cavity Wall Insulation
DG	Double Glazing
ECO	Energy Company Obligation
EHS	English Housing Survey
ETTC	Easy to Treat Cavity
EWI	External Wall Insulation
HEED	Homes Energy Efficiency Database
HTT	Hard to Treat (properties)
HTTC	Hard to Treat Cavity
HW	Hot Water
IAQ	Indoor Air Quality
kWh	kilo Watt hour
$MtCO_2e$	Metric Ton Carbon Dioxide (Equivalent)
NEED	National Energy Efficiency Data Framework
NI	Northern Ireland
OTEoH	Optimising the Thermal Efficiency of Housing (project)
R4tF	Retrofit for the Future Programme
SG	Secondary Glazing
SHS	Scottish Housing Survey
SPDG	Slim Profile Double Glazing
SWI	Solid Wall Insulation
TIWI	Thin External Wall Insulation
WHCS	Welsh Housing Condition Survey

1. Introduction: The Sixth Carbon Budget

The Committee on Climate Change (CCC) is publishing its recommendation on the level of the sixth carbon budget, as required under the Climate Change Act, to provide ministers with advice on the volume of greenhouse gases the UK can emit during the period 2033-2037 (Table 1). It will set the path to the UK's new net-zero emissions target in 2050, as the first carbon budget to be set into law following that commitment.

To inform this work the CCC launched a new Call for Evidence and commissioned a range of analysis across a range of sectors to inform its advice to the UK Government.

Table 1: UK carbon budgets 1-5 (CCC, 2020)

Budget	Carbon budget level	Reduction below 1990 levels
First carbon budget (2008 to 2012)	3,018 MtCO2e	25%
Second carbon budget (2013 to 2017)	2,782 MtCO2e	31%
Third carbon budget (2018 to 2022)	2,544 MtCO2e	37% by 2020
Fourth carbon budget (2023 to 2027)	1,950 MtCO2e	51% by 2025
Fifth carbon budget (2028 to 2032)	1,725 MtCO2e	57% by 2030

1.1. The Domestic Retrofit Challenge

In July of 2016, the fifth carbon budget was passed into legislation. As recommended by the Committee on Climate Change (CCC), the budget was set at a total of 1,725 $MtCO_2e$ that could be emitted over the period from 2028 to 2032. Analysis undertaken comparing the Government's abatement projections to the fifth carbon budget highlighted that there was an 'abatement gap' - a shortfall compared to the trajectory in 2030. The majority of this abatement gap was associated with direct emissions, with the largest sectoral abatement gap attributed to the residential stock, followed by commercial and public sector buildings (ACE and RAP, 2016).

Today, the existing UK residential stock consists of approximately 29 million dwellings and accounts for about one fifth of the UK's greenhouse gas emissions. As a result, the UK Government has been called upon to make sweeping policy changes to facilitate the large-scale improvement of existing homes to a high energy efficiency standard. Doing so not only saves carbon emissions, but there is an emerging and growing body of evidence on the multiple benefits of energy efficiency, which include wide range of impacts or 'co-benefits', such as thermal comfort, air quality improvements, fiscal benefits to the public budget (such as Value Added Tax paid by households taking up energy efficiency measures) that significantly add to the savings on energy costs (ACE and RAP, 2016). To date, funding for individual measures such as loft, cavity wall insulation and solid wall insulation has been made available through funding programmes such as CERT, CESP, ECO and the GDC (Green Deal Communities).

However, progress so far has been too slow, and as noted in CCC 2019 Progress report to Parliament (CCC, 2019), deployment of energy efficiency measures in buildings are running at less than 20% of the rate under the CCC indicators, having fallen sharply since policy changes in 2012. These indicators were set for the fifth carbon budget and ambition should be even higher following the setting of the net zero target. New policy is urgently needed to drive improvements in the energy efficiency of our housing stock.

1.2. The Need for Robust Assumptions

To support the significant step-change needed for the residential sector, robust analysis of the impact and technical potential of installing energy efficiency measures is needed, underpinned by the latest and best available evidence. As an increasing evidence base becomes available regarding in-situ performance, retrofit risks and unintended consequences, assumptions regarding the actual impact of installing energy efficiency measures are in continual need of validation and updating.

Recent debate regarding the credibility and transparency of the science that underlies policymaking across all sectors, has called for the adoption of research approaches and standards that ensure the ***replicability*** and

reproducibility of findings are maintained (Huebner et al., 2017). This is of increased importance when considering decisions that will inform national actions on climate change formulated thorough scenario development and modelling for future heat trajectories.

As such the following report and associated supplementary evidence focuses on the incorporation of a robust evidence base, as well as the definition of the detailed methods that underlie it, to allow for the systematic replication of findings, facilitate scrutiny of the work and allow future updates to easily incorporated as the evidence base on which it is based expands.

1.3. Study Aims, Objectives and Scope

As specified by the CCC, the following work aims to review and update the CCC's energy efficiency assumptions for the sixth carbon budget through the development of a fully updated set of cost and energy saving assumptions for ***fabric energy efficiency measures*** across the UK housing stock, which reflects the latest evidence (including in-use performance). ***Fabric energy efficiency measures*** are generally defined as measures that seek to improve the insulation performance and/or restrict uncontrolled air movement through the building envelope[1].

Based on the above mentioned aim, the following four key objectives were addressed:

- To review the available evidence on fabric efficiency measures, across all types of homes in the UK,
- To consider factors that may influence costs, savings and suitability and how assumptions can be used to capture these where appropriate,
- To undertake dynamic modelling, where appropriate, to inform assumptions, including on how different combinations of measures perform in situ,
- To undertake a comparative analysis of updated assumptions to the CCC's fifth carbon budget assumptions to highlight any deviations, and determine and justify the use of updated or original assumptions where appropriate.

In considering the remit of work and the project timeframe, the scope of this work is to:

- ***Primarily*** focus the work on gathering data on the costs and energy saving performance of single energy fabric efficiency measures from field trials, surveys, and case studies. This will include a degree of analysis of enabling measures and unintended consequences (including the risks and associated costs).
- Target the ***secondary*** focus on the impact of behavioural assumptions such as the impact of the takeback factor on savings and the performance gap through the review of existing evidence and feedback from key experts.
- Focus modelling to specified tasks that aim to fill in knowledge gaps for a defined set of house types where data does not exist or is difficult to robustly extrapolate.
- Investigate and implement formats for engagement with heritage building sector bodies and professionals to provide feedback that can be used to formulate an informed consensus on suitability and, where possible, the costs of measures associated with fabric energy efficiency measures for the sector.
- It should be noted that while embodied carbon is out of scope for the work presented in this report, it is acknowledged that whole-life carbon should in general be given increasing focus in analysing the potential for carbon reduction in the building sector.

[1] To enable a more holistic assessment, the remit of this definition has been extended in the report to include hot water tank insulation and overheating mitigation measures such as ventilation.

1.4. Overview of the Study Approach

Our approach aims to balance the benefits and limitations of different evidence sources, highlighted by our previous experience in investigating energy efficiency deployment and installation practice for the domestic retrofit sector, which are detailed in Section 2.1 Methodology for Generating Assumptions.

In practice, to produce robust assumptions, a mixed-method design was considered to be most appropriate due to its effectiveness in combining both quantitative and qualitative approaches and its flexibility in integrating the various research sources and approaches for data collection. This method, which has been increasingly used in the field of built environment research, has the potential to increase the validity and reliability of the resulting data by addressing the limitations associated with the theoretical nature of various modelling-based work and the anecdotal nature of case study research (Abowitz and Toole, 2010).

The approach involved the analysis of a wide body of evidence, including 'real-world' field trial and case study analysis, supported by both modelling and stakeholder feedback to provide an up-to-date and robust evidence base on which to build informed and traceable assumptions. To support this, the following main tasks, which will be discussed in further detail in relevant sections, were undertaken:

- Evidence-base and case study review: This included two forms of evidence analysis; general literature and datasets on energy efficiency measures and the analysis of specific case study information. The initial aim was to review 20 data sources; however, this was extended to over 150 datasets, studies and published reports.
- Dynamic Modelling: This involved the implementation of defined modelling tasks using the EP-Gen[2] modelling framework and the compilation of results to inform specific assumptions, specifically relating to the impact sequencing of measures and combining them in 'packages' on energy savings.
- Stakeholder engagement and feedback analysis: This exercise with heritage professionals was undertaken via a structured survey on an online portal, followed by a number of discussions to enable the gathering of data specific to the suitability of measures to the heritage sector.

1.5. Report Structure

The report is structured around the main themes described in the objectives of the report detailed in section 1.3 and is organised as follows:

- Section 1 - Introduction provides an overview of the report, summarising the aims, scope and overall approach of the work.
- Section 2 - Updating Fabric Energy Efficiency Assumptions provides updated assumptions for fabric retrofit measures in the UK residential sector. This specifically focuses on the ***energy savings*** and the ***costs*** associated with the installation of key identified measures. This includes the detailed approach for the review, analysis and synthesis of key evidence that was employed to support the generation of these assumptions, criteria for data inclusion and provision of 'adjustment factors' to be considered in the understanding and application of these assumptions.
- Section 3 – The Domestic Heritage Sector focuses on the approach employed and findings of a survey-based study specifically aiming to provide a framework for the understanding of the application of the general fabric assumptions to the heritage homes. In addition, the section provides in-depth feedback from heritage and design professionals working in this field that should be considered, highlighting the complex processes and considerations that underpin this.

[2] EnergyPlus Generator 2 (EPGen-2) is a novel Python-based interface to the EnergyPlus dynamic modelling software tool that has been developed by UCL. Further details can be found in Appendix A-4 of this report

- **Section 4 - Findings and Conclusions** highlights the overall findings of the study, compares the assumptions to those previously generated for the fifth carbon budget, and defines the key lessons from the analysis of data and generation of assumptions.
- **Appendices** incorporates the key supplementary information associated with this report.

Note:

In addition to this report, the detailed evidence and calculations that is referred to throughout the text has been provided in spreadsheet format. The report and spreadsheet should be considered as complementary parts of a complete analysis set. The list of assumptions spreadsheets are as follows:

- Sixth carbon budget fabric energy savings assumptions
- Sixth carbon budget fabric cost assumptions
- Sixth carbon budget domestic heritage assumptions

2. Updating Fabric Energy Efficiency Assumptions

The following sections highlight the approach that was used for the generation of assumptions for both savings and costs. As assumptions are based on existing datasets that reflect real installations, it is assumed that the measures covered (as a pre-requisite) comply with the requirements of the relevant building regulations (Part L1B and Part B, and their equivalent Sections and Technical Documents in Scotland and Northern Ireland)[3].

For high-rise flats in particular, where more stringent fire safety requirements now apply, an emerging body of evidence on the combustibility of insulation materials is being developed as manufacturers consider these new requirements. However, until this body of evidence becomes available, considerations in interpreting these new requirements for the assumptions generated are included in the principles for generating assumptions. In addition, where relevant evidence is available its incorporation is detailed in the data notes that accompany the assumptions.

Error! Reference source not found.Methodology for Generating Assumptions

As discussed in Section 1.4, to inform the CCC's advice on the sixth carbon budget, robust analysis of the impact and technical potential of installing energy efficiency measures is needed, underpinned by the latest and best available evidence. A range of evidence sources have been used for the generation of assumptions to date, each of which have limitations in their usefulness and applicability:

- **Modelling- based assumptions:** Modelling provides a framework that aims to represent a complex system as realistically as possible and enables the analysis of 'what-if' scenarios in an effective and time effective manner. However, as a desk-based analysis method, assumptions based solely on modelling may not sufficiently reflect actual 'real' use and performance or have benefitted from sufficient empirical validation to establish that findings translate well into reality[4].
- **Case study-based assumptions:** While specific case studies may highlight some in-depth real-world findings that help inform assumptions, these are often anecdotal and limited to those cases, where attempts to transfer this learning or generalise key lessons for wider application may present a challenge.

Thus, to address the limitations associated with the methods utilised in the production of previous assumptions, we sought to analyse a wider body of evidence through the following approach:

1-Evidence Source Compilation: A database of relevant literature, case studies and datasets relating to the topics listed below were collated for selection and inclusion in the evidence review in an accessible online database using the Zotero platform (www.zotero.com).

- Compilation of costs and savings associated with energy efficiency measures
- Variation in individual/whole house costs/savings
- Defining projected changes over time including costs/performance, future proofing
- Emergent energy efficiency measures and technologies such as thin internal wall insulation
- Projected vs delivered savings and costs
- Impacts and uncertainties: including behavioural impacts, and the performance gap
- Enabling measures and mitigation of unintended consequences: overheating, ventilation
- Initial heritage building analysis
- In-situ performance data/measurements

[3] Approved Document B states that, "In a building with a storey 18m or more above ground level, any insulation product used in the external wall construction should be of limited combustibility. The limits materials available to products achieving a European classification of Class A1 or A2, and the only testing standard deemed acceptable is BS EN 13501.(Potten, 2019)

[4] A significant body of evidence including sources and methods employed for the generation of previous fifth carbon budget assumptions have utilised SAP based calculations. While SAP (and similar) calculations and conventions a hugely important part of the overall drive to make building construction more energy efficient, the key issue to note is that it is above all a compliance tool and does not necessarily represent the 'real' energy consumption of a dwelling (Morgan, 2018).

2 - Evidence Review and Analysis: A rapid review of the evidence in the literature was undertaken. This included tagging the aforementioned resources for assessment, then critically analysing, organising and logging relevant data in table format.

3 - Evidence Gap Identification and Prioritisation: Current knowledge and data gaps relating to fabric energy efficiency measures were identified to determine whether sufficient published evidence exists to support robust assumptions, or highlight key areas where standardized assumptions would need to be made to enable extrapolation. This also helped identify the scope of modelling needed to support these assumptions and define the modelling tasks required.

2.1.1. Criteria for Data Inclusion and Main Data Sources

To ensure consistency in the formulation of assumptions, a set of criteria were defined to assess available datasets and sources and determine which were suitable for further review and subsequent inclusion in the generation of assumptions for savings and costs (Table 2).

Table 2: Criteria for data inclusion

Category	Criteria
Data Type	Energy Savings: Field trial data, case study Costs: Surveys, field trial data, case study, generated cost estimates
Data Metric	Energy Savings: kWh savings gas consumption Costs: £ whole house and/or material and labour (where applicable)
Year	Latest available with backstop of 2007
Disaggregation	Data should clearly allow for the disaggregation of energy saving impact and costs of single measures
Sample size	Evidence based on larger sample sizes will take precedent, inclusion of smaller case study-based work will be included to account for the lack of availability of data for large sample sizes for deep retrofits

The full list of the data sources is documented in both the references section and Appendix A-6. The incorporation of the data sources into the underlying calculations is detailed in Appendices A-2 and A3 of this report. The <u>two main</u> datasets that were used as the starting point for the base assumptions were:

- **Energy Savings - National Energy Efficiency Data - Framework:** NEED is a data framework set up by BEIS (formerly DECC) to provide a better understanding of building energy use and performance of energy efficiency measures in the UK. The data framework matches gas and electricity annualised meter data, collected for BEIS sub-national energy consumption statistics, with data on energy efficiency measures installed in homes from the Homes Energy Efficiency Database (HEED), Green Deal, the Energy Company Obligation (ECO) and the Feed-in Tariff scheme. It focuses on fabric efficiency measures that include solid wall insulation, cavity wall insulation and loft insulation. It also includes data about property attributes and household characteristics obtained from a range of sources (BEIS, 2019a).
- **Costings - CAR Domestic cost assumptions - What does it cost to retrofit homes?** This report produced by Cambridge Architectural Research (CAR) aimed to update the cost assumptions for BEIS's Energy Efficiency Modelling by collecting data on the actual cost of 18 measures intended to improve household energy efficiency. Data was collected via interviews with 52 installers from around England and Wales. Supplementary information was gathered by email where required. A review of 15 published literature sources on the costs of energy efficiency upgrades, including cost data from websites, was also included. The cost data was released as spreadsheets accompanying the main report (CAR, 2017).

2.1.2. Covered Fabric Energy Efficiency Measures

The scope of the assessment UK domestic stock fabric energy efficiency measures. As a starting point, the list of applicable measures included in the fifth carbon budget assumptions (Table 3) were reviewed and assessed against the existing 'real-world' evidence base to ensure that the list met the following criteria:

- Coverage of measures: The primary data sets included in the review are aligned to the measure categories
- Robustness of data: Data is available and deemed of sufficient quality to generate valid assumptions for the covered measure categories

Table 3 : Fifth carbon budget fabric energy efficiency measures list: coverage & robustness (Element Energy & EST, 2013)

Fifth Carbon Budget Measures	Coverage	Robustness
Solid wall insulation (External)	**High**	**High**
Solid wall insulation (Internal)	High	High
Easy to treat cavities (low cost - high impact)	High	High
Hard to treat cavities (high cost EWI - high impact)	Medium	Medium
Hard to treat cavities (low cost - high impact)	Medium	Medium
Limited potential easy to treat cavities (low cost - low impact)	Low	Low
Hard to treat cavities (high cost IWI - high impact)	Medium	Medium
Loft insulation 50-124mm (85 mm average)	Low	Low
Loft insulation 50-124 mm (HTT) (78 mm average)	Low	Low
Loft insulation 125-199mm (145 mm average)	Low	Low
Loft insulation 125-199 mm (HTT) (143 mm average)	Low	Low
Suspended timber floor	Medium	Medium
Solid floor	Low	Medium
Potential for Double glazing (from single glazing)	High	High
Potential for Double glazing (from pre-2002 double glazing-E rating)	Medium	Low
Double glazing (post-2002 double (C rating) assumed only marginal benefit from upgrade	Medium	Medium
Insulated doors	Medium	Medium
Draught proofing (draught stripping)	Medium	Medium
Reduced infiltration (foam, strips, sealant use)	Medium	Medium
Jacket HW cylinder to top up with jacket (24.3 mm average)	Medium	Medium
Foam HW cylinder to top up with jacket (15.3 mm average)	Medium	Medium

Based on the above assessment, the list (detailed in Table 4) was revised as follows:

- Various cavity and loft insulation categories as well as double glazing variants were consolidated/ and or revised into a more workable list that was better aligned to existing data sets.
- Several measures not previously included were added to reflect evolving technologies such as thin internal wall insulation (TIWI)[5], and as denoted in the table, with applications for both heritage properties and higher energy saving/high performance retrofit (e.g. Passivhaus/EnerPHit).
- The terms 'draught proofing/stripping' and 'reduced infiltration' are often used interchangeably in existing literature. For clarity in this report, draught proofing is intended to refer to measures such as closing a chimney, while infiltration reduction measures considered here include such measures as adding sealant to windows etc, these are considered minor (and often DIY) measures. This reverses the previously used terminology from the fifth carbon budget assumptions.
- Measures targeting overheating risk such as ventilation and shading variants were included.

[5] Thin internal insulation systems are generally those where the thickness ranges between 10mm to 20mm (BEIS, 2017b)

Table 4: Updated sixth carbon budget measures list

Sixth Carbon Budget Measures	Heritage Application	High Performance Retrofit	Overheating Mitigation
External (solid) wall insulation (EWI)		X	
Internal (solid) wall insulation (IWI)	X	X	
Thin internal (solid) wall insulation (TIWI)	X		
Cavity Wall Insulation: Easy to treat unfilled cavities (CWI-ETTC)			
Cavity Wall Insulation: Hard to treat unfilled cavities (CWI-HTTC)			
Cavity Wall Insulation: Partially filled cavities			
Loft insulation (LI)			
Loft insulation: Hard to Treat (LI-HTT)			
Suspended timber floor insulation			
Solid floor insulation		X	
Secondary glazing (Estimate savings from G and E rating)	X		
Double glazing (Estimate savings from G and E rating)			
Slim profile double glazing (Estimate savings from G and E rating)	X		
Triple glazing (Estimate savings from G and E rating)		X	
Insulated doors		X	
Draught proofing (draught stripping)*	X	X	
Reduced infiltration (foam, strips, sealant use)*		X	
Hot Water (HW) tank insulation			
Ventilation			X
Shading (Fixed, Shutters and Internal Blinds for costings)			X

- **Note:** The terms draught stripping and reduced infiltration are often used interchangeably in existing literature. For clarity in this report, reduced infiltration is used to refer to more minor measures such as the use of sealants and foam strips for windows or doors, whereas draught proofing is intended to refer to measures such as sealing a chimney. These are not mutually exclusive and can be applied together to maximise benefits if appropriate.

2.1.3. Housing Archetypes and Standard Assumptions

In producing the assumptions, it was important to consider the housing typologies that would be used to structure the assumptions. Following a review of the format of datasets in the evidence base, as well as work undertaken at UCL to develop stock modelling archetypes, a base set of eight geometric archetypes (Table 5), representative of the main typologies in the UK housing stock was determined. Where relevant in the report text, to differentiate them from archetypes used in referenced studies, these are referred to as *'Assumptions Domestic Archetypes'* (ADA).

These eight archetypes were further categorized into three size variants (S-Small, M-Medium and L-Large) to enable easier mapping and comparison to the fifth carbon budget assumptions and to provide a more detailed view, where applicable, of the impact of building scale and geometry on savings and costings. The average geometric properties of the archetypes applicable for this analysis such as Total Floor Area (TFA), Covered Floor Area (CFA) and Loft Area (See Appendix A-1), were derived from the following data sources:

- Donaldson, L., 2018. Floor Space in English Homes – main report. MHCLG.
- Scottish Government, 2017. Scottish house condition survey: 2017 key findings. Scottish Government.
- EST, 2019. Determining the costs of insulating non-standard cavity walls and lofts. Department for Business, Energy & Industrial Strategy.

Table 5: Assumptions domestic archetypes

Category	Types
Flats	Converted Flat High Rise Purpose Built Flat Low Rise Purpose Built Flat
Medium Houses	Mid Terrace House End Terrace House Bungalow
Large Houses	Semi-Detached House Detached House

While the ADA archetypes broadly mapped on available data used for the generation of savings and costs assumptions, in some cases where data gaps did exist, a further set of Standard Assumptions were derived from a review of data to provide a standardised framework for extrapolation of data. The full set of these standard assumptions is documented in Appendix A-1. While this approach provided a pragmatic method by which to address existing data gaps, the impact of the application of standardised assumptions on the interpretation of data is reflected upon in the relevant sections and in the conclusions of this report.

2.2. Updated Energy Savings Assumptions for the Sixth Carbon Budget

The following section discusses the updated energy savings assumptions for a range of fabric energy efficiency measures, this includes:

- Updated energy savings assumptions for the sixth carbon budget measures
- Energy savings adjustment factors to be considered when interpreting the assumptions
- An overview of the potential impact of using different implementation approaches on achievable savings

It is important to note, that throughout this report that the term 'savings' denotes the estimated absolute energy saving potential in (kWh) achievable from the installation of measures.

The following lists the principles applied for the incorporation of data to these assumptions:

- All assumptions are based on an evidence base that primarily includes published literature, in particular datasets that include actual energy saving performance and costs from surveys, field trials and case studies
- The analysis is based on gas savings derived from the installation of single measures, with package and whole house approaches quantified as a secondary output
- Baseline savings assumptions are based on a quantified kWh metric of gas savings, thus studies including this metric or allowing its derivation were considered in the first instance
- Where represented in percentage terms, baseline savings are based on total gas consumption for each dwelling type (in line with NEED). Note that this will mean the percentage savings as set out cannot be treated as purely additive.
- Where possible, data is based on the latest available data releases from the NEED dataset (2019, based on 2017), for the measures typically covered by the dataset
- The currently available NEED dataset does not cover recent data that includes the more stringent fire safety requirements for high-rise flats. However, for all achievable savings for high-rise flat typologies, for relevant measures, it was assumed these only involve materials that comply with more stringent requirements
- Where NEED does not cover fabric energy efficiency measures, a wider range of data sets, manufacturer information...etc. are considered where available and as appropriate (e.g. double, slim profile, triple glazing, internal/thin internal wall insulation, draught proofing, floor insulation)

- Adjustment factors generated from literature are provided as percentage, such that they can be used as an uplift or decrease in achievable baseline savings, to provide an understanding of the impact of these factors on assumptions and for application where relevant for the formulation of modelling scenarios.
- The sources, rationale and uncertainty associated with each assumption is clearly defined and logged to allow traceability and transparency

2.2.1. Overview of Energy Savings Assumptions

Based on the abovementioned principles, estimated energy savings were assumed for the range of measures covered. These are described as absolute values (kWh) in Table 19 and Table 20 as a percentage saving relative to the NEED total gas baseline consumption in Table 21 and Table 22. The sources and calculation approaches which underlie these assumptions are detailed in Appendix A-2.3 Energy Savings Data Notes.

Insulation measures: Allowing for variability between measure categories, the most significant energy savings across archetypes are associated with insulation measures applied to walls, which is in line with conventions regarding the proportion of fabric heat losses through plane elements[6]. Based on the methodology applied, savings associated with the application of floor insulation are also considerable. It should be noted that although this estimate is based on best-available data, the evidence-base in this area is comparatively limited.

Glazing upgrades: Based on the applied calculation methodology, savings from glazing are generally greater for triple glazing across all archetypes. While slim profile double and secondary glazing both achieve lower savings than conventional double glazing, the relative decrease in savings is marginal compared to the impact their roll-out can achieve for archetypes where conventional glazing installations are not an option (older and heritage buildings).

Other measures: While relatively easier to implement, measures such as reduced infiltration and hot water tank insulation can collectively achieve considerable savings, comparable to for example, some types of glazing upgrades, when combined and implemented properly.

Savings assumptions for flats: One of the key areas where data gaps did exist related to the absence of a specific 'flats' category in the NEED dataset. To address this, a broad assumption was made that the savings for flats were in line with bungalows given that both house types are generally single storey configurations and generally align in age bands (it is acknowledged that the average floor area of bungalows might be larger than some flat types, but this is addressed in the third point below). As such, for impacted measures (e.g. EWI), flats achieve a percentage saving over the NEED baseline that is much higher than some larger archetypes such as mid terraces. However, this aligns with some observed findings relating to stock archetypes. Reasons for this may include:

- Flats are in general newer than mid terraces, therefore underlying issues that might impact the achieved savings from the installation of measures post retrofit are less likely to occur. This includes structural issues, gaps, leakiness etc.
- Flats are more likely to be impacted by co-benefits of being located amongst other units that have also been insulated, while with single family home typologies such as mid terraces this is not always the case. In other words, a flat that has been insulated is highly likely to be next to, above or beneath another 'warm' neighbouring property that has also been insulated. This enables a higher savings percentage due to such factors as the minimisation of thermal bridges, better installation practice and, heat loss through party walls.

[6] Fabric heat losses through the building fabric can be categorised as: plane heat losses which occur through the main elements of the building fabric (roof, walls, windows and floor) & thermal bridge heat losses which occur through corners, junctions, and structural elements penetrating the insulation layer. Buildings also lose heat by ventilation, i.e., the passage of air through them.

- Finally, work currently is being undertaken in the area of the (Heat Loss) Form Factor. This is related to the impact of built form and floor area on heat loss and energy saving potential and a measure of 'compactness' of a building, where the more compact a building is, the easier it is to be energy efficient. It has been assumed that this factor can be generally used to compensate for the size difference between bungalows and flats when savings were assumed to be broadly similar.

2.2.2. Savings Adjustment Factors: Performance Gap, Take Back Factor and Behavioural Interventions

Various studies have identified several factors that may impact the extent of energy savings that are achieved through the installation of fabric energy efficiency measures. In addition, emerging research has also highlighted the further impact of behavioural interventions on achieved energy savings. As part of the remit of the work, UCL were tasked with identifying these factors and generating relevant 'adjustment factors' and identifying reference data used.

It is important to note that the main data set used, NEED, is based on measured energy use. This therefore affects the interpretation and application of some of these adjustment factors as it is assumed that the NEED data already incorporates their impact. It is nonetheless useful to understand the extent of the impact of adjustment factors within such contexts as the application of energy savings assumptions in the formulation of scenarios.

Performance gap: This describes the difference between theoretical and modelled energy saving performance of installed energy efficiency measures. The performance gap has been attributed to various issues such as installation quality, operational practices and incorrect modelling assumptions. Adjustment factors associated with the performance gap can, for example, be used to inform an assumption on the uplift in achievable energy savings with some closure of the gap with better installation practices. For this work a range of case-study based evidence sources were reviewed (Table 6). The average performance gap (as a percentage of intended energy saving) was estimated to be 28% across cases, which ranged between 7%-50%. This is higher that the percentage assumed in previous work commissioned by the CCC (Element Energy and UCL, 2019). Some general findings from evidence identified that:

- In a sample of 86 dwellings across various age bands, a greater performance gap was associated with dwellings in older age bands (Gupta et al., 2015). This is corroborated by a further study which found that this is likely due to the higher likelihood of older properties being initially underheated (Summerfield et al , 2019).
- For a sample of 24 dwellings retrofitted as part of the TSB Retrofit for the Future Programme- (RT4F) despite having a lower initial energy use than the archetype average, a lower performance gap was reported. While the approaches implemented for R4TF projects are considered of a higher standard compared to current retrofit practice, this suggests that well planned deep whole-house retrofit has the potential to considerably decrease the performance gap (Gupta and Gregg, 2016).
- For a sample of five retrofit demonstration house types, representative of the top five typology groups in terms of carbon emissions, thorough retrofit and inspection processes effectively lead to the 'closure' of the anticipated performance gap and houses delivered on the performance reduction target (PRP and Peabody, 2016).

Take back factor (or comfort factor): This describes the reduction in expected energy savings attributed to occupants increasing internal temperatures following the installation of energy efficiency measures. Adjustment factors associated with the take back factor can, for example, be used to inform an assumption on the extent by which comfort taking has impacted achieved savings in the case of measured in-use data such as that included in NEED.

The overall take back factor of 33% listed below is based on the average of ranges described across reviewed studies (Table 6). Despite the existence of some uncertainty in regards to sample size, findings also indicate that the take back factor can vary based on both economic factors and tenure status. Specifically, the take back effect decreases from 44% in poorer households to 29% in wealthier households and ranges from an average of 40% for rental properties to 19% for owner occupied dwellings.

Behavioural Interventions: These are considered to be low-cost and largely easy-to-implement occupant centred interventions aimed at reducing energy waste and carbon emissions. Adjustment factors associated with behavioral interventions can, for example, be used to inform an assumption on further savings that can be achieved through behavioral change programmes that may complement fabric energy efficiency measures. An evidence review carried out for DECC highlighted that these programmes can be effective in encouraging people to use less energy in their home and that households with more scope to reduce energy use (i.e. those with higher baseline energy consumption) experience larger savings in energy use with interventions (RAND, 2012). In an aim to quantify the potential impact of various approaches, a number of key studies were r eviewed and average ranges quantifying the potential impact of behavioural interventions were derived (Table 7).

Table 6: Quantification of performance gap and take back factor on energy savings

Type	Adjustment Factor	Range		Sources
		L	H	
Performance Gap for all dwellings	28%	7%	50%	Gupta, R., Gregg, M., Passmore, S., Stevens, G., 2015. Intent and outcomes from the Retrofit for the Future programme: key lessons. Building Research & Information 43, 435–451. Gupta, R., Gregg, M., 2016. Do deep low carbon domestic retrofits actually work? Energy and Buildings 129, 330–343. PRP, Peabody, 2016. ETI Domestic Retrofit Demonstration Project, Summative Report 1. ETI.
Take Back Factor for all dwellings	33%	12%	49%	Aydin, E., Kok, N., Brounen, D., 2017. Energy efficiency and household behaviour: the rebound effect in the residential sector. The RAND Journal of Economics 48, 749–782. Brom, P. van den, Meijer, A., Visscher, H., 2018. Performance gaps in energy consumption: household groups and building characteristics. Building Research & Information 46, 54–70.
Take Back Factor by Tenure				
Rental	40%	31%	49%	
Owner Occupied	19%	12%	27%	
Take Back Factor by Income				
Low Income	44%	40%	49%	
High Income	29%	19%	39%	

Table 7: Impact of behavioural interventions on achieved energy savings

Type	Adjustment Factor	Range		Sources
		L	H	
Feedback	10%	5%	15%	Darby, S. (2006) The Effectiveness of Feedback on Energy Consumption, A Review for DEFRA of the Literature on Metering, Billing and Direct Displays (Oxford: Environmental Change Institute Barbu, A.-D., Griffiths, N., Morton, G., European Environment Agency, 2013. Achieving energy efficiency through behaviour change: what does it take? Publications Office, Luxembourg. RAND, 2012. What Works in Changing Energy-Using Behaviours in the Home? A Rapid Evidence Assessment. Department for Environment and Climate Change. Timmins, C., 2019. Assessing the heating energy use through varying set-point and set-back temperatures in a whole house test facility.
Direct feedback (including smart meters)	10%	5%	15%	
Indirect feedback (e.g. enhanced billing)	6%	2%	10%	
Feedback and target setting	10%	5%	15%	
Energy audits	20%	20%	20%	
Lowering temperature by 1 degree (20C-19C)	8%	8%	45%	
Lowering temperatures and reducing operating times	16%			

- Please note that the adjustment factors listed relate to the impact of discrete measures. The application of a combination of these measures would not be equivalent to the sum of their individual impact due to the complex interactions between them.

2.2.3. Quantifying the Impact of Implementation Approaches

Due to the lack of real case study data that describes the relative impact of single measure versus package and whole house installation of measures, a comprehensive modelling exercise was undertaken for three house types, that are generally representative of the small, medium and large domestic properties. The modelling used UCL's in-house modelling tool EPGen-2 and employed archetypes developed by UCL, which are considered to be broadly representative of the UK domestic stock and map to those used for the updated assumptions. These represent small (high rise flats), medium (mid-terrace) and large (detached) dwellings. The detailed modelling process and full assumptions are listed in Appendix A-4 of this report. In general:

- Measures were selected based on typical installations for modelled house types
- Results intend to give a general estimation of magnitude of possible relative savings from installation of measures on individual, whole house and package-based approaches[7]

Table 8: Impact of implementation approaches on energy savings

	% Savings improvement over baseline for house type					
Scenario	**Flat (GF)**	**Flat (MF)**	**Flat (TF)**	**Average Flats**	**Mid-Terrace**	**Detached**
A-Individual Measures (Total)	58	73	82	71	69	65
Wall insulation	32	63	51	49	39	41
Loft ins	0	-1	26	8	17	11
Floor ins	13	1	1	5	10	5
Windows->double glazed	3	6	4	4	4	2
Draughtproofing + Reduced Infiltration	13	8	2	8	8	7
Ventilation	-2	-4	-2	-3	-4	-1
Shading	-1	0	0	0	-5	-1
B-Whole House	61	74	83	73	73	69
C-Packages (Total)	61	76	84	73	74	66
Package 1: Walls + Window Upgrade	36	68	54	53	44	44
Package 2: Floor + Loft Insulation	13	0	24	12	27	17
Package 3: Auxiliary Measures	12	8	6	9	3	6

Notes

- Measures are selected based on typical installations for house types
- Individual measure list does not denote order of installation & total impact of individual measures/packages is a simple total.
- Other adjustment factors not applied & results subject to modelling uncertainty
- All dwellings modelled in urban central London location (Islington weather file)

In interpreting the findings listed in Table 8, it should be noted that the total impact of individual measures and packages is an aggregation of each separate measure. In reality, the total collective savings associated with individual measures or packages would be expected to be still lower relative to a whole house approach. This is due the cumulative impact of workmanship issues and installation problems that are likely to occur across multiple installation stages. These issues are less likely to occur in a whole house approach as the holistic installation strategy employed will more effectively address issues such as interaction of measures and key junctions between building elements. The assessment given above is therefore expected to underestimate the benefits of a whole house approach to retrofit. Improved evidence on the benefits of a whole-house approach should be determined through future outputs from the current BEIS DEEP projects (BEIS, 2019b).

An additional factor that may impact results is the increased likelihood of take-back factor. A modelling exercise for a range of retrofit options and of 'energy use behaviours', indicated that if occupants change their energy use behaviour after a moderate' energy efficient retrofit, there is a significant risk that energy use will increase.

[7] 'Whole house' is defined as an installation approach where the application of all fabric energy efficiency suitable for a particular house takes place simultaneously. 'Package' refers to an installation approach where a subset of suitable, and preferably complementary, measures are combined together for simultaneous installation.

However, if 'significant improvements in heat loss and system efficiency are undertaken space heating energy use will reduce irrespective of occupant behaviour (Love, 2014).

Evidence on the achieved savings impact and the sequencing of measures using real case studies remains limited. A review of relevant modelling-based resources suggests that the benefits and payback times of individual measures vary according to the preceding energy efficiency measures that have been applied, but the annual energy consumption at the end of the modelling timeframe is similar for various orders of measure installation. Early implementation of measures that achieve significant reductions in annual energy use, such as external wall insulation and double glazing, are thought to yield the greatest benefits with regard to the cumulative energy savings (Banfill et al., 2013).

2.3. Updated Cost Assumptions for the Sixth Carbon Budget

The following section includes updated cost assumptions for a range of fabric energy efficiency measures. This includes:

- Updated cost assumptions for the proposed list of measures
- Assumed cost ranges for the proposed list of measures
- Cost adjustment factors and uncertainties to be considered in interpreting the assumptions
- An overview of cost trajectories

The updated list of cost assumptions, the process for their generation, and accompanying data notes that detail the underlying calculations used to generate them, are detailed in Appendix A-3.1 of this report. The principles applied for the incorporation of data to generate assumptions on costs are as follows:

- All assumptions are based on an evidence base that primarily includes published literature, in particular, cost estimates generated from contractors/installers and datasets of actual costs from field trials /case studies where available
- The analysis is based on costs associated with the installation of single measures, with package and whole house approaches costs quantified as a secondary output through adjustment factors
- Baseline cost assumptions are based on either a quantified £ per house or £ material and labour, thus studies including this metric or allowing its derivation are primarily considered. Other cost categories are defined and considered separately to allow flexibility in application
- Where possible, data is based on the latest available data releases from BEIS, namely:
    - Domestic cost assumptions - what does it cost to retrofit homes?
    - Determining the costs of insulating non-standard cavity walls and lofts
- Where these data sets do not cover fabric energy efficiency measures, a wider range of data sets are considered where available and as appropriate
- The currently available datasets do not cover recent data that includes the more stringent fire safety requirements for high-rise flats. However, for all costings for high-rise flat typologies, for relevant measures, it was assumed these only involve materials that comply with more stringent requirements
- Adjustment factors are provided as percentages, such that they can be used as an uplift or decrease in baseline costs. Adjustment factors generated from literature are provided as percentage, such that they can be used as an uplift or decrease in achievable baseline saving. These have been generated from literature to provide an understanding of the impact of these factors on assumptions and for application where relevant for the formulation of modelling scenarios. These cover cost impact categories such as project size, scale and location.
- The sources, rationale and uncertainty associated with each assumption is clearly defined and logged to allow traceability and transparency

2.3.1. Overview of Cost Assumptions

Based on the abovementioned principles, estimated cost assumptions were made for the range of sixth carbon budget measures covered (material and labour costs unless otherwise stated, although uncertainty remains around the scope of some of the costs reported). These are described as absolute values (£ installation per/house) in Table 23 and Table 24. The ranges for these costs are also detailed in Table 25. The sources and calculation approaches which underlie these assumptions are detailed in Appendix A-3.3 Costings Data Notes.

Insulation measures: The costs associated with solid wall insulation measures in general represent the largest outlay across measures, in particular for larger archetypes (e.g. detached houses). Internal insulation costs (both conventional and thin) tend to be lower and external scaffolding is not needed for installation. However, other costs associated with minimization of disruption (e.g. temporary moving costs) and replacement of kitchens and bathrooms should be factored in for cases where this might be required.

Glazing upgrades: Costs associated with glazing measures are comparable to those for the most expensive insulation measures. In smaller archetypes, the cost of some glazing measures exceeds those associated with a number of wall insulation measures such as internal and cavity wall insulation.

Other measures: Comparative costs for measures such as reduced infiltration and hot water tank insulation represent a relatively small outlay. However as discussed in Section 2.2.1, their collective impact may in some cases be comparable to that of much more expensive measures such as glazing.

Mitigation of overheating: The mitigation of overheating and maintenance of good indoor air quality (IAQ) is an important aspect to consider alongside implementation of retrofit measures. While the costs of the installation of standard ventilation measures (such as extract fans) is comparatively low, estimated costings for the installation of shading is considerably higher. In some cases (e.g. flat archetypes) the costs are comparable to some insulation measures and glazing upgrades. However, for these archetypes (in particular top-storey flats) the presence of adequate shading is of even greater importance given their increased propensity to overheat (Symonds et al., 2017). It should be noted that Mechanical ventilation with heat recovery (MVHR) was not considered within the scope of this work as it is primarily a heating technology (therefore not within the remit of fabric energy efficiency measures).

2.3.2. Cost Adjustment Factors and Uncertainties

Fabric energy efficiency measure costings quoted across the sources reviewed incorporate a range of methodologies, which include various cost categories. Generally it is understood that the costs include labour and materials unless otherwise stated, although the scope of the costs from CAR data remains uncertain. For fabric energy efficiency measures that may not cover additional fixed costs, a number of supplementary cost categories are expected.

These costs are generated in a number of ways and can collectively contribute up to 50% of the total costs involved (AECB, 2011 & EU directorate 2016). For this work, they have been catalogued and are derived from a range of sources (Table 9), but are regarded as overheads that are unlikely to change regardless of the change in factors such property type, scale…etc.

Further cost impact factors: These encompass characteristics, either inherent to the properties themselves or associated with the implementation approach to delivering fabric energy efficiency measures, that may impact the overall costs. While the most important factors (property size and type) are both incorporated into the assumptions generated in this report, further cost impact factors listed below should be considered:

- **Economies of scale:** The CAR costings dataset incorporates some suggested scale-related cost efficiency savings, however these were based on limited sample sizes. Adjustment factors associated with economies of scale can for example inform assumptions where a number of properties simultaneously undergo installation such as in a street-by-street-approach[8]. In some cases, an increased number of properties might reduce some aspects of installation costs.
  However, a report by Changeworks (2012) suggests that many of the high costs such as logistics, planning permission, scaffolding, unexpected works and making good are fixed which means that cost reduction though economies of scale, although significant, may not be reduced as much as previously thought.

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[8] The following delivery/deployment strategies can be employed, in increasing scale of implementation (Raslan et al., 2017):
1-Pepper-pot: Installation in a number of selected properties within an area, whereby these properties may not be located near each other. This approach is often found in cases where retrofit is taken up by early adopters.
2-Street-by-street: A number of properties on a single street may undergo installation simultaneously allowing for more efficient supply practices as well as the opportunity for achieving economies of scale.
3-Area-based: Deployment to all properties in a defined area (neighbourhood, estate etc.). This solution provides the greatest opportunity for achieving economies of scale, an opportunity for decreased project duration, but may involve increased disruption in the area.

- **Project size and regional variations:** A review of evidence found guidelines relating to overall project size (which may be used as a proxy for single house versus multiple house installations) and regional variations around the UK (Table 10 and Table 11). Adjustment factors associated with these can for example be used to inform assumptions associated with large scale installations (e.g. estate-based installations for social housing providers) and assumptions regarding cost differences around the UK.
- **Sectoral variations:** Previous work undertaken by UCL on EWI collated costs of delivery that differentiated between private and social sectors (ACE, 2011). This found that private sector costs, estimated at £10,600-£14,600, were in general higher than social sector which were estimated at £8,400. This may be attributed to economies of scale as social landlords are able to carry out mass retrofit projects or differences in materials and finishes. While this this work focused on EWI, it can be assumed that similar variations may be assumed for other measures (Raslan et al., 2017). Adjustment factors associated with sectoral variations can for example be used to inform assumptions associated with owner occupier vs social housing costs at stock level.

Table 9: Supplementary 'fixed' cost assumptions

Cost Type	Cost Item	Unit	Average	Range	Price Year	Source
Construction Overheads	Full scaffold to front and back of houses	Fixed £/house	3700	1475-7900	2016	PRP, Peabody, 2016. ETI Domestic Retrofit Demonstration Project, Summative Report 1. ETI.
	Scaffolding - external walls (insulation) only	Fixed £/house	780	700-990	2011-2016	Rickaby, 2017. Capital costs of energy improvement measures. Savills
Finance	Item VAT	% of Project Cost	15%	N/A	2011	EST, 2011. FutureFit: Installation phase in-depth findings. Affinity Sutton.
	Insulation VAT	% of Project Cost	5%	N/A	2011	
	Inflation	% of Project Cost	12%	10-14%	2016	Confidential Project (2016), 5th Studio
,Planning/ Management	Planning/Building Control*	Fixed £/house	750	N/A	2016	PRP, Peabody, 2016. ETI Domestic Retrofit Demonstration Project, Summative Report 1. ETI.
	Survey and Design**	Fixed £/house	1275	450-2500	2016	
	Insurance, Administration & Profit	% of Project Cost	6.5%	N/A	2016	

Note:
*These costs would apply to projects not covered under permitted development rights, those located in 'designated areas' such as conservation areas and heritage properties

**These costs would more likely apply to extensive retrofit projects (i.e. whole house) that may incorporate significant changes to the exterior and/or interior of the property and older properties where pre-retrofit repairs might be required

Table 10: Suggested economies of scale/ project size: comparative costings

Project value (£)	Cost factor	Cost Adjustment (%)	Source
50,000	1.16	16%	Cost modelling, (2019) Q4 2019 cost data. Online.
100,000	1.12	12%	
250,000	1.07	7%	
500,000	1.03	3%	
750,000	1.01	1%	
1,000,000	1	0%	
1,250,000	0.98	-2%	
1,500,000	0.97	-3%	
2,000,000	0.96	-4%	
3,000,000	0.94	-6%	
4,000,000	0.925	7.5%	

*Based on a £1,000,000 construction project baseline = 1 has a cost factor of approximately 1

Table 11: UK construction cost regional variations: comparative costings

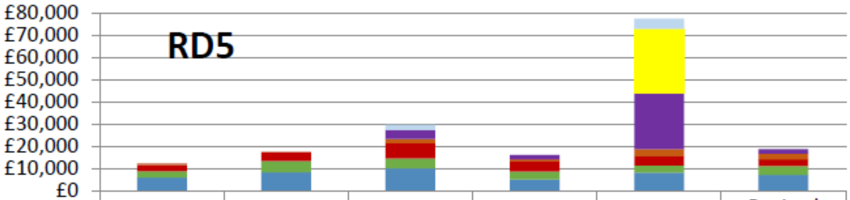
Region	Index	Source
UK National Average	100	Cost modelling [WWW Document], 2019. URL https://costmodelling.com/ (accessed 12.14.19).
North East	93	
North West	99	
Yorkshire and Humberside	97	
West Midlands	99	
East Midlands	97	
East Anglia	102	
South West	100	
South East	108	
Outer London	111	
Inner London	117	
Wales	96	
Scotland	98	
Northern Ireland	84	

* Indices set at current tender price index 181 (Q2-2019, Year 2000 = 100) and UK national average index 100

Cost uncertainties: It should be noted that while the assumptions generated in this report are based on a robust analysis of best-available data, retrofit delivery costs have been shown to be subject to significant uncertainties. In the recent ETI demonstration project (PRP and Peabody, 2016) the Outturn (actual cost of delivery) was compared to a range of projected costs. These included:

- Cost generated via a desk-based estimation for the ETI's Optimising Thermal Efficiency of Existing Homes (OTEoEH) project
- A Business as Usual (BAU) cost which assumed current contractor practices and supply chain arrangements
- Quoted project costs by a national contractor
- Expected costs based on the initial retrofit approach proposed in the study
- Expected costs based on the revised retrofit approach proposed in the study

The analysis across the retrofits implemented as part of this project illustrated that additional works. For one case study (Figure 1) this resulted an approximate 100% increase in estimated costings. This included disputed costs (which incorporate the value of the contractual disagreements) and variation in condition contingency (the estimated / actual costs for unexpected additional costs arising from deteriorated buildings; with older properties having higher estimated values) contributed to a significant costings uplift in practice.



	OTEoEH	BAU	National Contractor	Retrofit Approach	Out-Turn	Revised Retrofit Approach
Additional Works		-	2,087	-	4,537	-
Disputed		-	-	-	29,151	-
Condition Contingency		-	4,152	2,000	25,109	1,875
O/H & P	682.84	125	1,940	1,000	3,174	2,625
Prelims	2,731.36	3,923	6,902	4,460	4,200	3,013
Material	2,871	5,040	4,579	3,609	3,124	3,925
Labour	6,001	8,366	9,993	5,135	8,237	7,253
Total	12,286	17,454	29,653	16,204	77,532	18,691

Figure 1: Comparative retrofit costings of a 1945-1964 Semi-Detached: ETI demonstration project

2.3.3. Cost Trajectories

There is limited evidence concerning the potential cost changes or reduction trajectory of energy efficiency measures. It is expected that the ongoing BEIS Whole House Retrofit (WHR) project will produce evidence to meet this current knowledge gap. A review of current studies that may supplement the existing assumptions have highlighted the following points:

- Reinventing retrofit: How to scale up home energy efficiency in the UK: This recent EU report estimates that an Energiesprong-based retrofit cost reduction of 54% (from £75,000 to £35,000) versus an achievable 15% reduction for a conventional retrofit (from £47,000-£40,000) between 2018 to 2025 (Green Alliance, 2019).
- Passivhaus Construction Costs: This report focusing on Passivhaus level construction projects looked at several case studies. The study estimated that PassivHaus standard best practice was 8% higher than conventional construction and was expected to fall to 4% with the implementation of 'key success factors' which underlie the Passivhaus approach. While the study specifically looked at new build, it provides a guideline for cost uplift comparison between conventional and EnerPhit (the Passivhaus standard approach) retrofits (Passivhaus Trust, 2019).
- Offsite construction: Independent KPMG research found that in spite of the increased construction costs associated with one-off offsite construction projects, financial net savings of 7% were possible as a consequence of the shortened construction period (KPMG, 2016).

3. The Domestic Heritage Sector

There are a wide range of buildings that face additional challenges in decarbonising, including those formally recognised as having some form of heritage value (namely listed homes and homes in conservation areas) as well as traditional buildings more widely – generally considered to be those built prior to 1919. Our evidence gathering for the purposes of this work is focused on the former but many of the findings will be applicable to traditional buildings more generally.

Understanding the factors impacting fabric energy efficiency measure deployment for these buildings is important for the purposes of better understanding the likely costs associated with getting to net zero, as well as informing policy, learning and innovation. A stakeholder engagement exercise with heritage professionals and building designers with expertise in the heritage sector was undertaken to inform the assumptions contained in this report.

3.1. Overview of Heritage Suitability Assessment Methodology

Surveys enable the gathering of data that relates to real world practices, situations or views. As a research instrument, surveys have been widely used as in the wider scope of built environment research (e.g. Altavilla et al., 2004; Mahdavi, 2004). Quantitative analytical techniques are applied to then draw inferences from the data that is gathered on existing relationships (Davison, 1998).

For this exercise, a survey was undertaken via Opinio, (https://opinio.ucl.ac.uk/). This structured online feedback portal was used to engage a wide range of stakeholders, to gather views from the design and heritage community regarding the suitability of fabric energy efficiency measures for heritage categories in the current regulatory and planning environment[9]. The format involved the use of a pre-prepared online interactive data feedback form, where information was gathered from key invited participants. An email invitation to the survey was sent to representatives from the heritage bodies, members of stakeholder groups such as the EDGE, council planning departments who have issued specific guidelines in this area (e.g. Westminster, Bristol and Bath) and contacts through the UCL Institute of Sustainable Heritage (UCL-ISH). Feedback provided information regarding:

- Suitability assumptions for a range of energy efficiency measures
- Practical issues for consideration
- Identification of important lessons learned to the point of completion and occupation

Over 30 responses were received, this was followed by a number of follow up discussions (via email and in person with consenting participants) to enable further clarification/elaboration of key points, which were then analysed and collated for this report.

Note

The UK data protection legislation is set out in the Data Protection Act 2018 (DPA) and the General Data Protection Regulation (GDPR) (which also forms part of UK law). To ensure GDPR compliance, the following principles were applied:

- Survey responses were anonymized in such a manner that the data subject is not or no longer identifiable
- No sensitive data was collected, and participants were not categorized as vulnerable
- Participants who were interested in participating in further discussions were invited to give explicit and informed consent and submit their contact details.

[9] In addition to their commonplace application as part of consultation processes such as those involving building regulations and policy, they have been used to successfully and effectively compile information for large scale data surveys in research and engagement with stakeholders.

3.2. The Suitability of Energy Efficiency Measures: Survey findings

Survey participants provided responses regarding homes located in conservation areas as well as the following heritage categories utilised across in England/Wales, Scotland & Northern Ireland, respectively:

- **Conservation area:** dwellings in areas of special architectural & historic interest/character
- **Grade I/A/A**: dwellings of exceptional interest
- **Grade II*/B/B+**: particularly important dwellings of more than special interest
- **Grade II/C/ B1&B2**: dwellings that are of special interest, warranting every effort to preserve them

The main categories of suitability (Table 12) were generated based on the percentage of the responses recorded (Table 13), these were sub-categorised into wider range of suitability outcomes than initially proposed, to more closely capture the range of views included:

- **Suitable for most dwellings:** Measures that are generally acceptable for most dwellings within the heritage category
- **Suitable for most dwellings (limited):** Measure(s) that are generally deemed suitable for the majority of dwellings within a particular heritage category. However, their application should warrant more careful consideration in application and/or is likely to face constraints for some dwellings.
- **Suitable for some dwellings:** Measures that are generally acceptable for some of dwellings within the heritage category
- **Suitable for some dwellings (limited):** Measure(s) were deemed suitable for some dwellings, within a particular heritage category. However, their application is more limited, should warrant more careful consideration in application and/or is likely to face constraints for some dwellings.
- **Unsuitable for all dwellings:** Measures that are generally not suitable for all dwellings within a heritage category

Table 12: Heritage suitability matrix

Measure/Category	Conservation Area	Grade I	Grade II*	Grade II
External wall insulation-all facades visible from road	Suitable for some dwellings	Unsuitable for all dwellings	Suitable for some dwellings (limited)	Suitable for some dwellings (limited)
External wall insulation-facades not visible from road	Suitable for most dwellings	Suitable for some dwellings (limited)	Suitable for some dwellings (limited)	Suitable for some dwellings (limited)
Internal wall insulation applied to all external walls	Suitable for some dwellings	Suitable for some dwellings (limited)	Suitable for some dwellings	Suitable for some dwellings
Loft Insulation	Suitable for most dwellings	Suitable for most dwellings (limited)	Suitable for most dwellings (limited)	Suitable for most dwellings (limited)
Insulating suspended floors	Suitable for most dwellings (limited)	Suitable for some dwellings	Suitable for some dwellings	Suitable for most dwellings (limited)
Insulating solid floors	Suitable for some dwellings	Suitable for some dwellings	Suitable for some dwellings	Suitable for some dwellings
Secondary glazing	Suitable for most dwellings (limited)	Suitable for some dwellings	Suitable for some dwellings	Suitable for some dwellings
Double glazed windows	Suitable for some dwellings	Suitable for some dwellings (limited)*	Suitable for some dwellings (limited)	Suitable for some dwellings (limited)
Slim profile double glazing	Suitable for some dwellings	Suitable for some dwellings	Suitable for some dwellings	Suitable for some dwellings
Draught proofing	Suitable for most dwellings (limited)	Suitable for most dwellings (limited)	Suitable for most dwellings (limited)	Suitable for most dwellings (limited)
Reduced Infiltration	Suitable for most dwellings	Suitable for most dwellings (limited)	Suitable for most dwellings (limited)	Suitable for most dwellings (limited)
Installing external shading	Suitable for some dwellings	Suitable for some dwellings (limited)*	Suitable for some dwellings	Suitable for some dwellings
Installing shutters	Suitable for some dwellings	Suitable for some dwellings	Suitable for some dwellings	Suitable for some dwellings

***Note:** For Grade I it is assumed that measures designated as suitable for some dwellings (limited) would be limited to special cases and likely to include like for like replacement in line with the original features

Table 13: Recorded responses for survey

Category	Conservation Area			Grade I			Grade II*			Grade II		
Measure/Suitability	Suitable for all dwellings	Suitable for some dwellings	Unsuitable for all dwellings	Suitable for all dwellings	Suitable for some dwellings	Unsuitable for all dwellings	Suitable for all dwellings	Suitable for some dwellings	Unsuitable for all dwellings	Suitable for all dwellings	Suitable for some dwellings	Unsuitable for all dwellings
External solid wall insulation applied to all facades visible from the road	0%	50%	50%	0%	29%	71%	0%	41%	59%	0%	44%	56%
External solid wall insulation applied only to facades not visible from the road	0%	75%	25%	0%	59%	41%	0%	59%	41%	6%	59%	35%
Internal wall insulation applied to all external walls	25%	60%	15%	6%	59%	35%	6%	65%	29%	12%	71%	18%
Loft Insulation	80%	20%	0%	59%	41%	0%	59%	41%	0%	65%	35%	0%
Insulating suspended floors	50%	50%	0%	24%	71%	26%	26%	76%	0%	47%	53%	0%
Insulating solid floors	25%	65%	10%	6%	71%	24%	6%	82%	12%	12%	76%	12%
Secondary glazing	45%	50%	5%	18%	65%	18%	26%	59%	18%	24%	71%	6%
Double glazed windows	5%	90%	5%	6%	47%	47%	6%	59%	35%	6%	65%	29%
Slim profile double glazing	15%	85%	0%	6%	88%	6%	6%	88%	6%	6%	88%	6%
Draught proofing	60%	40%	0%	41%	47%	12%	47%	53%	0%	53%	47%	0%
Reduced Infiltration	80%	20%	0%	53%	47%	0%	53%	47%	0%	63%	38%	0%
Installing external shading	5%	85%	10%	6%	59%	35%	12%	59%	29%	12%	76%	12%
Installing shutters	15%	85%	0%	18%	59%	24%	12%	82%	6%	12%	88%	0%

***Note:** Percentage denotes the degree of acceptability based on responses from survey cohort

3.3. Further Considerations: Detailed Respondent Feedback

While the suitability matrix provides some generalised feedback on the extent to which measures are currently considered suitable for different types of property, the variability in the heritage sector necessitates that every building is considered on a case-by-case basis and would generally require a bespoke assessment and recommendations. Through the survey, further feedback regarding considerations associated with fabric energy efficiency measures was provided. These are summarised around the main themes listed below:

General suitability of fabric measures for the heritage sector:

- Current conservation philosophy is increasingly recognising the importance of 'intangible heritage'[10]. Therefore, potentially strong arguments could be made for the application of some fabric energy efficiency measures if this enables the ongoing use of the building as a functioning asset for a specific heritage activity.
- Any retrofits must be looked at in whole-life terms - including their impact on the longevity of the building. The reversibility of measures is also a major consideration.
- Some listed buildings can incorporate areas which are less significant from a heritage perspective, where the installation of (additional) fabric measures would be allowed.

Risk management:

- For the heritage sector, fabric energy efficiency measures were viewed to be potentially damaging if applied incorrectly. Some practitioners considered them to be unnecessary and instead championed investment in better technical equipment, more usable control systems and efficient low carbon energy supplies.
- Issues associated with impact, risk and unintended consequences should be considered and guided by such resources as those described in the STBA Guidance Wheel (STBA, 2015), the PAS 2035 matrix (BSI, 2019) and the body of work on unintended consequences from retrofit (e.g. Shrubsole et al., 2014).
- With climate change, overheating together with moisture and indoor air quality issues, should be factored into planning for retrofit in general, and in particular within the heritage sector.

Specific suitability considerations:

- Strategies need to be considered for their aesthetic qualities so as not to detract from the original vernacular.
- Materials need to be assessed carefully for their breathability so as not to damage the underlying fabric of the structure. Both the internal conditions and moisture management issues should be considered.
- There is a general view that foam or plastic based materials should not be used. Breathable products such as cork granule and lime-based insulation renders, wood fibre-based board insulation, hemp-based insulants etc, reduce the risk considerably, allow the building to buffer humidity as it would have done prior to using insulation and retain some of its thermal mass.
- The use of vapour permeable (wood fibre) insulation, in conjunction with a suitable ventilation system is now considered to be a possible solution for historic and listed solid wall buildings. If the thickness of this is carefully gauged to the moisture load and the factors of orientation, construction and exposure, then the risk of interstitial condensation or mould formation has been found to be very low.
- External insulation is preferable to internal insulation wherever possible. Its application should be supported by a discussion based on aesthetics (to ensure it can be incorporated discretely) and local planning flexibility.

[10] The term intangible heritage, which was used in the feedback provided by survey participants, refers to 'cultural heritage'. This has changed content considerably in recent decades and now extends beyond material 'monuments' to include traditions and practices, partially owing to the instruments developed by UNESCO (UNESCO, 2020)

- Unless internal insulation is carefully considered, there are greater risks of interstitial condensation. This risk is much higher with materials which are not breathable such XPS, and foam-based products.
- Solid walls and floors are at high risk from insulation trapping water from both condensation and leaks (which are more likely to occur in older buildings).
- Blanket support for draught-proofing was limited due to the fact that in many cases draughts provide background ventilation which is essential to deal with both internally and externally generated moisture loads.
- Post-occupancy monitoring in heritage buildings is showing that the performance gap in many heritage buildings is inverted - i.e. installed reality delivers an improvement on the approved modelling and design target. This is thought to be due to the fact that solid walls have been found to have much better U-Values than what was previously assumed for modelling. This is largely due to the poor and inconsistent nature of the materials and construction, where resultant air-voids act as a good insulant.
- There is little technical knowledge about the insulating behaviour of thick stone walls although they seem in practice to mollify external climate effectively. They may also be vulnerable to degradation if insulation is applied.
- High performance vacuum glazing (e.g. LandVac) and Low-E (thermal) glass[11], were highlighted a possible glazing material that might be suitable for some listed buildings.
- Thin and breathable insulating plasters may be suitable within buildings on external walls

3.4. Heritage Energy Savings and Costings

The body of evidence regarding achievable savings with the heritage sector and any factors that might specifically influence it remains relatively limited. As such, the energy savings generated for the general stock, in conjunction with the information provided in the suitability matrix, can be used to provide guidance in formulating scenarios relating to this sector.

For costings (Table 14), supplementary evidence from Bath and North East Somerset Council 'Retrofitting Estimate Spreadsheet' (Bath & North East Somerset Council, 2013)[12] was used to update existing heritage cost uplift assumptions included in the recent Element Energy recent UCL work on Hard to Decarbonise homes (Element Energy and UCL, 2019). For the final assumptions used in the subsequent work to inform the Sixth Carbon Budget see Element Energy for the CCC (2020) *Development of trajectories for residential heat decarbonisation to inform the Sixth Carbon Budget.*

[11] Low-emissivity glass (or Low-E glass) is a type of energy-efficient glass designed to prevent heat escaping out through windows.

[12] Based on real costs from contractors/manufacturers including applicable rates, overheads, prices, VAT etc for a series of idealised buildings.

Table 14: Heritage cost uplifts (Bath & North East Somerset Council, 2013)

	17th Century (£)	% increase on standard	18th Century Townhouse (£)	% increase on standard	Victorian-Edwardian (£)	% increase on standard	Ave % change	Notes
External Wall Insulation	40450	652%	12015	123%	30184	461%	618%	EWI/IWI denotes application on rear/other facades for heritage properties.
Internal Wall Insulation	30465	255%	21520	150%	28261	229%	317%	
Loft Insulation	1846	113%	614	-29%	1369	58%	71%	
Suspended Floor Insulation	1909	15%	5082	206%	4771	187%	204%	
Solid Floor Insulation	10252	N/A	14834	N/A	2282	N/A	N/A	
Secondary Glazing	5345	N/A	9716	N/A	17430	N/A	N/A	
Draught Proofing	264	N/A	533	N/A	667	N/A	N/A	
Window Draughtproofing	N/A	N/A	8987	65%	12357	127%	96%	
Shutters	6000	N/A	1600	N/A	16500	N/A	N/A	

4. Findings: Comparison and Limitations of Assumptions

The following section summarises the findings of this work, comparing the data and assumptions produced as part of this work to previous fifth carbon budget assumptions and highlighting key considerations to be taken into account when interpreting the work.

4.1. Discussion: Comparison to Fifth Carbon Budget Assumptions

As part of this work, the fifth carbon budget assumptions were reviewed at three key stages:

- **Stage 1:** During the initial review of the available body of evidence to provide a baseline for assumptions, to enable the early identification of key areas of uncertainty and help focus further analysis.
- **Stage 2:** The full scope of the fifth carbon budget variants (135) were equivalenced and compared to the initial assumptions generated for this work. This aimed to gauge the trajectory of change in assumptions and assess their applicability to the previously defined archetypes.
- **Stage 3:** On completion of the updated assumptions, a final comparison was undertaken to highlight the differences between data sources used, assess variability between the fifth carbon budget and updated assumptions.

Table 15 summarises the data source used for each set of assumptions. In general, the body of evidence incorporated into the updated assumptions broadly address the limitations associated with the theoretical nature of the modelling-based work employed as the basis for generating the fifth carbon budget assumptions.

Table 15: Comparison between data sources used for fifth carbon budget and updated assumptions (Element Energy and EST, 2013)

	Fifth carbon budget evidence	Updated sixth carbon budget evidence	Comment
Consumption Baseline	SAP calculations based on: SAP conventions (combination of standard assumptions & averaging across SAP bands & a modelling-based In-built (2012) report	NEED in-use consumption levels (2015 & 2017 average) for stock	Updated data includes in-use measured data rather than modelling based assumptions
Savings	SAP base calculation based on conventions (combination of standard assumptions & averaging across bands) in addition to sources such as Building Regulations Part L1B (2010) conventions, figures derived from a modelling based In-built (2012) & Energy Saving Trust (2005) GPG Improving airtightness in dwellings reports	In-use post installation data from NEED dataset (2019, based on 2017), referencing NEED (2005-2017) consumption levels where required. Further statistical releases & case study data such as: TIWI field trial data (Glew, et al 2019), installed case study data (e.g. Pelmakers & Elwell , 2017, Heath et all 2010) updated savings incorporating latest data on HTT cavities (EST 2019) , industry data, standards & research (e.g. BFRC 2019, NHBC, 2017, Ofgem 2008)	Updated data includes in-use measured data supplemented by further range of field trial & case study data when required. Also includes industry standards product technical specification requirements.
Costs	An analysis of data (1999-2009) to derive estimated costs, supplemented by SPON's Architect's books (2013) & National Insulation Association Guidance	Base statistical data derived from average values from CAR/BEIS database for covered dwelling level costs for typologies in addition to further field trial & case study data, such as: TIWI field trial data (Glew, et al for BEIS. Forthcoming), installed case study data (e.g. Heath et all 2010) updated costings incorporating latest data on HTT cavities (EST 2019) , industry data, standards & research (e.g. PDP 2019), contractor/ cost consultant costings (e.g. Green, et al 2019, Rickaby,2017) & specific research (e.g. Porritt, 2012)	Updated data provides more up-to-date estimates that include more realistic costings supplied by contactors & delivered on-site costings obtained from field trials.
Performance Gap	Covered as part of a derived 'in-use factor' where calculation formula was applied to savings based on DECC Green Deal impact assessment, supplemented by further research into delivered performance (Sanders & Phillipson 2006).	Domestic retrofit specific case study analysis including deep retrofit (Gupta, et al, 2015, 2016) & demonstration cases (PRP & Peabody, 2016).	Impacts of performance gap and takeback now implicit in savings assumptions based on NEED data. Updated data on expected scale of these impacts differentiates between categories that were previously combined under 'in-use factor' for more flexibility in application. Data updates Green Deal
Take back factor		Domestic retrofit specific case study analysis including in-depth research on household groups (e.g. Brom,. et al., 2018.)	

			assumptions with case studies.
Behavioural Interventions	Standard SAP values supplemented by ECI, University of Oxford (1997) & non-domestic smart meter roll-out Impact Assessment (DECC 2012)	Updated ECI research (Darby, 2006) on the effectiveness of feedback & large pan-European cohort study (Barbu, et al 2013)	Updated data extends behavioural intervention categories & incorporates case study elements cited

A further comparison of assumptions was undertaken for a key fifth carbon budget semi-detached archetype (this is represented by Variant 7 and Variant 8 in the fifth carbon budget stock), which is comparable to the medium semi-detached house ADA archetype used in this report.

Challenges in directly comparing fifth carbon budget and new assumptions

- Comparing costs and savings between the fifth carbon budget and the updated assumptions presented a challenge as they are often not generated on a like-for-like basis. For example, in relation to costs, fifth carbon budget assumptions are based on semi-detached homes with floor area of between 49.5 m^2-55.5 m^2, whilst the average semi-detached home in BEIS's assumptions has a floor area of 80m^2. It is also unclear to what extent interviewees for the study considered this floor area in providing costs, as opposed to providing them for semi-detached homes in general based on their experience.
- To allow for comparison, an area equivalencing exercise was undertaken. For cost comparison, a further adjustment took place where the costs were equivalenced based on Construction Output Price Indices (OPIs) issued by the ONS (ONS, 2020). This used the price index for the equivalent years from the assumptions as the baseline[13].
- For savings, the fifth carbon budget assumptions are based on SAP estimates for archetypes of specific dimensions as described in Table 15. The new assumptions are based on NEED which incorporates real world savings from all the semi-detached homes in the sample covered each year (of undisclosed sizes).

Main differences between fifth carbon budget and new assumptions

While not all measure categories were directly comparable, some findings include:

- Estimated savings for solid wall insulation (SWI) were in general lower in the updated assumptions. In the fifth carbon budget assumptions (CCC, 2015), it was noted that NEED was showing reduced savings relative to SAP, with some of this difference attributed to the fact that uninsulated solid walls have a lower U-Value than previously thought (1.4 W/m^2K as opposed to the standard SAP assumption of 2.1 W/m^2K, Loucari et al, 2016). The savings for fifth carbon budget were not updated to reflect this, as the evidence was still emerging. This is thought to be one of the main reasons for the differences shown here.
- Estimated energy savings for loft insulation typologies (both ETT and HTT), are in general higher than for previous assumptions. In general, these are less comparable than other measures as new data does not differentiate between different top-up levels.
- HTT cavities show a decrease in savings than previously assumed. NEED data does not differentiate between Easy to Treat Cavity (ETTC) and Hard to Treat Cavity (HTTC) and there is a lack of evidence in general literature that distinguishes between the performance of each. Whilst EWI or IWI solutions for HTTC might be expected to have higher savings, the evidence used does not suggest that this is generally the preferred solution for HTTC walls. The 2017 EST study quantifying the impact of insulating HTTCs (which was modelled with SAP) was examined and assessed as a possible source of guidelines/data for on

[13] Method:
1-To account for archetype size variation, a size adjustment was undertaken, where the sixth carbon budget costs or savings were calculated (where relevant) per/m2 elements , then multiplied by the corresponding area assumptions for the fifth carbon budget variants
Further adjustment for costs:
2-Sixth carbon budget costs per m2 or per unit equivalenced as per the price index values from assumption year = adjusted sixth carbon budget costs
3-To calculate new cost for fifth carbon budget archetypes = fifth carbon budget area X adjusted sixth carbon budget cost/m2 (where relevant)

generating savings however findings were deemed highly uncertain. Therefore, in line with the fifth carbon budget approach, savings were assumed to be the same as ETTC, which were lower in this study than previously assumed.

- Costs for double glazing have increased while associated energy savings have significantly decreased. While increased market competitiveness in the double glazing market, alongside the increased availability and affordability of alternative glazing options (e.g. Triple Glazing) would have been expected to result in an overall decrease in costs, the data incorporated into the formulation of new assumptions includes more up-to-date market research and more recent contractor estimations (sample size of six companies and seven contractors, respectively) which are more reflective of the current market.
- Costs for IWI have significantly increased compared to previous assumptions. In the 2013 report, which informed the fifth carbon budget (2015), assumptions were based on the Solid Wall Insulation Supply Chain Review (2009) undertaken by Purple research on behalf of the Energy Saving Trust and the Energy Efficiency Partnership for Homes. As this evidence base references much older data, the CAR dataset used in this report can be considered to provide a more up-to-date estimation of the current market.
- Floor insulation costs, in particular suspended solid floor insulation, has also increased significantly compared to previous assumptions. In the CAR dataset (CAR, 2017) costs vary significantly depending on what is included such as whether the floorboards are lifted as part of ongoing works, or whether they need to be lifted specifically for the installation of insulation. The difference in cost may therefore in-part be attributed to the varying scope of costs considered.
- Minor cost categories such as HW tank insulation has also increased in cost, despite having a minimal impact on overall costings.

4.2. Further Research and Limitations

This report and the work that underlies it has provided updated estimates of the potential energy savings (based on metered energy savings) and costs associated with the installation of fabric energy efficiency measures for the UK domestic sector. In doing so, the report has incorporated an updated and improved evidence-base on which to base assumptions. The methodology adopted has sought to incorporate a wider range of evidence based on 'real-data' from both field trials and case studies. The main limitations that should be considered when interpreting the assumptions contained in this report include:

- ***Data vs. Assumptions:*** While a comprehensive review of available sources and datasets was carried out, the main available statistical releases on which this work is based (the NEED dataset and the CAR costings), had inherent limitations in regards to the coverage of the data (both in relation to archetypes and the measures covered). As noted in Section 2.1.1 NEED is based on specific schemes and may not capture all retrofits undertaken in the UK. The data may therefore is not necessarily indicative of savings that would be achieved where measures installed in the wider stock.
  In addition, the CAR dataset is based on comparatively small sample sizes for some measures and there are uncertainties regarding the materials associated with the measures covered for a number of the costings. To address this, certain assumptions had to be made to enable the extrapolation of data where it was found to be missing. The cases in which these assumptions were used were nonetheless explicitly recorded to ensure transparency.
- ***Modelling vs. Reality*:** To address further evidence gaps, a modelling exercise was undertaken to inform our understanding of the impact of combining measures. While modelling aims to represent a complex system but it cannot precisely replicate it, especially in the case of occupant behaviour and this remains an important evidence gap.
- ***Real homes vs. Archetypes:*** The archetypes around which the assumptions were structured, were developed to be to be broadly representative of the housing stock and to enable close mapping to the available evidence. As with all archetypes, they are however idealized representations of typologies within the UK stock. Real homes, and their occupants, will deviate from these assumptions that are inherent to these archetypes.

- *Case Studies:* Due to the inherent nature of case study-based research, the ability to generalise findings is often limited and attempts to transfer this learning or key lessons for wider application can present a challenge (Yin, 2011).

Key recommendations to address the abovementioned limitations and provide the knowledge base to address the main data gaps found, can be listed as follows:

- To enable rigorous evaluation of projects, more consistent information needs to be made available in regard to the real-world performance of fabric energy efficiency measures. Historical field trials have been limited in scope and have mainly dealt with the installation of a set combination of measures. Since the disaggregation of the impacts of individual measures is often challenging given the data available from the field trials, this limits the flexibility of applying their findings for a subset or alternative combinations of these measures for further analysis.
- Within the group of case study projects and field trials analysed, key limitations associated with the availability and consistency of data in regard to costings and performance improvements was found. This needs to be addressed through careful design and commissioning of research projects in this area.
- The coverage of the NEED dataset requires expansion beyond the impact of fabric measures already included. As the number of flats within the stock increases, flat archetypes should be differentiated from the general stock within the dataset to facilitate more robust future analysis.

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The following list includes the main data sources used for this analysis. These are cited in both this data note and the analysis spreadsheet.

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Appendices

A-1 Standard Assumptions for Extrapolation

Table 16: Assumptions Dwelling Archetypes: geometric area statistics

	Average Dwelling Total Floor Area TFA by type (over all floors m2)			Covered (External) wall area by type (m2) (Excluding Windows and Doors)	Loft area by type (m2)	Sources
Type	England [1]	Scotland [2]	Average (weighted)	Average [3]	Average [3*]	1-Donaldson, L., 2018. Floor Space in English Homes – main report. MHCLG. 2-Scottish Government, 2017. Scottish house condition survey: 2017 key findings. Scottish Government.3-EST, 2019. Determining the costs of insulating non-standard cavity walls and lofts. Department for Business, Energy & Industrial Strategy.
CNV Flat	65	75	69	29	61	
Flat LR	55	67	55	29	55	
Flat HR	55	67	55	29	55	
Mid Terrace	81	94	81	43	39	
End Terrace	86	94	86	77	39	
Semi-Detached	93	101	93	82	49	
Detached	152	146	151	172	73	
Bungalow	77	N/A	77	45	77	

Note: * Where EST loft area estimates are considerably different than expected for single storey house types (e.g. exceeds the TFA), the loft area is taken as equivalent to TFA

Table 17: Relational size assumptions for data extrapolation (where data is not available for specific archetype)

Small property variant = 0.7 average value*	* Not based in absolute min & max floor area of each type but assumed main range. Based on UCL expertise in archetypes.
Large property variant = 1.3 average value *	
Bungalow = 0.75 detached (where required)	
End Terrace = 1.3 Mid Terrace (where required)	
Flats = Bungalow (where required)	

Table 18: Number of windows & typical window areas for house archetypes

Type	No	Notes	Typical window area (m2)	Source
CNV Flat	4	2 Bed	14	NHBC, 2017. Windows - making it clear- Energy, daylighting and thermal comfort. National House-Building Council.
Flat LR	4	2 Bed	11	
Flat HR	4	2 Bed	11	
Mid Terrace	5	2 Bed	16	
End Terrace	5	2 Bed	15	
Semi-Detached	7	Average SD	16	
Detached	12	Average D	36	
Bungalow	5	2 Bed	19	

A-2 Updated Energy Savings Assumptions and Data Notes

A-2.1-Process for Assumptions Generation

1-Definintion of archetype dataset:

1.1-Review evidence base to define criteria for generating assumptions for domestic archetypes (ADA)

1.2-Define appropriate assumptions around housing archetype typologies for data structuring and mapping

1.3-Generate assumptions to be used for mapping and extrapolation where needed (e.g. assumptions for area approximations for variants etc)

2-Definition of measures covered:

2.1-Review evidence base to define criteria

2.2-Define subsequent list of measures to be included

3-Review NEED dataset outputs: Solid Wall, Cavity Wall, Loft Insulation

3.1- Define NEED measure coverage and gaps

3.2- Map NEED data to ADA, applying generated assumptions where needed to allow extrapolation to those typologies not explicitly covered by NEED.

3.3- Cross reference NEED assumptions generated with any available case study data to determine agreement/disagreement of assumptions

3.4- If within acceptable range (<= 10%) no adjustment is required, if beyond re-examine evidence base to determine if revision is needed and apply required adjustment

4-Review and analyse wider data sets for other measures:

4.1- Determine most appropriate/complete dataset to be used for other measures

4.2- Map data to ADA, applying generated assumptions where needed to allow extrapolation to those typologies not explicitly covered by datasets

4.3- Cross reference assumptions generated with any available case study data to determine agreement/disagreement of assumptions

4.4- If within acceptable range (<= 10%) no adjustment is required, if beyond re-examine evidence base to determine and apply required revision

5-Define and determine adjustment factors

5.1- Review literature to determine appropriate savings-related adjustment factors (performance gap, take back factor)

5.2- Determine appropriate ranges from evidence and define framework for application (e.g. house type, tenure type etc.)

A-2.2-Detailed Energy Savings Assumptions Tables

Table 19: Assumptions for energy savings from fabric retrofit measures: converted flats, purpose built flats & mid terrace houses (kWh) – **Uncertainty:** Low Medium High

Measures/ size		Converted Flat			Purpose-Built Low-Rise Flat			Purpose-Built High-Rise Flat			Mid-Terrace House			Refer to date note for data sources & calculations
		S	M	L	S	M	L	S	M	L	S	M	L	
1	Solid wall insulation (External)	1050	1500	1950	1050	1500	1950	1050	1500	1950	840	1200	1560	S1.1
2	Solid wall insulation (Internal)	887	1268	1648	887	1268	1648	887	1268	1648	710	1014	1318	S1.2
3	Solid Wall insulation (Thin)	852	1217	1582	852	1217	1582	852	1217	1582	681	973	1265	S1.3
4	Easy to treat cavities (Unfilled)	770	1100	1430	770	1100	1430	770	1100	1430	350	500	650	S1.4
5	Hard to treat cavities (Unfilled)	770	1100	1430	770	1100	1430	770	1100	1430	350	500	650	S1.5
6	Partially filled cavities	887	1268	1648	887	1268	1648	887	1268	1648	710	1014	1318	S1.6
7	Loft insulation	560	800	1040	560	800	1040	0	0	0	420	600	780	S1.7
8	Loft insulation (HTT)	560	800	1040	560	800	1040	0	0	0	420	600	780	S1.8
9	Suspended timber floor insulation	580	828	1076	417	596	775	417	596	775	661	944	1227	S1.9
10	Solid floor insulation	580	828	1076	417	596	775	417	596	775	661	944	1227	S1.10
11.a	Secondary glazing (From Band G)	502	502	502	394	394	394	394	394	394	564	564	564	S1.11
11.b	Secondary glazing (From Band E)	228	228	228	179	179	179	179	179	179	256	256	256	S1.11
12.a	Double glazing (From Band G)	541	541	541	424	424	424	424	424	424	607	607	607	S1.12
12.b	Double glazing (From Band E)	246	246	246	193	193	193	193	193	193	276	276	276	S1.12
13.a	Double Glazing- Slim profile (From Band G)	491	491	491	386	386	386	386	386	386	552	552	552	S1.13
13.b	Double Glazing- Slim profile (From Band E)	197	197	197	154	154	154	154	154	154	221	221	221	S1.13
14.a	Triple Glazing (From Band G)	688	688	688	540	540	540	540	540	540	773	773	773	S1.14
14.b	Triple Glazing (From Band E)	393	393	393	309	309	309	309	309	309	442	442	442	S1.14
15	Insulated doors	0	0	0	140	140	140	0	0	0	140	280	280	S1.15
16	Draught proofing (draught stripping)	171	283	405	123	204	291	123	204	291	238	350	469	S1.16
17	Reduced infiltration (foam, strips, sealant)	145	207	269	104	149	194	104	149	194	165	236	307	S1.17
18	HW Tank insulation	404	461	452	291	332	325	291	332	325	343	453	539	S1.18
19	Ventilation	0	0	0	0	0	0	0	0	0	0	0	0	S1.19
20	Shading	0	0	0	0	0	0	0	0	0	0	0	0	S1.20

Table 20: Assumptions for energy savings from fabric retrofit measures: end terrace, semi detached, detached & bungalow houses (kWh) – **Uncertainty:** Low Medium High

Measures/ size		End Terrace			Semi Detached			Detached			Bungalow			Refer to date note for data sources & calculations
		S	M	L	S	M	L	S	M	L	S	M	L	
1	Solid wall insulation (External)	1190	1700	2210	1470	2100	2730	1890	2700	3510	1050	1500	1950	S1.1
2	Solid wall insulation (Internal)	1006	1437	1867	1242	1775	2307	1597	2282	2966	887	1268	1648	S1.2
3	Solid Wall insulation (Thin)	965	1379	1793	1192	1704	2215	1533	2190	2847	852	1217	1582	S1.3
4	Easy to treat cavities (Unfilled)	630	900	1170	840	1200	1560	1470	2100	2730	770	1100	1430	S1.4
5	Hard to treat cavities (Unfilled)	630	900	1170	840	1200	1560	1470	2100	2730	770	1100	1430	S1.5
6	Partially filled cavities	1006	1437	1867	1242	1775	2307	1597	2282	2966	887	1268	1648	S1.6
7	Loft insulation	280	400	520	350	500	650	630	900	1170	560	800	1040	S1.7
8	Loft insulation (HTT)	280	400	520	350	500	650	630	900	1170	560	800	1040	S1.8
9	Suspended timber floor insulation	708	1012	1316	787	1124	1461	1044	1492	1940	764	1092	1420	S1.9
10	Solid floor insulation	708	1012	1316	787	1124	1461	1044	1492	1940	764	1092	1420	S1.10
11.a	Secondary glazing (From Band G)	547	547	547	588	588	588	1280	1280	1280	664	664	664	S1.11
11.b	Secondary glazing (From Band E)	249	249	249	267	267	267	582	582	582	302	302	302	S1.11
12.a	Double glazing (From Band G)	589	589	589	634	634	634	1379	1379	1379	715	715	715	S1.12
12.b	Double glazing (From Band E)	268	268	268	288	288	288	627	627	627	325	325	325	S1.12
13.a	Double Glazing- Slim profile (From Band G)	536	536	536	576	576	576	1254	1254	1254	650	650	650	S1.13
13.b	Double Glazing- Slim profile (From Band E)	214	214	214	230	230	230	501	501	501	260	260	260	S1.13
14.a	Triple Glazing (From Band G)	750	750	750	806	806	806	1755	1755	1755	910	910	910	S1.14
14.b	Triple Glazing (From Band E)	429	429	429	461	461	461	1003	1003	1003	520	520	520	S1.14
15	Insulated doors	140	280	280	140	280	280	140	280	280	140	280	280	S1.15
16	Draught proofing (draught stripping)	239	350	467	264	387	511	317	459	603	216	317	421	S1.16
17	Reduced infiltration (foam, strips, sealant)	177	253	329	197	281	365	261	373	485	191	273	355	S1.17
18	HW Tank insulation	312	410	486	294	372	429	306	384	437	287	363	418	S1.18
19	Ventilation	0	0	0	0	0	0	0	0	0	0	0	0	S1.19
20	Shading	0	0	0	0	0	0	0	0	0	0	0	0	S1.20

Table 21: Assumptions for energy savings from fabric retrofit measures: converted flats, purpose built flats & mid terrace houses (% saving over NEED annual metered gas consumption baseline)

Uncertainty: Low Medium High

Measures/ size		Converted Flat			Purpose-Built Low-Rise Flat			Purpose-Built High-Rise Flat			Mid-Terrace House			Refer to date note for data sources & calculations
		S	M	L	S	M	L	S	M	L	S	M	L	
1	Solid wall insulation (External)	14%	14%	14%	20%	20%	20%	20%	20%	20%	10%	10%	10%	S1.1
2	Solid wall insulation (Internal)	12%	12%	12%	17%	17%	17%	17%	17%	17%	9%	9%	9%	S1.2
3	Solid Wall insulation (Thin)	12%	12%	12%	16%	16%	16%	16%	16%	16%	8%	8%	8%	S1.3
4	Easy to treat cavities (Unfilled)	11%	11%	11%	15%	15%	15%	15%	15%	15%	4%	4%	4%	S1.4
5	Hard to treat cavities (Unfilled)	11%	11%	11%	15%	15%	15%	15%	15%	15%	4%	4%	4%	S1.5
6	Partially filled cavities	12%	12%	12%	17%	17%	17%	17%	17%	17%	9%	9%	9%	S1.6
7	Loft insulation	8%	8%	8%	11%	11%	11%	0%	0%	0%	5%	5%	5%	S1.7
8	Loft insulation (HTT)	8%	8%	8%	11%	11%	11%	0%	0%	0%	5%	5%	5%	S1.8
9	Suspended timber floor insulation	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	S1.9
10	Solid floor insulation	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	S1.10
11.a	Secondary glazing (From Band G)	7%	5%	4%	8%	5%	4%	8%	5%	4%	7%	5%	4%	S1.11
11.b	Secondary glazing (From Band E)	3%	2%	2%	3%	2%	2%	3%	2%	2%	3%	2%	2%	S1.11
12.a	Double glazing (From Band G)	7%	5%	4%	8%	6%	4%	8%	6%	4%	7%	5%	4%	S1.12
12.b	Double glazing (From Band E)	3%	2%	2%	4%	3%	2%	4%	3%	2%	3%	2%	2%	S1.12
13.a	Double Glazing- Slim profile (From Band G)	7%	5%	4%	7%	5%	4%	7%	5%	4%	7%	5%	4%	S1.13
13.b	Double Glazing- Slim profile (From Band E)	3%	2%	1%	3%	2%	2%	3%	2%	2%	3%	2%	1%	S1.13
14.a	Triple Glazing (From Band G)	9%	7%	5%	10%	7%	6%	10%	7%	6%	9%	7%	5%	S1.14
14.b	Triple Glazing (From Band E)	5%	4%	3%	6%	4%	3%	6%	4%	3%	5%	4%	3%	S1.14
15	Insulated doors	0%	0%	0%	3%	2%	1%	0%	0%	0%	2%	2%	2%	S1.15
16	Draught proofing (draught stripping)	2%	3%	3%	2%	3%	3%	2%	3%	3%	3%	3%	3%	S1.16
17	Reduced infiltration (foam, strips, sealant)	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	S1.17
18	HW Tank insulation	6%	4%	3%	6%	4%	3%	6%	4%	3%	4%	4%	4%	S1.18
19	Ventilation	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	S1.19
20	Shading	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	S1.20

Table 22: Assumptions for energy savings from fabric retrofit measures: end terrace, semi detached, detached & bungalow houses (% saving over NEED annual metered gas consumption baseline)

Uncertainty: Low Medium High

Measures/ size		End Terrace			Semi Detached			Detached			Bungalow			Refer to date note for data sources & calculations
		S	M	L	S	M	L	S	M	L	S	M	L	
1	Solid wall insulation (External)	13%	13%	13%	15%	15%	15%	14%	14%	14%	11%	11%	11%	S1.1
2	Solid wall insulation (Internal)	11%	11%	11%	13%	13%	13%	12%	12%	12%	9%	9%	9%	S1.2
3	Solid Wall insulation (Thin)	11%	11%	11%	12%	12%	12%	12%	12%	12%	9%	9%	9%	S1.3
4	Easy to treat cavities (Unfilled)	7%	7%	7%	9%	9%	9%	11%	11%	11%	8%	8%	8%	S1.4
5	Hard to treat cavities (Unfilled)	7%	7%	7%	9%	9%	9%	11%	11%	11%	8%	8%	8%	S1.5
6	Partially filled cavities	11%	11%	11%	13%	13%	13%	12%	12%	12%	9%	9%	9%	S1.6
7	Loft insulation	3%	3%	3%	4%	4%	4%	5%	5%	5%	6%	6%	6%	S1.7
8	Loft insulation (HTT)	3%	3%	3%	4%	4%	4%	5%	5%	5%	6%	6%	6%	S1.8
9	Suspended timber floor insulation	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	S1.9
10	Solid floor insulation	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	8%	S1.10
11.a	Secondary glazing (From Band G)	6%	4%	3%	6%	4%	3%	10%	7%	5%	7%	5%	4%	S1.11
11.b	Secondary glazing (From Band E)	3%	2%	2%	3%	2%	1%	4%	3%	2%	3%	2%	2%	S1.11
12.a	Double glazing (From Band G)	7%	5%	4%	6%	5%	3%	11%	7%	6%	7%	5%	4%	S1.12
12.b	Double glazing (From Band E)	3%	2%	2%	3%	2%	2%	5%	3%	3%	3%	2%	2%	S1.12
13.a	Double Glazing- Slim profile (From Band G)	6%	4%	3%	6%	4%	3%	10%	7%	5%	7%	5%	4%	S1.13
13.b	Double Glazing- Slim profile (From Band E)	2%	2%	1%	2%	2%	1%	4%	3%	2%	3%	2%	1%	S1.13
14.a	Triple Glazing (From Band G)	8%	6%	5%	8%	6%	4%	13%	9%	7%	10%	7%	5%	S1.14
14.b	Triple Glazing (From Band E)	5%	3%	3%	5%	3%	3%	8%	5%	4%	5%	4%	3%	S1.14
15	Insulated doors	2%	2%	2%	1%	2%	2%	1%	2%	1%	1%	2%	2%	S1.15
16	Draught proofing (draught stripping)	3%	3%	3%	3%	3%	3%	2%	2%	2%	2%	2%	2%	S1.16
17	Reduced infiltration (foam, strips, sealant)	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	S1.17
18	HW Tank insulation	4%	3%	3%	3%	3%	2%	2%	2%	2%	3%	3%	2%	S1.18
19	Ventilation	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	S1.19
20	Shading	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	S1.20

A-2.3-Energy Savings Data Notes

The following describe the underlying calculations used for the generation of the base energy savings assumptions & reference data used. The work is based on the use of **best-available data**. It is intended that these notes are used in conjunction with the data in across the tables in Appendix A-2-3 (cross referencing each note).

Notes:

a. For final savings assumptions, where relevant further adjustment of the base data was undertaken following an assessment of uncertainty & comparison against applicable case study data (this further adjustment is detailed in the Savings Adjustment Factors)

b. Savings use the BEIS. 2017. National Energy Efficiency Data Framework (NEED): Headline figures: Summary consumption statistics dataset for baseline energy consumption for estimation of percentage savings over baseline (average metered annual gas consumption - 2015 & 2017)

c. Where the NEED baseline consumption data is incorporated in the generation of assumptions for the selected measures savings, the average of the full data range (2005-2017) is considered.

d. Where required, to determine, SML size variants, values were normalised for m^2 for each typology based on area assumptions (Tables 16 & 17) derived from data from:
- Donaldson, L..2018 Floor Space in English Homes – main report. MHCLG.
- Scottish Government 2017: Scottish house condition survey - 2017 key findings. Scottish Government
- EST.2019.Determining the costs of insulating non-standard cavity walls & lofts. Department for Business, Energy & Industrial Strategy

e. Glazing area assumptions refer to Table 18

S1.1	**External Wall Insulation:** External solid wall insulation energy saving (kWh/annum) = NEED Mean Impact for house type (kWh/annum) X House type area adjustment factor • BEIS, 2015. Green Deal & Energy Company Obligation (ECO): headline statistics:-November 2015 Base statistical data is derived from mean values from NEED database for house typologies included. NEED data assumed to relate to EWI as it is the predominant type of SWI (95.5% versus 4.5% for IWI) installed in the UK To determine SML size variants sources listed in Note d above, were used & where required, the data refers to relational size assumptions detailed in the Standard Assumptions to extrapolate across typologies. For high rise flats it is assumed that only non-combustible materials are used, this is assumed to only have an implication on the type & extra thickness of material used rather than on performance. This is based on an MHCLG study on a new build which suggests that an additional 35mm of space would be needed, & for a rainscreen Aluminium Cladding Material façade an additional 40mm would be needed when using Mineral fibre insulation rather than phenolic foam (MHCLG, 2018).
S1.2	**Internal Wall Insulation:** **Internal wall insulation energy saving (kWh/annum)= Derived EWI saving (kWh/annum) X IWI performance reduction factor (%)** As NEED does not differentiate between EWI & IWI (the dataset lists one category for Solid Wall Insulation), based on relative EWI/IWI installation figures highlighted in ECO / Green Deal Statistics, it is assumed that the majority of recorded SWI installations are EWI. • DECC/BEIS .2015. Data tables: Green Deal, ECO & insulation levels, up to June 2015, BEIS. Therefore, to derive the assumptions for IWI a **15.5%** reduction factor was applied to account for expected decreased performance of typical IWI compared to EWI. In deriving this, two main sources were considered: • Kosny, J. & Kossecka, E..2002. Multi-dimensional heat transfer through complex building envelope assemblies in hourly energy simulation programs Energy & Buildings, 34(5): 445-454 : Confirms that the placement of the insulating material is more efficient when **situated externally** • EST .2006 (CE184) Practical refurbishment of solid-walled houses: Highlights a **15.5%** reduction in comparative performance of IWI compared to EWI using installations of 60mm & 120mm thicknesses respectively (considered typical for both when IWI thicknesses are smaller to minimise internal space loss). Much of the research in this area is based on modelling studies & there is a need for more field work in this area to check the underlying assumptions of the models.

S1.3	**Thin Internal Wall Insulation:** **Thin internal wall insulation energy saving (kWh/annum) = Derived IWI saving (kWh/annum) X TIWI performance reduction factor (%)** The evidence base for TIWI performance is under development & is based on ongoing research: • Glew, D., Parker, D., Miles-Shenton, D., Fletcher, M., Thomas, F., Booth, J., Cobden, L. for BEIS (Forthcoming). Thin Internal Wall Insulation (TIWI) Project. Leeds Beckett University for BEIS: based on emerging findings at the time of writing, assumptions are generated from IWI savings with a **4%** reduction factor applied. The reduction factor is based on the average relative performance improvement figure from the most recent BEIS TIWI field trials (including PIR, Aerogel, EPS, Cork render & Latex foam roll). This gave a range of 10%-17% improvement over base case Heat Transfer Coefficient & difference of 4% reduction in performance on average compared to IWI.
S1.4	**Cavity Wall Insulation (Easy to Treat – ETT):** **Cavity Wall Insulation (Easy to Treat-ETT) energy saving (kWh/annum) = NEED Mean Impact for house type (kWh/annum) x House type area adjustment factor** Base statistical data derived from mean values from NEED Database for covered typologies. For the purposes of calculation, NEED data is assumed to relate to Easy to Treat CWI. To determine SML size variants, sources listed in Note d above were used & where required, the data refers to relational size assumptions detailed in the Standard Assumptions to extrapolate across typologies.
S1.5	Cavity Wall Insulation (Hard to Treat-HTT): Cavity Wall Insulation (Hard to Treat-HTT) energy saving (kWh/annum) =NEED Mean Impact for house type (kWh/annum) x House type area adjustment factor NEED data does not differentiate between Easy to Treat Cavity (ETTC) & Hard to Treat Cavity (HTTC) & there is a lack of evidence in general literature that differentiates between the performance of each. Whilst EWI or IWI solutions might be expected to have higher savings, the evidence does not suggest that this is generally the preferred solution for HTT cavity walls. • Ofgem.2013. Energy Companies Obligation: Supplementary Guidance: While ECO guidance differentiates between six categories of hard-to-treat cavities under ECO, it does not detail any performance implications associated with HTTC (only skills/material requirements) • EST, 2017. Quantification of non-standard cavity walls & lofts in Great Britain. Department for Business, Energy & Industrial Strategy. The 2017 EST study quantifying the impact of insulating HTTCs was examined & assessed as a possible source of guidelines/data for on generating savings. This EST data was modelled using SAP & primarily quantifies carbon savings. When converted using quoted BEIS conversion factor for natural gas kwh for year produced (2016), this showed marginal savings of 50-150 kWh across house types (approximately ~10% of NEED savings for CWI) using this method it was therefore likely to be not considered a cost-effective/implementable option & the finding was therefore deemed highly uncertain. As such, the EST 2017 study was not included. Therefore, for the purposes of data calculation, it is assumed that there is only a cost/skill implication & theoretically the savings performance potential, in line with 5CB assumptions, is therefore the same as ETTC.
S1.6	Cavity Wall Insulation (Partial Fill): Cavity Wall Insulation (Partial Fill) energy saving (kWh/annum) = Derived IWI Savings (kWh/annum) • EST 2019. Determining the costs of insulating non-standard cavity walls & lofts. Department for Business, Energy & Industrial Strategy : Latest EST research assumes that the majority of partially filled cavity walls have failed insulation (i.e. insulation boards not secured to the inner leaf) & will therefore require internal wall insulation (IWI), rather than assuming the partially insulated cavities can be simply filled with additional insulation. In addition, the extent to which a cavity is partially insulated is variable & to date there has not been a robust methodology to determine the extent that it is insulated to without destructive site testing. As such it would be a reasonable assumption to adhere to the absolute saving from IWI. Assumptions are therefore assumed to be broadly the same as IWI

S1.7	Loft Insulation: Loft Insulation energy saving (kWh/annum) = NEED mean Impact for house type (kWh/annum) X House type area adjustment factor • BEIS, 2015. Green Deal & Energy Company Obligation (ECO): headline statistics-November 2015 Base statistical data is derived from mean values from NEED Database for covered typologies. NEED data assumed to relate to standard loft insulation as it is the predominant type installed in the UK To determine, SML size variants sources listed in Note d above, were used & where required, the data refers to relational size assumptions detailed in the Standard Assumptions to extrapolate across typologies.
S1.8	Loft Insulation- Hard to Treat (HTTL) Loft Insulation- Hard to Treat (HTTL) energy saving (kWh/annum) =NEED mean impact for house type (kWh/annum) X House type area adjustment factor Base statistical data is derived from mean values from NEED Database for covered typologies. NEED data does not differentiate between Easy to Treat Loft (ETTL) & Hard to Treat Loft (HTTL) & there is a lack of evidence that differentiates between the performance of each. The same methodology (& outcome) was applied to determine the applicability of EST 2017 data on HTTL in this exercise. It is assumed that there is a cost implication rather than a performance implication compared to ETTL. To determine SML size variants, sources listed in Note d above, were used & where required, the data refers to relational size assumptions detailed in the Standard Assumptions to extrapolate across typologies.
S1.9	Suspended Floor Insulation: Suspended floor insulation energy saving(kWh/annum) = NEED Baseline Consumption NEED Baseline Consumption (kWh/annum) X Proportion savings estimate (%) • BEIS. 2017. National Energy Efficiency Data Framework (NEED): Headline figures: Summary consumption statistics: No NEED measure specific data exists for floor insulation. For the purposes of this calculation, the NEED baseline consumption (as note above) was used as a starting point. • Pelsmakers, S., Elwell, C.A. 2017. Suspended timber ground floors: Heat loss reduction potential of insulation interventions. Energy & Buildings 153, 549–563: A heat loss reduction factor of 78% (average from Pelsmakers monitoring study) is applied to standard heat loss fraction of floors resulting in an estimated **8%** saving from baseline consumption across house types
S1.10	Solid Floor Insulation: Solid floor insulation energy saving (kWh/annum) = Suspended Floor saving (kWh/annum) • BEIS. 2017. National Energy Efficiency Data Framework (NEED): Headline figures: Summary consumption statistics: No NEED measure specific data exists for floor insulation. For the purposes of this calculation, NEED baseline consumption were used as a starting point & the assumed savings for suspended floor insulation (based on method described in S1.9) was used. • Pelsmakers, S., Elwell, C.A. 2017. Suspended timber ground floors: Heat loss reduction potential of insulation interventions. Energy & Buildings 153, 549–563: A heat loss reduction factor of 78% (average from Pelsmakers monitoring study) is applied to standard heat loss fraction of floors resulting in an estimated **8%** saving from baseline consumption across house types
S1.11	Secondary Glazing: Secondary Glazing energy saving (kWh/annum) = Energy saving moving from G or E to mid band C rated window (kWh/m^2/annum) X average glazing area for house type (m^2) Table 18: • BFRC 2019 Rating Scheme for Windows & Doors, British Fenestration Rating Council. • NHBC, 2017. Windows - making it clear- Energy, daylighting & thermal comfort. National House-Building Council. Secondary glazing is assumed to be equivalent to double glazing = C rated as per BFRC scale (based on EST recommendations). This was informed by an online market review of secondary glazing manufacturers. This highlighted that some manufacturers specify a 0.8W/m^{2}K U-value, which allowing for in-use performance reductions, would compare to a C rated double glazed unit. These units utilise Low-E glass. As such, savings were calculated as resulting energy savings for two options a: replacing a G rated (single glazed window) & b: replacing a mid-E rated window (older double glazing) based on BFRC Energy Index x average glazing area for housing typology from NHBC assumptions. Please note that the initial estimate is based on BFRC rating based on verified experimental testing of glazing configurations, while original SAP calculations are based on modelling estimates. For secondary glazing a **35%** reduction factor was applied to estimated savings to account for the pattern of over-estimation (30-50%) for glazing types attributed to issues such as installation quality. This was derived from

	over seven types that were assessed in situ & compared to manufacturer specification in the following studies: • Swan, W., Fitton, R., Gorse, C., Farmer, D., Benjaber, M.A.A., 2017. The staged retrofit of a solid wall property under controlled conditions. Energy & Buildings 156, • Heath, N., Baker, P., Menzies, G., 2010. Slim-profile double glazing: Thermal performance & embodied energy. Historic Scotland.
S1.12	Double Glazing: Double Glazing energy saving (kWh/annum) = Energy saving moving from G or E to mid band C rated window ($kWh/m^2/annum$) X average glazing area for house type (m^2) • BFRC 2019). Rating Scheme for Windows & Doors, British Fenestration Rating Council. • NHBC, 2017. Windows - making it clear- Energy, daylighting & thermal comfort. National House-Building Council. Double glazing assumed to be C rated as per BFRC scale. As such, savings were calculated as resulting savings for two options a: replacing a G rated (single glazed window) & b: replacing a mid-E rated window (older Double Glazing) based on BFRC Energy Index x average glazing area for housing typology from NHBC assumptions. Please note that the initial estimate is based on BFRC rating based on verified experimental testing of glazing configurations, while original SAP calculations are based on modelling estimates. For double glazing a **30%** reduction factor was applied to estimated savings to account for the pattern of over-estimation (30-50%) for glazing types attributed to issues such as installation quality. This was derived from over seven types that were assessed in situ & compared to manufacturer specification in the following studies: • Swan, W., Fitton, R., Gorse, C., Farmer, D., Benjaber, M.A.A., 2017. The staged retrofit of a solid wall property under controlled conditions. Energy & Buildings 156, • Heath, N., Baker, P., Menzies, G., 2010. Slim-profile double glazing: Thermal performance & embodied energy. Historic Scotland.
S1.13	Slim Profile Double Glazing: Slim Profile Double Glazing energy saving (kWh/annum) = Energy saving moving from G or E to lower band C rated window ($kWh/m^2/annum$) X average glazing area for house type (m^2) • BFRC 2019. Rating Scheme for Windows & Doors, British Fenestration Rating Council. • NHBC, 2017. Windows - making it clear- Energy, daylighting & thermal comfort. National House-Building Council Slim profile double glazing assumed to be lower band C rated as per BFRC scale based on general in-situ performance outcomes in: • Heath, N., Baker, P., Menzies, G., 2010. Slim-profile double glazing: Thermal performance & embodied energy. Historic Scotland. As such, savings were calculated as resulting savings for two options a: replacing both a G rated (single glazed window) & b: replacing a mid-E rated window (older Double Glazing) based on BFRC Energy Index x average glazing area for housing typology from NHBC assumptions. Please note that the initial estimate is based on BFRC rating based on verified experimental testing of glazing configurations, while original SAP calculations are based on modelling estimates. For slim profile double glazing a **30%** reduction factor was applied to estimated savings to account for the pattern of over-estimation (30-50%) for glazing types attributed to issues such as installation quality. This was derived from over seven types that were assessed in situ & compared to manufacturer specification in the following studies: • Swan, W., Fitton, R., Gorse, C., Farmer, D., Benjaber, M.A.A., 2017. The staged retrofit of a solid wall property under controlled conditions. Energy & Buildings 156, • Heath, N., Baker, P., Menzies, G., 2010. Slim-profile double glazing: Thermal performance & embodied energy. Historic Scotland.
S1.14	Triple Glazing: Triple glazing energy saving (kWh/annum) = Energy saving moving from G or E to A++ rated window ($kWh/m^2/annum$) X average glazing area (m^2) for house type • BFRC 2019 Rating Scheme for Windows & Doors, British Fenestration Rating Council. • NHBC, 2017. Windows - making it clear- Energy, daylighting & thermal comfort. National House-Building Council. Savings were calculated as resulting savings for two options a: over both a G rated (single glazed window) & over a mid-E rated window (older double glazing) based on BFRC Energy Index x average glazing area for housing

	typology from NHBC assumptions. Please note that the initial estimate is based on BFRC rating based on verified experimental testing of glazing configurations, while original SAP calculations are based on modelling estimates. For triple glazing a **30%** reduction factor was applied to estimated savings to account for the pattern of over-estimation (30-50%) for glazing types attributed to issues such as installation quality. This was derived from over seven types that were assessed in situ & compared to manufacturer specification in the following studies: • Swan, W., Fitton, R., Gorse, C., Farmer, D., Benjaber, M.A.A., 2017. The staged retrofit of a solid wall property under controlled conditions. Energy & Buildings 156, • Heath, N., Baker, P., Menzies, G., 2010. Slim-profile double glazing: Thermal performance & embodied energy. Historic Scotland.
S1.15	Insulated Doors: Insulated door energy saving (kWh/annum) = Energy saving moving from G to A++ door (kWh/m^2/annum) X average door area for house type (m^2) • BFRC 2019. Rating Scheme for Windows & Doors, British Fenestration Rating Council. Replacement door assumed to be A++ rated as per BFRC scale. Savings calculated as resulting savings over a G rated door based on BFRC Energy Index x average external door area of 2m^2. BFRC rating based on verified experimental testing of door configurations. LR flat doors assumed to be external, otherwise no replacement door required due to adjacency to internal space (internal foyer/hallway). Medium & large house types are assumed to have two external doors.
S1.16	Draught Proofing: Draught proofing energy saving (kWh/annum) = NEED Baseline Consumption (kWh/annum) X Proportion savings estimate (%) • BEIS. 2017. National Energy Efficiency Data Framework (NEED): Headline figures: Summary consumption statistics • Ofgem 2008. Energy Saving Matrix Values based on % savings of total consumption from Ofgem Energy Savings Matrix (2008) estimated for draughtproofing (range **2.3-3.1%** based on house type) applied to BEIS NEED based baseline gas consumption. The terms draught proofing/stripping & reduced infiltration are often used interchangeably in existing literature. For clarity in this report, draught proofing is intended to refer to measures such as sealing a chimney.
S1.17	Reduced Infiltration: Reduced infiltration energy saving (kWh/annum) = NEED Baseline Consumption (kWh/annum) X Proportion savings estimate (%) • BEIS. 2017. National Energy Efficiency Data Framework (NEED): Headline figures: Summary consumption statistics • ETI 2013 Single dwelling implementation plan, Energy Technologies Institute Infiltration reduction measures considered here include such measures as adding sealant to windows…etc. these are considered minor (& often DIY) measures. Therefore, assumed values based on **2%** savings of total consumption from ETI study applied to BEIS NEED based baseline gas consumption
S1.18	HW Tank Insulation: HW Tank Insulation=(kWh/annum) = NEED Baseline Consumption (kWh/annum) X Proportion savings estimate (%) • BEIS. 2017. National Energy Efficiency Data Framework (NEED): Headline figures: Summary consumption statistics • Ofgem 2008 Energy Saving Matrix Values based on % savings of total consumption from Ofgem Energy Savings Matrix (2008) (range **1.8-5.6%** based on house type) applied to BEIS NEED based baseline gas consumption
S1.19	Ventilation: Ventilation not assumed to be heating energy saving measure (but is likely to have marginal increase on electrical energy use), but mitigation for overheating/ IAQ measure
S1.20	Shading: Shading not assumed to be heating energy saving measure (likely to have marginal increase on energy use due to limitation of heat gain), but mitigation for overheating.

A-3 Updated Costing Assumptions and Data Notes

A-3.1-Process for Assumptions Generation

1-Defininition of archetype dataset:

1.1-Review evidence base to define criteria for generating assumptions for domestic archetypes (ADA)

1.2-Define appropriate assumptions of housing archetype typologies for data structuring and mapping

1.3-Generate assumptions to be used for mapping and extrapolation where needed (e.g. assumptions for area approximations for variants etc)

2-Definition of measures covered:

2.1-Review evidence base to define criteria

2.2-Define subsequent list of measures to be included

3-Review BEIS cost dataset outputs

3.1- Define BEIS measure costs coverage and gaps

3.2- Map BEIS cost data to ADA, applying generated assumptions where needed to allow extrapolation to those typologies not explicitly covered by BEIS cost data.

3.3- Cross reference BEIS cost assumptions generated with any available case study data to determine agreement/disagreement of assumptions

3.4- If within acceptable range (<= 10%) no adjustment is required, if beyond re-examine evidence base to determine and apply required revision

4-Review and analyse wider data sets for other measures:

4.1- Determine most appropriate/complete dataset to be used for other measures

4.2- Map data to ADA, applying generated assumptions where needed to allow extrapolation to those typologies not explicitly covered by datasets

4.3- Cross reference assumptions generated with any available case study data to determine agreement/disagreement of assumptions

4.4- If within acceptable range (<= 10%) no adjustment is required, if beyond re-examine evidence base to determine and apply required revision

5-Define and determine adjustment factors

5.1- Review literature to determine appropriate cost-related adjustment factors (economies of scale, regional variation, project size)

5.2- Determine appropriate ranges from evidence and define framework for application (e.g. house type, size etc.)

A-3.2-Detailed Costings Assumptions Tables

Table 23: Assumptions for costings of fabric retrofit measures: converted flats, purpose built flats & mid terrace houses (in £ material + labour, * denotes additional uncertainty over scope of costs) -Uncertainty: Low Medium High

Measures/ size		Converted Flat			Purpose-Built Low-Rise Flat			Purpose-Built High-Rise Flat			Mid-Terrace House			Refer to date note for data sources & calculations	Final Price Year
		S	M	L	S	M	L	S	M	L	S	M	L		
1	Solid wall insulation (External)*	4200	6000	7800	4200	6000	7800	4200	6000	7800	5005	7150	9295	C1.1	2015-16
2	Solid wall insulation (Internal)*	2205	3150	4095	2205	3150	4095	2205	3150	4095	2695	3850	5005	C1.2	2015-16
3	Solid Wall insulation (Thin)*	1588	2268	2948	1588	2268	2948	1588	2268	2948	1940	2772	3604	C1.3	2015-16
4	Easy to treat cavities (Unfilled)*	284	405	527	284	405	527	284	405	527	338	482	627	C1.4	2015-16
5	Hard to treat cavities (Unfilled)*	1988	2840	3692	2135	3050	3965	2135	3050	3965	3199	4570	5941	C1.5	2019
6	Partially filled cavities	2205	3150	4095	2205	3150	4095	2205	3150	4095	2695	3850	5005	C1.6	2015-16
7	Loft insulation*	263	375	488	263	375	488	263	375	488	270	385	501	C1.7	2015-16
8	Loft insulation (HTT)*	3097	4425	5752	5901	8431	10960	5901	8431	10960	1416	2023	2629	C1.8	2019
9	Suspended timber floor insulation	2457	3510	4563	1928	2755	3581	1928	2755	3581	1534	2191	2849	C1.9	2015-16
10	Solid floor insulation	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2454	3506	4558	C1.10	2015-16
11	Secondary glazing*	2100	3000	3900	2100	3000	3900	2100	3000	3900	3115	4450	5785	C1.11	2015-16
12	Double glazing *	2100	3000	3900	2100	3000	3900	2100	3000	3900	3115	4450	5785	C1.12	2015-16
13	Double Glazing- Slim profile*	2520	3600	4680	2520	3600	4680	2520	3600	4680	3738	5340	6942	C1.13	2015-16
14	Triple Glazing*	2573	3675	4778	2573	3675	4778	2573	3675	4778	3816	5451	7087	C1.14	2015-16
15	Insulated doors	0	0	0	1000	1000	1000	0	0	0	1000	2000	2000	C1.15	2012-15
16	Draught proofing (draught stripping)	65	65	65	65	65	65	65	65	65	135	135	135	C1.16	2015-16
17	Reduced infiltration (foam, strips, sealant)	16	16	16	16	16	16	16	16	16	34	34	34	C1.17	2015-16
18	HW Tank insulation	85	85	85	85	85	85	85	85	85	85	85	85	C1.18	2015-16
19	Ventilation	500	500	500	500	500	500	500	500	500	500	500	500	C1.19	2012-15
20.a	Shading Fixed	1701 - 3717	1701 - 3717	1701 - 3717	1701 - 3717	1701 - 3717	1701 - 3717	1701 - 3717	1701 - 3717	1701 - 3717	1260 - 2205	1260 - 2205	1260 - 2205	C1.20	2011
20.b	Shading Internal	1200	1200	1200	1200	1200	1200	1200	1200	1200	1600	1600	1600	C1.20	2012
20.c	Shading Shutters	3150	3150	3150	3150	3150	3150	3150	3150	3150	3272	3272	3272	C1.20	2012

Table 24: Assumptions for costings of fabric retrofit measures: end-terrace, semi detached, detached & bungalow houses (in £ material + labour, * denotes additional uncertainty over scope of costs)-
Uncertainty: Low Medium High

Measures/ size		End-Terrace			Semi-Detached			Detached			Bungalow			Refer to date note for data sources & calculations	Final Price Year
		S	M	L	S	M	L	S	M	L	S	M	L		
1	Solid wall insulation (External)*	6507	9295	12084	5670	8100	10530	7595	10850	14105	6860	9800	12740	C1.1	2015-16
2	Solid wall insulation (Internal)*	3504	5005	6507	4830	6900	8970	5810	8300	10790	4410	6300	8190	C1.2	2015-16
3	Solid Wall insulation (Thin)*	2523	3604	4685	3478	4968	6458	4183	5976	7769	3175	4536	5897	C1.3	2015-16
4	Easy to treat cavities (Unfilled)*	439	627	815	416	594	773	571	815	1060	455	650	845	C1.4	2015-16
5	Hard to treat cavities (Unfilled)*	4921	7030	9139	3990	5700	7410	7350	10500	13650	5513	7875	10238	C1.5	2019
6	Partially filled cavities	3504	5005	6507	4830	6900	8970	5810	8300	10790	4410	6300	8190	C1.6	2015-16
7	Loft insulation*	350	501	651	291	415	540	389	555	722	434	620	806	C1.7	2015-16
8	Loft insulation (HTT)*	1257	1796	2335	1542	2203	2865	2944	4205	5467	2208	3154	4100	C1.8	2019
9	Suspended timber floor insulation	1576	2251	2926	1694	2420	3146	2612	3731	4850	2708	3868	5028	C1.9	2015-16
10	Solid floor insulation	3241	3601	4682	2710	3872	5034	4179	5970	7760	4332	6189	8045	C1.10	2015-16
11	Secondary glazing*	4050	5785	7521	4165	5950	7735	4970	7100	9230	4620	6600	8580	C1.11	2015-16
12	Double glazing *	4050	5785	7521	4165	5950	7735	4970	7100	9230	4620	6600	8580	C1.12	2015-16
13	Double Glazing- Slim profile*	4859	6942	9025	4998	7140	9282	5964	8520	11076	5544	7920	10296	C1.13	2015-16
14	Triple Glazing*	4961	7087	9213	5102	7289	9475	6088	8698	11307	5660	8085	10511	C1.14	2015-16
15	Insulated doors	1000	2000	2000	1000	2000	2000	1000	2000	2000	1000	2000	2000	C1.15	2012-15
16	Draught proofing (draught stripping)	135	135	135	275	275	275	275	275	275	135	135	135	C1.16	2015-16
17	Reduced infiltration (foam, strips, sealant)	34	34	34	69	69	69	69	69	69	34	34	34	C1.17	2015-16
18	HW Tank insulation	85	85	85	85	85	85	85	85	85	85	85	85	C1.18	2015-16
19	Ventilation	500	500	500	500	500	500	500	500	500	500	500	500	C1.19	2015-16
20.a	Shading Fixed	1260 - 2205	1260 - 2205	1260 - 2205	2394 - 4126	2394 - 4126	2394 - 4126	2363 - 5575	2363 - 5575	2363 - 5575	1260 - 2205	1260 - 2205	1260 - 2205	C1.20	2011
20.b	Shading Internal	1600	1600	1600	2200	2200	2200	2600	2600	2600	1600	1600	1600	C1.20	2012
20.c	Shading Shutters	3272	3272	3272	4510	4510	4510	5694	5694	5694	3272	3272	3272	C1.20	2012

Table 25: Costings Ranges: ranges represent the lowest cost for the smallest archetype and the highest cost for the largest archetype - **Uncertainty:** Low Medium High

	Measures	L	H	Notes
1	**Solid wall insulation (External)**	£ 4,300	£ 20,000	BEIS/CAR Data-CAR, 2017. What Does It Cost to Retrofit Homes? Department for Business, Energy & Industrial Strategy.
2	**Solid wall insulation (Internal)**	£ 2,500	£ 11,600	BEIS/CAR Data-CAR, 2017. What Does It Cost to Retrofit Homes? Department for Business, Energy & Industrial Strategy.
3	**Solid Wall insulation (Thin) (m2)**	£ 30	£ 140	L-Thermo Paint, H-Aerogel. Glew, D., Parker, D., Miles-Shenton, D., Fletcher, M., Thomas, F., Booth, J., Cobden, L., for BEIS (Forthcoming). Thin Internal Wall Insulation (TIWI) Project.
4	**Easy to treat cavities (Unfilled)**	£ 300	£ 1,200	BEIS/CAR Data-CAR, 2017. What Does It Cost to Retrofit Homes? Department for Business, Energy & Industrial Strategy.
5	**Hard to treat cavities (Unfilled)**	£ 1,300	£ 13,400	EST, 2019. Determining the costs of insulating non-standard cavity walls and lofts. Department for Business, Energy & Industrial Strategy.
6	**Partially filled cavities**	£ 2,500	£ 11,600	Ranges for IWI used-BEIS/CAR Data-CAR, 2017. What Does It Cost to Retrofit Homes? Department for Business, Energy & Industrial Strategy.
7	**Loft insulation**	£ 180	£ 955	BEIS/CAR Data-CAR, 2017. What Does It Cost to Retrofit Homes? Department for Business, Energy & Industrial Strategy.
8	**Loft insulation (HTT)**	£ 611	£ 9360	EST, 2019. Determining the costs of insulating non-standard cavity walls and lofts. Department for Business, Energy & Industrial Strategy.
9	**Suspended timber floor insulation**	£ 550	£ 900	BEIS/CAR Data-CAR, 2017. What Does It Cost to Retrofit Homes? Department for Business, Energy & Industrial Strategy.
10	**Solid floor insulation**	£ 550	£ 900	BEIS/CAR Data-CAR, 2017. What Does It Cost to Retrofit Homes? Department for Business, Energy & Industrial Strategy.
11	**Secondary glazing (per window)**	£ 300	£ 1,000	BEIS/CAR Data-CAR, 2017. What Does It Cost to Retrofit Homes? Department for Business, Energy & Industrial Strategy.
12	**Double glazing (per window)**	£ 300	£ 1,000	BEIS/CAR Data-CAR, 2017. What Does It Cost to Retrofit Homes? Department for Business, Energy & Industrial Strategy.
13	**Double Glazing- Slim profile**	N/A	N/A	No ranges identified in datasets
14	**Triple Glazing**	N/A	N/A	No ranges identified in datasets
15	**Insulated doors (per unit)**	£ 400	£ 1,400	Derived from range in Rickaby (2017) Capital costs of energy improvement measures. Savills
16	**Draught proofing (draught stripping) (m2)**	£ 65	£ 680	Derived from quoted ranges in BEIS/CAR Data-CAR, 2017. What Does It Cost to Retrofit Homes? Department for Business, Energy & Industrial Strategy. Rickaby (2017) Capital costs of energy improvement measures. Savills
17	**Reduced infiltration (foam, strips, sealant use) (m2)**	£ 20	£ 75	Derived from quoted ranges in BEIS/CAR Data-CAR, 2017. What Does It Cost to Retrofit Homes? Department for Business, Energy & Industrial Strategy.
18	**HW Tank insulation (per unit)**	£ 80	£ 90	BEIS/CAR Data-CAR, 2017 (Average of ranges for the two HTT typologies analysed) What Does It Cost to Retrofit Homes? Department for Business, Energy & Industrial Strategy.
19	**Ventilation (per unit)**	£ 350	£ 708	Derived from range in Rickaby (2017) Capital costs of energy improvement measures .Savills
20.a	**Shading Fixed (per unit)**	£ 252	£ 929	No ranges identified in datasets range denotes Porritt Estimates
20.b	**Shading Internal (per unit)**	£ 216	£ 320	No ranges identified in datasets range denotes Porritt Estimates
20.c	**Shading Shutters (per unit)**	£ 474	£ 654	No ranges identified in datasets range denotes Porritt Estimates

A-3.3-Costings Data Notes

The following notes describe the analysis process used for the generation of the base costings assumptions & reference data used. The work is based on the use of **best-available data**. It is intended that these notes are used in conjunction with the data across tables in Appendix A-3.2 (cross referencing each note).

Notes:

a. For final costings assumptions, where relevant further adjustment of the base data was undertaken following an assessment of uncertainty & comparison against applicable collated literature datasets & case study data.

b. Whilst savings have been varied between flat types in proportion to dimensions, the same costs were assumed for all flat types due to limitations in the CAR data.

c. Where required, to determine, SML size variants, values were normalised for m^2 for each typology based on area assumptions (Tables 16 & 17) derived from data from:
   - Donaldson, L..2018 Floor Space in English Homes – main report. MHCLG.
   - Scottish Government 2017: Scottish house condition survey - 2017 key findings. Scottish Government
   - EST.2019.Determining the costs of insulating non-standard cavity walls & lofts. Department for Business, Energy & Industrial Strategy

d. Glazing area assumptions refer to Table 18

<table>
<tr><td>C1.1</td><td>External Wall Insulation:

External wall insulation cost (£) = BEIS average cost (£)

• CAR, 2017. What Does It Cost to Retrofit Homes? Department for Business, Energy & Industrial Strategy.

Base statistical data is derived from average values from CAR/BEIS database for covered dwelling level costs for typologies as follows: The medium (i.e. central costs) only were averaged for the small & large property of each archetype in the CAR dataset. This was then assumed to be equivalent to the M variant in the assumptions & extrapolated using the standard assumptions referred to in Note c.

For high-rise flats, while the CAR dataset recognises that a cost increase can be associated with high-rise flats (mainly attributed to increased scaffolding), this is neither disaggregated nor quantified. Additionally, the dataset as a whole does not provide details on the material types covered under any of the measure categories, making it difficult to attribute costings to particular material types. It is therefore assumed that the range of costings represent the average across a range of materials used. In considering the additional cost implications associated with more stringent fire safety requirements the façade system as whole rather than the insulation material alone should be considered. However, as a benchmark, costs associated with mineral wool (generally categorised as non-combustible) with phenolic foam (generally categorised as more combustible) were considered. While market-based costs vary considerably, Tetlow et al (2015) found that the average cost of mineral wool was £ 65-70/ m^2 installed for EWI compared to £ 80-85/ m^2 installed for phenolic foam. In light of the uncertainty in costs found in the evidence base it was assumed that no significant cost adjustments can for now be associated with installation of EWI in high-rise flats (other than increased scaffolding costs assumed to be already incorporated in the 'total' cost used).</td></tr>
<tr><td>C1.2</td><td>Internal Wall Insulation:

Internal wall insulation cost (£)= BEIS average cost (£)

• CAR, 2017. What Does It Cost to Retrofit Homes? Department for Business, Energy & Industrial Strategy.

Base statistical data is derived from average values from CAR/BEIS database for covered dwelling level costs for typologies, using the following approach: The medium (i.e. central costs) only were averaged for the small & large property of each archetype in the CAR dataset. This was then assumed to be equivalent to the M variant in the assumptions & extrapolated using the standard assumptions referred to in Note c.</td></tr>
<tr><td>C1.3</td><td>Thin Internal Wall Insulation:

Thin internal wall insulation cost (£) = IWI Cost (£) - 28% Cost Reduction (£)

• CAR, 2017. What Does It Cost to Retrofit Homes? Department for Business, Energy & Industrial Strategy.
• Glew, D., Parker, D., Miles-Shenton, D., Fletcher, M., Thomas, F., Booth, J., Cobden, L., for BEIS (Forthcoming). Thin Internal Wall Insulation (TIWI) Project.

As before, where base statistical data derived from average values from CAR/BEIS database for covered</td></tr>
</table>

	typologies. IWI costings used as based costs with a cost reduction factor of an average **28%** applied based on BEIS TIWI field trials (including PIR, Aerogel, EPS, Cork render & Latex foam roll against Phenolic Board IWI). Where required, the data refers to relational size assumptions detailed in the Standard Assumptions to extrapolate across typologies
C1.4	Cavity Wall Insulation (Easy to Treat-ETT): Cavity wall insulation cost (Easy to Treat-ETT) (£) = BEIS calculated cost (£) • CAR, 2017. What Does It Cost to Retrofit Homes? Department for Business, Energy & Industrial Strategy. Base statistical data is derived from average values from CAR/BEIS database for covered dwelling level costs for typologies-CWI assumed to refer to Easy to Treat Cavity (ETTC) wall - using the following approach: The medium (i.e. central costs) only were averaged for the small & large property of each archetype in the CAR dataset. This was then assumed to be equivalent to the M variant in the assumptions & extrapolated using the standard assumptions referred to in Note c.
C1.5	Cavity Wall Insulation (Hard to Treat-HTT): Cavity Wall Insulation (Hard to Treat-HTT) (£) = EST 2019 HTTC Average Cost (£) • EST, 2019. Determining the costs of insulating non-standard cavity walls & lofts. Department for Business, Energy & Industrial Strategy. Whilst EWI or IWI solutions might be expected to have higher energy savings, the evidence used does not suggest that this is generally the preferred solution for HTT cavity walls. BEIS/CAR Data does not explicitly cover HTTC (lower costs quoted more likely to be associated with ETTC). Costs were therefore derived from EST 2019 report, where based on contractor/ organisation quotes the costs for a range of HTTC were generated through modelling. These were used to generate cost assumptions for covered typologies, where average values from EST report (costs for 'uninsulated non-standard cavity walls') were used as a starting point (average EST value = cost for medium variant). Note that this average is understood to include some partial fill walls. Costs quoted in this report include the costs of providing guarantees, equipment hire, inspection, "making good", margin/profit made by installers and equipment hire. To determine, SML size variants, sources listed in Note c above, were used & where required, the data refers to relational size assumptions detailed in the Standard Assumptions to extrapolate across typologies.
C1.6	Partial Fill: Partial Fill (£) = IWI cost (£) Based on EST report (2019), partial fill is assumed to be addressed through IWI, therefore base statistical data derived from average values from CAR/BEIS database for covered typologies. • CAR, 2017. What Does It Cost to Retrofit Homes? Department for Business, Energy & Industrial Strategy. • EST 2019.Determining the costs of insulating non-standard cavity walls & lofts. Department for Business, Energy & Industrial Strategy To determine, SML size variants sources listed in Note c above, were used & where required, the data refers to relational size assumptions detailed in the Standard Assumptions to extrapolate across typologies.
C1.7	Loft Insulation (Easy to Treat- ETT): Loft Insulation (Easy to Treat- ETT) (£) = BEIS calculated cost (£) • CAR, 2017. What Does It Cost to Retrofit Homes? Department for Business, Energy & Industrial Strategy. Base statistical data derived from average values from CAR/BEIS database for covered dwelling level costs for typologies, using the following approach: The medium (i.e. central costs) only were averaged for the small & large property of each archetype in the CAR dataset. This was then assumed to be equivalent to the M variant in the assumptions & extrapolated using the standard assumptions referred to in Note c.
C1.8	Loft Insulation (Hard to Treat- HTT): Loft Insulation (Hard to Treat- HTT) cost (£) = BEIS calculated cost (£) EST, 2019. Determining the costs of insulating non-standard cavity walls & lofts. Department for Business, Energy & Industrial Strategy. Costs were derived from EST 2019 report, where average values were used as a starting point. For each archetype a weighted average cost was produced reflecting the costs of different HTT loft/roof types, weighted by prevalence in the archetype stock (average EST value = cost for medium variant). In all flats, loft/roof insulation costs are expected to only apply to top floor flats.

C1.9	**Suspended Floor Insulation:** Suspended Floor Insulation cost (£) = Average £/m^2 values from CAR/BEIS X house type area (m^2) • CAR, 2017. What Does It Cost to Retrofit Homes? Department for Business, Energy & Industrial Strategy. Due to limited sample size in base statistical data, as well as the much lower costings quoted than those found in the literature for insulating suspended timber floors, values for suspended floor insulation were derived from average £/m^2 values from CAR/BEIS database for covered typologies rather than dwelling level costings used for other elements. Costs given were assumed to apply suspended floor insulation based on typologies listed in evidence (older properties & statement in evidence referring to no solid floor contractors being interviewed). To determine, SML size variants, sources listed in Note c above, were used & where required, the data refers to relational size assumptions detailed in the Standard Assumptions to extrapolate across typologies.
C1.10	**Solid Floor Insulation:** Solid Floor Insulation cost (£) = Average £/m^2 values from solid floor estimates X house type area (m^2) Data derived from average values from two studies due to lack of data in CAR/BEIS study: • Green, G., Lannon, S., Patterson, J., Iowerth, H., 2019. Homes of today for tomorrow: Decarbonising Welsh Housing between 2020 & 2050- STAGE 2: Exploring the potential of the Welsh housing stock to meet 2050 decarbonisation targets. Welsh School of Architecture, Cardiff University. • Rickaby, P .2017. Capital Costs of Energy Improvement Measures. Savills (From 8 projects around the UK) To determine, SML size variants, sources listed in Note c above, were used & where required, the data refers to relational size assumptions detailed in the Standard Assumptions to extrapolate across typologies.
C1.11	**Secondary Glazing:** Secondary glazing costs (£) = Derived DG Costs (£) • CAR, 2017. What Does It Cost to Retrofit Homes? Department for Business, Energy & Industrial Strategy. Base statistical data derived from average values from CAR/BEIS database for covered dwelling level costs for typologies, using the following approach: The medium (i.e. central costs) only were averaged for the small & large property of each archetype in the CAR dataset. This was then assumed to be equivalent to the M variant in the assumptions & extrapolated using the standard assumptions referred to in Note c. Please note that while the per window costs for a DIY installation included in the CAR dataset are substantially lower, in this report it is assumed that professional installation would be more consistent with the energy savings assumed above, therefore this is reflected in the costs used. Where installed as a DIY measure it is likely performance would be lower in some homes, with high performance particularly hard to achieve through DIY application in the heritage stock where secondary glazing is expected to be of particular value.
C1.12	**Double Glazing:** Double glazing cost (£) = BEIS calculated cost (£) • CAR, 2017. What Does It Cost to Retrofit Homes? Department for Business, Energy & Industrial Strategy. Base statistical data derived from average values from CAR/BEIS database for covered dwelling level costs for typologies, using the following approach: The medium (i.e. central costs) only were averaged for the small & large property of each archetype in the CAR dataset. This was then assumed to be equivalent to the M variant in the assumptions & extrapolated using the standard assumptions rreferred to in Note c.
C1.13	**Slim Double Glazing:** Slim double glazing cost (£) = DG cost (£) + 20% cost uplift • Heath, N., Baker, P., Menzies, G., 2010. Slim-profile double glazing: Thermal performance & embodied energy. Historic Scotland. SPDG assumed to have **20%** cost uplift based on costing on Pilkington Slimline variant in Heath et al work in Scottish heritage buildings achieves optimal performance.
C1.14	**Triple Glazing:** Triple glazing cost (£) = DG cost (£) + 22.5% cost uplift Data from Retrofit for the future suggests an ~ 120% uplift in costs between DG & TG (2013), a review of commercial websites suggests that the cost gap between DG & TG is decreasing to an estimated 22%- 40%

	uplift where current estimates based on commercial websites (e.g. https://www.kjmgroup.co.uk/blog/triple-glazing-cost) & data received from PDP (Input from PDP London, January 2019) assumes a range of 5%-20% cost increase (15% average overall). Considering these sources, an average value of **22.5%** uplift is therefore assumed over the cost of DG.
C1.15	Insulated Door: Insulated door cost (£) = average cost from Rickaby (2017) (£) An assumed £1000/unit cost from the average costs quoted in Rickaby (2017) Capital Costs of Energy Improvement Measures, Savills. is used where applicable. No doors are installed in converted & high-rise flats due to adjacency to internal spaces. Medium & large house types assumed to have 2 doors.
C1.16	Draught proofing: Draught proofing cost (£) = BEIS cost range (£) Based on the range quoted the BEIS/CAR report CAR, 2017. What Does It Cost to Retrofit Homes? Department for Business, Energy & Industrial Strategy of £85-275/home as a DIY measure from literature & cost estimates from interviews. Flat variants £85, end terrace/mid terrace/bungalow £180 & semi-detached /detached £275. The terms draught proofing/stripping & reduced infiltration are often used interchangeably in existing literature. For clarity in this report, draught proofing is intended to refer to measures such as closing a chimney.
C1.17	Reduced Infiltration: Draught proofing cost (£) = 0.25 BEIS cost range (£) Based on the range quoted the BEIS/CAR report of £85-275/home as a DIY measure from literature & cost estimates from interviews. Flat variants £85, end terrace/mid terrace/bungalow £180 & semi-detached /detached £275. Window sealant & film costs are minimal compared to draught-proofing therefore assumed to be **25%** of total average draught proofing cost quoted in study
C1.18	HW Tank Jacket: HW tank cost (£) = 0.25 BEIS fixed unit cost (£) Fixed unit cost from CAR, 2017. What Does It Cost to Retrofit Homes? Department for Business, Energy & Industrial Strategy.
C1.19	Ventilation: Ventilation cost (£) = combined cost from Rickaby (2017) (£) Combined fixed cost of installing extract fan ventilation to kitchen & bathroom quoted in Rickaby (2017) Capital Costs of Energy Improvement Measures. Savills. (From eight projects around the UK)
C1.20	Shading: Shading cost (£) = cost range in Porritt (2012) (£) Cost for shutters, internal blinds & external fixed shading (differs based on orientation) for house types, extracted from Porritt, S.M., 2012. Adapting UK Dwellings for Heat Waves. DeMontfort University which derive figures from installers quotes & (for fixed shading) Spon's Architect's price book for the year quoted (2011). Data for bungalows assumed to be same as end/mid terrace due to same number of windows.

A-4 Dynamic Modelling approach

The EnergyPlus Generator 2 (EPGen-2) is a novel Python-based interface to EnergyPlus developed by UCL for automated batch mode modelling (large number of runs). It allows high volume/detailed simulation of building archetypes/improvement package combinations in time effective manner. EPGen-2 was used for the implementation of a defined scope of detailed modelling tasks to address gaps in evidence regarding the impact of sequencing and combination of fabric energy efficiency measures on energy savings. The process involved in the implementation of this modelling exercise as follows:

1-Definition of modelling scope: identification of gaps and requirements: Findings from the evidence review exercise pointed to an evidence gap from surrounding the impact of both sequencing and the combination of measures in a systematic way that could be broadly used to generate guidelines for application across various archetypes.

2-Definition of archetypes: A defined group of modelling cases (three in total) to help provide robust evidence to support formulation of assumptions. The defined archetypes are detailed in the table below.

Table 26: Modelled house types

	Dwelling Type	Dwelling Age	Wall type	Floors/ Storeys
S	Purpose built flat, high rise	1965 to 1874	Solid	12
M	Mid terrace	1900 to 1918	Solid	2
L	Detached	post 1990	Cavity	2

3-Definition of measures and running of models: The following measures, representative of the types likely to be installed in the defined archetypes, were defined. A series of modelling runs for the individual, and whole house implementation of measures as well as three packages types was undertaken. The results were then analysed for the formulation of general guidelines.

Table 27: Modelled measures

		Single / WH measures list	S (HR Flat)	M (Mid Terrace)	L (Detached)
WI	1	Solid wall insulation (External)	X		
	2	Solid wall insulation (Internal)		X	
	3	Solid Wall insulation (Thin)			
	4	Easy to treat cavities (Unfilled)			X
	5	Hard to treat cavities (Unfilled)			
	6	Partially filled cavities			
LI	7	Loft insulation 0.15		X	
	8	Loft insulation (HTT) 0.15			X
FI	9	Suspended timber floor insulation 0.2		X	
	10	Solid floor insulation 0.2			X
WD	11	Secondary glazing G-value to		X	
	12	Double glazing - G-value to	X		
	13	Double Glazing- Slim profile			
	14	Triple Glazing			
	15	Insulated doors U-Value to		X	X
A	16	Draught proofing (draught stripping)	X	X	X
	17	Reduced infiltration (foam, strips, sealant use)	X	X	X
TI	18	HW Tank insulation	X	X	X
	19	Ventilation	X	X	X
	20	Shading	X	X	X
Packages			**S**	**M**	**L**
A- Wall Insulation + Associated measures			1,12,16	2,11,15,16	4,16
B - Loft + Floors			N/A	7,9	9
C - Auxiliary Measures			17,19,20	17,19,20	17,18,19,20

A-5 Wider Evidence Base

The following list includes the wider evidence base that was considered in informing this work.

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