Centre for Sustainable Energy

Cost of carbon reduction in new buildings

Final report

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Currie & Brown

Executive Summary

The UK has a legal commitment to reduce carbon emissions by 80% by 2050. This report considers different options for achieving carbon savings in new housing and non-domestic buildings and assesses their costs and other factors relevant to the development of local planning policies. The development of specific policy options will reflect local priorities, viability and other considerations but the information on costs and other relevant policy considerations is intended to help inform these decisions in developing effective policies that deliver carbon savings whilst protecting housing supply and household costs.

A range of dwelling and non-domestic buildings were considered, and detailed energy and cost modelling undertaken for five house types investigating a wide range of energy efficiency, low carbon heating and renewable power generation strategies. The costs of a variety of policy options were considered involving minimum levels of energy efficiency, onsite carbon savings and then the achievement of net zero carbon standards considering regulated energy or both regulated and unregulated energy. Allowable solutions/carbon offset payments could be used at a cost of £95 per tonne to meet the net zero carbon target once onsite carbon reduction targets had been achieved.

Analysis suggests that it is possible to achieve net zero regulated carbon emissions from a combination of energy efficiency on site carbon reductions and allowable solutions for an additional capital cost of between 5-7% for homes and non-domestic buildings. Achieving net zero regulated and unregulated emission is likely to result in a cost impact of 7-11% for homes.

The costs of achieving these standards are likely to fall overtime both because of reducing technology costs but particularly because reducing carbon intensity of grid electricity means that the carbon emissions of new homes will be lower than the level estimated by current regulatory compliance methods (SAP2012 and SBEM). Changes to carbon emission factors for electricity should also strongly favour the use of heat pumps for providing space heating and hot water.

The adoption of minimum levels of energy efficiency as part of a policy target would be liable to increase the costs of achieving carbon savings (net zero carbon costs might be 2% lower without energy efficiency requirements), but may nonetheless be justified on the basis of the impact on household bills and because more energy efficient homes will reduce overall (and particularly peak) demand for energy and should thereby reduce costs on the wider energy generation and supply infrastructure.

A range of specific policy considerations are identified covering, for example:

- Modelling methods
- Assumptions about the efficiency of heating systems
- Need to help reduce the costs of renewable energy through leveraging collective buying power
- Implications of including or omitting energy efficiency standards
- Adoption of Passivhaus certification as a possible compliance method

The options considered in this study are illustrative of possible solutions to achieving carbon reductions and the associated costs. The potential for the challenge of new standards to spur innovative, new approaches should not be overlooked.

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Glossary

Standard Assessment Procedure (SAP)
SAP is a procedure by which the energy performance of a home is assessed, it is the typical method used for the purposes of assessing compliance with Building Regulations Part L1a. SAP calculates the energy use, cost of energy and carbon emissions of a home, the last of which (the Dwelling Emission Rate) must be lower than the calculated Target Emission Rate. The Target Emission Rate is calculated by modelling a home of the same form and size but built to the minimum standards required by Building Regulations. The version of SAP used to assess compliance for new homes is currently SAP 2012, a more recent SAP10 has been published by BRE on behalf of Government but this has not yet been adopted for use in assessing Part L1a compliance.

Regulated energy

Energy use that is regulated by Part L of Building Regulations. This includes energy used for space heating, hot water and lighting together with directly associated pumps (for circulating water) and fans (eg for ventilation).

Unregulated energy

Energy use that is not controlled by Part L of Building Regulations. In homes this includes energy use for cooking, white goods and small power (eg, TV's, kettles, toasters, IT, etc). The quantity of unregulated energy in a home is estimated in SAP2012 using information on the building area.

In non-domestic buildings unregulated energy also includes that used for vertical transportation (lifts and escalators) and process loads such as industrial activities or server rooms.

Mechanical Ventilation & Heat Recovery (MVHR)
MVHR is a mechanism for providing ventilation that provides a controlled supply of outside air that has been warmed by extracting heat from the stale air being extracted from the property. In this way the unit provides the necessary ventilation with minimal loss of heat in the home. When external temperatures are higher, the MVHR is capable of operating in 'bypass' mode whereby there is no heating of the incoming air. The system uses electric fans and so has running costs and associated carbon emission but in a well-insulated and air-tight home the saving in heating energy use is greater than that required to operate the MVHR unit.

Emission factor
Emission factors are the amount of carbon emitted to supply a given quantity (eg 1 kWh) of energy. Emission factors exist for a wide range of fuels and also for electricity. In recent years the emission factor for electricity has reduced considerably as a result of increased use of renewable energy and of lower carbon sources of power generation. Emission factors for fuels are largely unchanged. The reducing emission factor for electricity means it is becoming an increasingly low carbon source of energy, particularly when used within highly efficient technologies such as heat pumps.

Allowable solutions/ Carbon Offsetting
Allowable Solutions is the term given to the various 'carbon offsetting' measures that might be used to reduce carbon emissions in the built environment and thereby offset any residual emissions associated with a new development after any minimum onsite reduction targets have been achieved. By making a payment into a fund a developer can offset their residual emissions and the collected money can then be used by the local authority to invest in suitable carbon reduction initiatives. This topic is considered further in a companion report by the Centre for Sustainable Energy.

Photovoltaics
Photovoltaics (PV) are renewable energy technologies that generate electricity from solar energy. There are a range of PV technologies ranging from thin film solutions that can be overlain on existing surfaces (eg glass) through to discrete panels made of a mono or polycrystalline silicon substrate. The electricity generated by a PV is direct current (DC) so it needs to pass through an inverter to be converted into the alternating current (AC) that can be used within a home.

Merton Rule
The Merton Rule is a term used to describe planning requirements to incorporate a minimum level of renewable energy within development, the concept was first popularised by its introduction in, and advocacy by, the London Borough of Merton.

Passivhaus
Passivhaus is an international energy standard that was originally developed for housing and is now applied to a range of building types. A building certified to the Passivhaus standard must meet stringent standards for energy consumption for heating (15kWh per m^2) and for overall energy demand. In addition, there are design requirements to control the quality of the internal environment for example by controlling internal surface temperatures and the risk of overheating to provide a comfortable living space.

Heat pumps

Heat pumps typically use electricity to compress and thereby increase the temperature of air or water and then extract the heat to provide space heating or domestic hot water. Common heat pumps are either air source (ASHP) that extract heat from the air or ground source (GSHP) where heat extracted from water that has absorbed heat from the ground. Because some of the heat suppled is already present in the air or water, the energy used by the heat pump is only a fraction of the useful heat supplied to the building. For example, an ASHP may output over three times more heat energy than it requires to in the form of electric power.

Kilowatt peak (kWp) capacity
In the context of photovoltaic panels, the peak capacity is the maximum theoretical output of the system under standardised test conditions. In practice, the output of a fixed PV array will vary throughout the day according to its orientation and incline, presence of oversharing, the position of the sun and weather conditions.

U-value
A u-value is a measure of the rate of heat transfer across a structure divided by the temperature difference (in Kelvin) across the structure. It is measured in watts per m^2 per Kelvin of temperature difference or Wm^2K. Lower U values equate to better insulative properties and reduced heat loss. Part L of building regulations sets minimum standards for the U values of different building elements (eg floor, window, roof or external walls) but building to lower U values is one method that can help to reduce energy consumption.

1. Introduction

This report considers how planning policy can help reduce carbon emissions from new This report considers how planning policy can help reduce carbon emissions from new developments (both residential and non-residential) and also reduce energy bills. Currie & Brown evaluated the capital and running cost implications of a range of potential energy policy options being considered by planning authorities in the West of England for inclusion within future planning policy.

1.1 Scope – domestic properties

The analysis considers the following home types:

- Detached houses
- Semi-detached houses
- Terraced houses
- Low rise flats (2 beds)
- Medium rise flats (1 bed)

Reference information on each house type is included in Appendix A.

The analysis considers four areas of carbon reduction measures for new homes:

- **Improved energy efficiency** - achieved through a combination of enhanced fabric standards and use of low carbon heating sources. Energy efficiency standards range from the current Part L Notional[1] specification to a series of improved energy efficiency standards with reduced heating requirements
- **Heating and hot water source** - using either a gas boiler or Air Source Heat Pump (ASHP)
- **Generation of renewable energy onsite** - to further reduce net energy consumption and carbon emissions. Photovoltaics (PV) are the reference example.
- **Investment in Allowable Solutions/ Carbon Offsetting**– to offset residual emissions to achieve net zero carbon emissions for either regulated or regulated and unregulated operational energy use.

Results are presented in the form of carbon emission savings, household bills and construction cost relative to current building regulations (Part L1a 2013).

Carbon emissions are calculated using the SAP 2012 method and emissions factors but with higher assumed efficiencies for ASHP (see Section 2). (It is recognised that SAP 2012 emission factors for electricity no longer reflect the actual carbon intensity of grid electricity and are substantially higher than those reported by the Department of Business, Energy and Industrial Strategy (BEIS) and reflected in the new SAP 10 method which was published in late July 2018.

As it is not yet clear how Part L and the SAP method will change, this report does not make firm proposals for performance standards under a future regulatory regime, nonetheless some analysis of the implications of adopting the emission factors set out in SAP 10 is included to illustrate how this might affect development strategies.

[1] The notional specification is a specification which, if followed, would achieve the requirements of Part L 2013. The specification higher than the minimum performance standard for each element specified in the regulations, a developer is not obligated to follow the notional specification and could build to a lower standard in some parts of the building and compensate by achieving a higher standard elsewhere.

1.2 Scope – non-domestic properties

The opportunities for, and costs implications of, carbon reductions in non-domestic properties were considered based on a review of recent studies of the topic to identify the level of savings that could be achieved and their implications for different development types.

1.3 Considerations and policy options

A wide range of policy options were considered in formulating the developed proposals, these were refined based on the results of iterative analysis with the aim of meeting the following considerations:

- **Ambitious** – retaining the goal of achieving true Zero Carbon for new development
- **Simple** - a proportionate solution that works for different project and development types
- **Flexible** – for developers so that they can determine the solution that works for them
- **Timely** – recognising the unique opportunities of a new build situation to embed performance standards that would be very difficult or expensive to achieve retrospectively
- **Affordable** - avoidance of adverse impacts on households in the form of additional running costs
- **High performance** – aiming for high quality buildings that perform well and support comfortable and healthy lives
- **Deliverable** – by developers at scale and with available technologies and skills
- **Incentivising best practice** – by supporting those wishing to deliver exemplary performance

Options comprise different minimum requirements for carbon emissions from operational energy use beginning with reduction in energy demand through energy efficiency measures followed by reduction in overall onsite carbon emissions required to meet this demand from the use of low carbon systems and renewable energy generation and finally the delivery of net zero carbon emissions including through the use of allowable solutions/ carbon offset payments, either for regulated energy alone or for both regulated or unregulated energy use. Each option is defined in comparison to the performance of a home built to the Part L 2013 notional specification.

1.4 About Currie & Brown

Currie & Brown is a global asset management and construction consultancy with expertise in project and cost management across the built environment. Our advisory services team has longstanding experience of research and analysis on approaches to delivering higher performance standards and lower carbon emissions in buildings. Our team have worked with organisations such as the Zero Carbon Hub and the UK Government for over 10 years on this topic. This includes preparation of the Zero Carbon Hub's reports on the costs of zero carbon homes[2][3].

[2] Zero Carbon Hub, 2014. Cost Analysis: Meeting the Zero Carbon Standard
[3] DCLG, 2008. Cost Analysis of The Code for Sustainable Homes

2. Policy Context

The context for the study is the global, national and local commitment to reducing emissions of carbon dioxide (CO_2) which are causing climate change. The global commitment was reflected in the UN's 2015 Paris Agreement which commits signatory nations to

"…pursue efforts to limit temperature increase to a 1.5-degree rise[4]*"*.

At the national level, the UK's 2008 Climate Change Act sets a legally binding target, stating that:

"It is the duty of the Secretary of State to ensure that the net UK carbon account for the year 2050 is at least 80% lower than the 1990 baseline."

The 2017 Clean Growth Strategy echoes this whilst recognising the opportunities it creates, noting that

"*Success in this mission will improve our quality of life and increase our economic prosperity".*

The legislative framework for the planning system carries forward this commitment. Section 19 of the 2004 Planning and Compulsory Purchase Act, as amended by Section 182 of the Planning Act 2008[5] states:

'*Development plan documents must (taken as a whole) include policies designed to secure that the development and use of land in the local planning authority's area contribute to the mitigation of, and adaptation to, climate change.'*

The 2008 Planning and Energy Act[6] sets out powers for local authorities to set local carbon reduction standards that go beyond national Building Regulations. The Deregulation Act 2015 contained wording to repeal the power for authorities to set energy efficiency standards above Building Regulations (whilst leaving intact the power to require carbon reductions through renewable energy). However the Deregulation Act changes have not been commenced.

In 2018, these powers were reconfirmed in the "Government response to the draft revised National Planning Policy Framework consultation[7]"

To clarify, the Framework does not prevent local authorities from using their existing powers under the Planning and Energy Act 2008 or other legislation where applicable to set higher ambition. In particular, local authorities are not restricted in their ability to require energy efficiency standards above Building Regulations. The Government remains committed to delivering the clean growth mission to halve the energy usage of new buildings by 2030.

The 2018 National Planning Policy Framework (NPPF) states that

"*The purpose of the planning system is to contribute to the achievement of sustainable development'*[8]*.*

Paragraph 93 goes on to state the role of addressing climate change in achieving sustainable development:

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[4] UNFCC: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement
[5] Available at https://www.legislation.gov.uk/ukpga/2008/29/section/182
[6] Available at http://www.legislation.gov.uk/ukpga/2008/21/pdfs/ukpga_20080021_en.pdf
[7] Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/728498/180724_NPPF_Gov_response.pdf
[8] Paragraph 6: https://www.gov.uk/guidance/national-planning-policy-framework/achieving-sustainable-development

"Planning plays a key role in helping shape places to secure radical reductions in greenhouse gas emissions, minimising vulnerability and providing resilience to the impacts of climate change, and supporting the delivery of renewable and low carbon energy and associated infrastructure. This is central to the economic, social and environmental dimensions of sustainable development".

The challenge to the building sector is set out in the 2018 Committee on Climate Change (CCC) report[9]. Their analysis suggests that overall emission across the UK building stock needs to fall by around 20% between 2017 and 2030 to meet the Climate Change Act commitments. This is a challenging target, given that after a period of decline, in 2017 carbon emissions from buildings rose 1%. Any increase in emissions from new buildings will make the Climate Change Act commitment harder to meet.

[9] Reducing UK emissions: 2018 Progress Report to Parliament: Committee on Climate Change (2018) https://www.theccc.org.uk/wp-content/uploads/2018/06/CCC-2018-Progress-Report-to-Parliament.pdf

SECTION 1: COST OF LOW CARBON IN RESIDENTIAL DEVELOPMENT

3. Routes to zero carbon under current regulatory regime

The aim of this section is to describe the approach to determining low cost routes to achieving a range of policy options using standard construction methods and under the current regulatory regime (Part L1a 2013). Section 7 considers the costs associated with meeting Passivhaus standards in housing.

To assess the cost implications of reducing carbon emissions from new homes five representative domestic property designs were analysed with a variety of levels of energy efficiency, heating system and onsite renewable energy generation. Key methodological points are listed below and then summarised in the remainder of this section, further detail is provided in the appendices.

1. Policy options
   - Net zero carbon target
   - Components of a net zero-carbon standard
2. Reference house types
3. Energy/carbon modelling
   - Using SAP 2012 assumptions and Part L 2013 as the baseline
   - Sensitivity testing to SAP 10
4. Efficiency measures and low carbon technologies
   - ASHP efficiencies
   - PV outputs
   - Energy storage
   - Allowable solutions
5. Cost analysis
   - Capital cost modelling
   - Running costs modelling

Information on each of the above points is provided below with, further detail in appendices.

3.1 Policy options

Net zero carbon target
Reflecting variations in existing planning policies across the UK, the scope of work included two options for net 'zero carbon':

- net zero regulated emissions, i.e. including emissions relating to energy used for space heating and ventilation, hot water supply and lighting
- net zero regulated *and* unregulated emissions, i.e. including all regulated emissions and an allowance for the emissions from other energy used for cooking, appliances and other small power consumption[10].

Study results are shown against each of these two targets against a scale showing total regulated emissions as 100% and additional unregulated emissions as above 100%. The ratio between

[10] The allowance for unregulated carbon emission is determined from the floor area and associated assumed occupancy of each home as specified in the SAP method.

regulated and unregulated emission varies by building type, but in general the unregulated emissions represent an additional 80-95% of the home's regulated carbon emissions.

Components of a net zero carbon standard
In achieving the net zero carbon standard, policy options were considered that specify different levels of energy efficiency, onsite carbon reductions and then total reduction in regulated or regulated and unregulated emissions. Once the minimum onsite carbon reduction standard has been met, the analysis allows the use of 'allowable solutions/ carbon offset' payments to address any residual carbon reductions required to achieve the relevant net zero standard.

Table 3.1 summarises the different policy options considered for the carbon performance of new homes. All emission reductions requirements are compared to the performance of a home built to the Part L 2013 notional specification and heated with gas.

Table 3.1 Policy options considered for carbon reductions in new homes

Option	Level 1 - Minimum carbon reduction from energy efficiency	Level 2- Minimum total reduction in carbon onsite	Level 3- Reduction in total regulated emissions	Level 4 - Reduction in total unregulated carbon emissions
1	10%	35%	100%	100%
2	10%	50%	100%	100%
3	0%	35%	100%	100%
Note: The carbon reductions achieved at each level are cumulative not additive, i.e. the total carbon saved at Level 2 includes that already achieved in meeting any requirements at Level 1				

3.2 Reference house types

The different home types used as references in this study are shown in Table 3.2. Areas and energy performance for flats are averaged across a 4 (low rise) or 8 (medium rise) storey block. These building dimensions are consistent with those used previously by central Government when assessing implications of different options for changes to Building Regulations Part L1a.

Table 3.2 Dimensions and baseline carbon emissions of each home type

	Detached	Semi-detached	Terraced	1B Flat	2B Flat
AREAS (m^2)					
Total internal floor area	117.1	84.4	84.4	50.0	70.1
Exposed wall	156.3	93.8	52.0	18.0	41.3
Semi-exposed wall	0.0	0.0	0.0	24.0	12.1
Party wall	0.0	41.8	83.6	28.1	29.2

	Detached	Semi-detached	Terraced	1B Flat	2B Flat
Roof - Main	58.1	41.8	41.8	50.0	70.1
Floor	58.9	42.6	42.6	50.0	70.1
Windows	26.2	14.6	14.6	9.8	13.8
Doors	2.1	2.1	2.1	2.1	2.1
HEIGHT (m)					
Floor to ceiling	2.4	2.4	2.4	2.4	2.4
BASELINE CARBON (Part L 2013 notional specification)					
Regulated Target Emission Rate ($kgCO_2e$ m^2)	17.27	18.33	16.73	17.60	13.93
Unregulated carbon emissions ($kgCO_2e$ m^2)	13.92	15.70	15.70	16.30	16.97
Total regulated and unregulated emissions ($kgCO_2e$ m^2)	31.19	34.03	32.44	33.90	30.90
Total regulated carbon emissions per home (tCO_2e y^{-1})	2.02	1.55	1.41	0.88	0.98
Total regulated and unregulated carbon emissions per home (tCO_2e y^{-1})	3.65	2.87	2.74	1.70	2.17

3.3 Energy / carbon modelling

The policy options considered in this report use the standard national methodology set out in the Building Regulations regime for calculating carbon emissions. Building Regulations compliant buildings are the baseline against which carbon savings are measured.

Baseline of SAP 2012 and Part L 2013

This analysis considers the energy demand by fuel type and use as estimated by Standard Assessment Procedure (SAP) 2012 modelling software used for assessing the compliance of new housing in England against the requirements of Part L1a of Building Regulations. The associated levels of energy consumption and consequential carbon emissions are estimated using SAP 2012 data except for the efficiency factors for ASHP where a higher heating efficiency factor of 300% has been used[11].

SAP 2012 is now over 6 years old and some of the assumptions, notably carbon emission factors for electricity, are out of date due to the increasing amount of renewable electricity on the grid and the decline of coal power stations. Emission factors for gas and electricity are 0.216 and 0.519 kg per kWh respectively in SAP 2012. By contrast the most recent published (but as yet unadopted for building regulations) version called SAP 10 has the same emission factors for gas but a factor of 0.233 kg per kWh for electricity - a value less than half that of that used in SAP 2012.

[11] This is because the current efficiency factor used in SAP calculations is now believed to be out of date as efficiency of ASHP's has improved.

Therefore, each unit of electricity consumption is assumed to result in around half the emissions predicted in SAP 2012. The issues caused by these outdated emissions factors are set out further in the Section 5.

However, SAP 2012 and Part L 2013 has been used as a basis for this analysis, despite it containing several out of date assumptions, because:

a. developers submitting planning applications will be using this method to demonstrate compliance with Building Regulations and for consistency and simplicity this method is also used in this study.

b. When a new version of SAP is adopted as the compliance method then the full range of changes, which may extend beyond new carbon emission factors, will need to be considered when determining the most suitable standards for development. For example, the SAP 10 method includes changes to the approach to heating and ventilation system performance and also to temperature control which will also affect the calculations. The revised Part L of the Building Regulations may also introduce further changes that will affect the baseline for policy standards.

Policy Consideration 1: SAP
Use the current SAP and Part L regime when setting policy and the compliance regime, for ease of use by developers and since future changes to SAP and Part L are unknown.

Sensitivity testing to SAP 10
To ensure that policy drives genuine reductions in carbon emissions from buildings, policy options have been sensitivity tested using the emission factors in the more recent, but as yet unadopted, compliance method SAP 10.

3.4 Energy and carbon reduction measures

Energy demand for heating, hot water, lighting and pumps and fans were calculated by AECOM using an SAP 2012 compliant model. A wide range of specification options were assessed for each house type. These produced energy efficiency savings ranging from under 10% to nearly 35% for detached houses, and between 15-20% for flats.

The most energy efficient option considered was a specification that, when modelled in SAP, gave a space heating demand level of 15kWh per m^2. This is broadly analogous to the Passivhaus specification although it is assessed at the level of individual dwellings and so would be a higher theoretical standard for some building types (i.e. flat or end terrace) than would be required to achieve Passivhaus certification[12].

Each specification was developed to represent a ‘fabric first’ approach to energy efficiency but also incorporating high levels of air tightness and associated ventilation systems (eg MVHR) where needed to achieve the higher performance standards.

Table 3.3 summarises the range of energy efficiency measures considered for each home type and the options for heating systems and renewable energies the various specifications tested are described in Appendix B.

[12] This is because for Passivhaus’ the whole building is assessed when determining performance against the 15kWh m^2 target. Therefore, if the average performance of a whole a terrace of houses is compliant it is likely that the least efficient homes(those on the ends of the terrace) will have energy demand above the average.

Table 3.3 Range of considered specification options

Category		Part L Notional specification*	Other options considered
Energy demand reduction			
Walls	Exposed (W/m².K)	0.18	0.17, 0.15, 0.13
	Semi exposed (W/m².K)	N/A, 0.21	
Floors	Ground Floor (W/m².K)	0.13	0.15, 0.11
Roofs	Exposed Roof (W/m².K)	0.13	0.11
Doors	U-value (W/m².K)	1.0	1.2
Windows	U-value (W/m².K)	1.4	1.2, 0.8
Ventilation	Type	Nat Vent	MVHR
Air Permeability	(m³/h.m² @50pa)	5.0	3.0, 2.0, 1.0
Thermal Bridging	Y-value	0.05	0.04
Heating supply**			
		Gas boiler (91% efficient) ▪ System boiler for detached ▪ combi boiler for semi, terraced and low-rise flats) ▪ Centralised boiler for medium rise flats	ASHP (300% efficient) ▪ Individual units for houses and low-rise flats, ▪ Centralised system in medium rise flats
Renewable energies			
		Na	Photovoltaic panels up to a maximum of 40% of the ground floor area of the home. A sensitivity analysis with PV allowed up to 100% of floor area is shown in Appendix D.

* the Part L notional specification is a specification that is assumed for calculating the target emission rate that a new development must achieve or exceed. Therefore, if applied, the specification would deliver compliance with the requirements of Part L 2013.

**This study does not consider the implications of connecting homes to a heat network, this analysis has been undertaken by others.

Of the differing heating supply options considered, a preference emerged for the ASHP solution as part of a heating hierarchy on the basis that it has the potential to deliver greater longer-term

carbon savings and avoids a source of localised combustion with associated air quality implications.

ASHP efficiencies

The energy consumed by an ASHP was estimated using bespoke factors for the efficiency of the system for space heating. In practice this means a heating efficiency of 300% and sufficiently large radiators to enable lower operating temperatures of around 40-45ºC.

This efficiency is higher than that used in SAP 2012 and reflects an adjustment based on the experience of West of England local authorities of how these systems perform in practice in new homes. Performance of the ASHP for providing hot water was taken to be equivalent to that derived by SAP 2012 for each home.

Policy Consideration 2: ASHP Efficiencies

In evaluating schemes that involve the use of ASHP's, planning authorities should ensure that there is evidence to justify the use of a higher heating efficiency factor (e.g. 300%) on the basis of the system design and specification. Planning authorities should also ensure that there are commitments to appropriately commission the system to enable it to perform to this standard in practice.

Photovoltaic performance and utilisation

PV panels are a core technology used to reduce the net carbon emissions from each home after appropriate energy efficiency and low carbon heating solutions have been adopted.

PV panels generate electricity using energy from the sun. This energy is typically sent to an inverter unit which converts the power in to AC current at a voltage that can be used within the home or, if there is insufficient demand in the home, exports it into the grid for others to use. In assessing the costs and performance of PV systems it was assumed that each kW peak (kWp) of installed capacity covers 7.5m^2 of roof area and that each kWp of capacity generates approximately 830kWh of electricity each year[13].

The estimated fixed (per installation) and variable (per kWp installed) costs of PV are taken as £740 and £1,100 respectively. A 2kWp system would therefore have an installed cost of £2,940 (£740+2*£1,100).

These rates were identified from analysis of published rates secured from a regional competition to provide PV for houses in London[14]. These costs represent a discount on those typically seen on the speculative PV market but are taken to be indicative of the rates that could be secured should the West of England local authorities follow a similar process. In the absence of such a 'buying club' approach to delivery, the costs to individual (especially SME developers) would be higher.

Policy Consideration 3: Supporting lower costs for photovoltaics

To support the cost-effective delivery of PV local authorities, have an important role in enabling bulk procurement/'buying club' solutions that will reduce costs to developers.

[13] Using the SAP 2012 calculation method, A 1kWp PV array that is well orientated and inclined will generate between 720 and 940 kWh each year. A median of 830kWh was selected as being representative of a reasonably optimised installation in south west England. For ideally designed installations the output may be slightly higher, whereas in more northerly locations the output of even and ideally located installation may be slightly lower.

[14] Data taken from Solar Together in July 2018.

Storage

Generation of electricity via PV can be used to reduce energy bills and the net carbon emissions of the home. It is important to remember that even a home with zero net energy use or carbon emissions is still likely to have a reliance on the electricity grid or gas infrastructure to provide energy at periods of peak demand, especially if it is overcast or dark. While a net zero home may generate surplus electricity during the day in summer it is likely to have a demand for external energy (i.e. grid electricity or gas) at 7pm in the middle of February when the demand for heat and lighting high and there is no onsite generation.

The impact of winter heating peak demand for electricity is likely to be exacerbated where homes are heated using electricity. The increase in the peak electricity demand will in part be dependent on the type of heating system used i.e. it will be significantly higher for direct (resistive) electric heating such as electric boilers and panel heaters than heat pumps on account of the higher efficiency of heat pumps. While new homes and particularly those built to high standards of energy efficiency are likely to have far smaller peak heating energy requirements than existing homes, they are still likely to have higher demand for energy at times when onsite generation is low.

Battery or thermal storage systems can help to increase the proportion of electricity generated in a home that is used within the dwelling, providing both financial benefits to households in the form of reduced bills and helping to minimise the burden on the electricity supply system and by reducing the level and duration of peaks in demand.
The costs and performance of electricity and thermal storage systems are improving rapidly with the costs of lithium ion batteries now about 50% lower than in 2013 and projected to fall further in the coming decade. Recognising the benefits of energy storage, developers should be encouraged to take cost effective steps to help households store energy. This might include enabling energy from PV to be used to heat domestic (or central heating) hot water tanks or thermal stores when there is more generation than demand, or in time the installation of battery storage. SAP 10 includes methodologies for factoring in the benefits of energy storage into the household costs of an energy strategy and once adopted this will provide a mechanism for demonstrating some of the benefits of these measures.

Policy Consideration 4: Support for storage
To help reduce levels of peak demand on the electricity system, planning policies could include support for measures to reduce peak demand for electricity. Nonetheless it is important that these measures are appropriately considered. Proposals should be supported by evidence that their sizing is suitable for the intended use using a robust methodology. Proposals should also describe how they will benefit homeowners and show that they are suitably located to enable access but without reducing space.

Allowable Solutions/ carbon offset

Where the combination of onsite carbon reduction measures (i.e. energy efficiency, heating system and renewable energy) is insufficient to achieve the overall zero carbon target, then a further cost for a contribution towards 'allowable solutions' is added to the cost of the policy option. This cost is calculated at £95 per tonne of residual carbon dioxide equivalent (CO_2e) emissions for 30 years - i.e. a total payment of £2,850 per tonne of residual CO_2e.

The allowable solutions/ carbon offset price was established in a separate study completed by the Centre for Sustainable Energy[15], the price reflects that proposed by the Greater London Authority in the draft new London Plan and is broadly consistent with the marginal cost of carbon reductions achieved by installing PV using SAP 2012 emission factors.

[15] Centre for Sustainable Energy, 2018. Carbon offsetting in the West of England Authorities.

3.5 Cost analysis

Capital cost modelling

Cost analysis considers the additional costs of implementing the specified carbon reduction measures in comparison to the costs of building the same home to the Part L 2013 notional specification. Costs are based on Currie & Brown's professional experience of project costs and are developed from detailed specifications of the full range of cost implications for each element.

The cost of building each home to varying standards and performance levels was estimated through the development of elemental cost models for each home as built to the Part L 2013 notional specification and then adapting these costs for each relevant building element to achieve a different standard. In some cases, the alternate specification simply involves varying the thickness of an insulation layer while in others the implications are more wide ranging, for example in achieving higher levels of air tightness which would require the use of specific technologies together with close attention to detail on site.

Appendix C contains full details of the cost assumptions.

For homes that have particularly low levels of space heating demand, e.g. houses with heating demand of 25kWh per m^2 or below, then there are potential cost savings associated with a reduction in the extent of the internal heating distribution system. This could be realised both in terms of fewer radiators and by moving the radiators towards the core of the building and thereby reducing the length of pipe runs. There is evidence for these savings from Passivhaus projects which typically involve substantially reduced heating distribution systems. Potential cost savings associated with these efficiencies are not factored into the core cost analysis but are considered as a sensitivity option to assess their implications on the costs of meeting each policy.

Cost analysis for the certified Passivhaus projects includes allowances for additional verification and reporting.

Putting cost estimates in context

The costs presented in this report are for a medium sized developer, building several hundred to a thousand homes a year and operating in the West Midlands / South West BCIS[16] regions.

It is important to remember that the costs of developing new homes can vary very widely for a range of factors, not least: location, ground conditions, site constraints, access, topography, quality of finishes, design complexity, supply chain and management.

Construction costs can also be subject to sudden and significant change because of market or economic factors. For example, varying exchange rates, skills or materials shortages and interest rates. In the 12 months from May 2017 to May 2018 average housing materials costs increased by around 5%. However, this number is likely to conceal larger variations in specific items.

These extensive factors mean that a benchmark cost analysis is only indicative of overall cost implications of different policy options and their relative significance.

Potential for cost reductions

Cost analysis is based on rates as of mid-2018. An indication of how these costs may change in the future are estimated based on published cost projection data for key solutions such as photovoltaics, ASHP and achieving higher standards of airtightness.

[16] Building Cost Information Service

Some of the technologies and materials used in energy efficient homes are well established, while others are relatively new (eg mechanical ventilation with heat recovery systems) or rarely achieved (e.g. very high air tightness). Analysis of the potential for reduced costs associated with achieving higher standards of energy efficiency suggest that the cost premium associated with the most energy efficient standards may fall by around 20-30% between 2020 and 2030 as project teams become more familiar with achieving high levels of air tightness and the markets for new technologies become more established. In addition, it is likely that there will be further reductions in the costs of PV with costs falling by a further 35% on 2020 levels by 2030.

These cost trajectories mean that it should become less expensive to build to lower carbon standards over time perhaps in the order of 30% over the next decade. This excludes the costs of allowable solutions which are assumed to be unchanged.

However, the scale and speed of changes in costs associated with different technologies is relatively small and slow in comparison to other factors such as the changes to the modelling method. For example, the most recent update to the SAP methodology (SAP10) proposes a 55% reduction in the emission factor for electricity. This, or a similar change, together with other methodological amendments, could immediately come in to effect when a new version of SAP is adopted for compliance purposes. Government projections are that by 2030 the emission factor for electricity will have reduced further to around 0.1 $kgCO_2e$ per kWh a further reduction of approximately 50% on the SAP 10 figure and a reduction of over 75% on the SAP 2012 factor. These changes will have a very material impact on the total estimated carbon emissions of new homes and the effectiveness of different options for their reduction.

The costs of meeting a specific standard will change markedly when modelling methods and emission factors are changed. These changes, which may be introduced within the next two years, are likely to have a more material effect on the costs of meeting a target than changes in the capital costs of specific solutions.

Policy Consideration 5: Future review

The approach to meeting different energy and carbon requirements should be reviewed as modelling methods, assumptions and the wider regulatory environment change to ensure that standards remain appropriate. These studies should revisit cost analysis as, while subject to many variables, the additional costs of building to lower carbon standards should reduce overtime.

Running costs

Costs for net energy used and income from any exported energy is estimated using retail domestic energy prices for gas and electricity published by BEIS[17] in 2017 together with the export tariffs used for energy sold into the grid for installations registered under the feed-in tariff. No allowance for a generation tariff is included as the longer-term availability of this incentive is uncertain. Prices used for 2020 (an assumed policy implementation date) are:

- £0.165 per kWh (16.5p) for electricity consumption
- £0.0365 per kWh (3.65p) for gas consumption
- £0.0524 per kWh (5.24p) for electricity export to the grid - the reference assumption is that 50% of the electricity used in the home is exported to the grid

[17] BEIS, 2017. Tables supporting the Treasury Green Book supplementary appraisal guidance on valuing energy use and greenhouse gas (GHG) emissions.

In addition to energy costs, the modelling includes savings from avoiding a standing charge without a gas supply. This results in an indicative saving of £120 per year for homes using only electricity.

4. Residential

Each of the three core policy options for achieving a net zero carbon standard (either regulated only or regulated and unregulated) were modelled for each house type and the lowest overall cost options identified for homes heated with both gas boilers and ASHP's.

Information on each policy option is presented using both graphs and tables showing the costs and carbon savings (against the baseline of a home built to Part L 2013 and heated with gas) of the following steps:

- Energy efficiency
- Adoption of an ASHP for space heating and hot water (where applicable)
- Use of photovoltaic panels to achieve or exceed the minimum level of onsite carbon emission reduction
- Use of allowable solutions to achieve net zero regulated or regulated and unregulated carbon emissions.

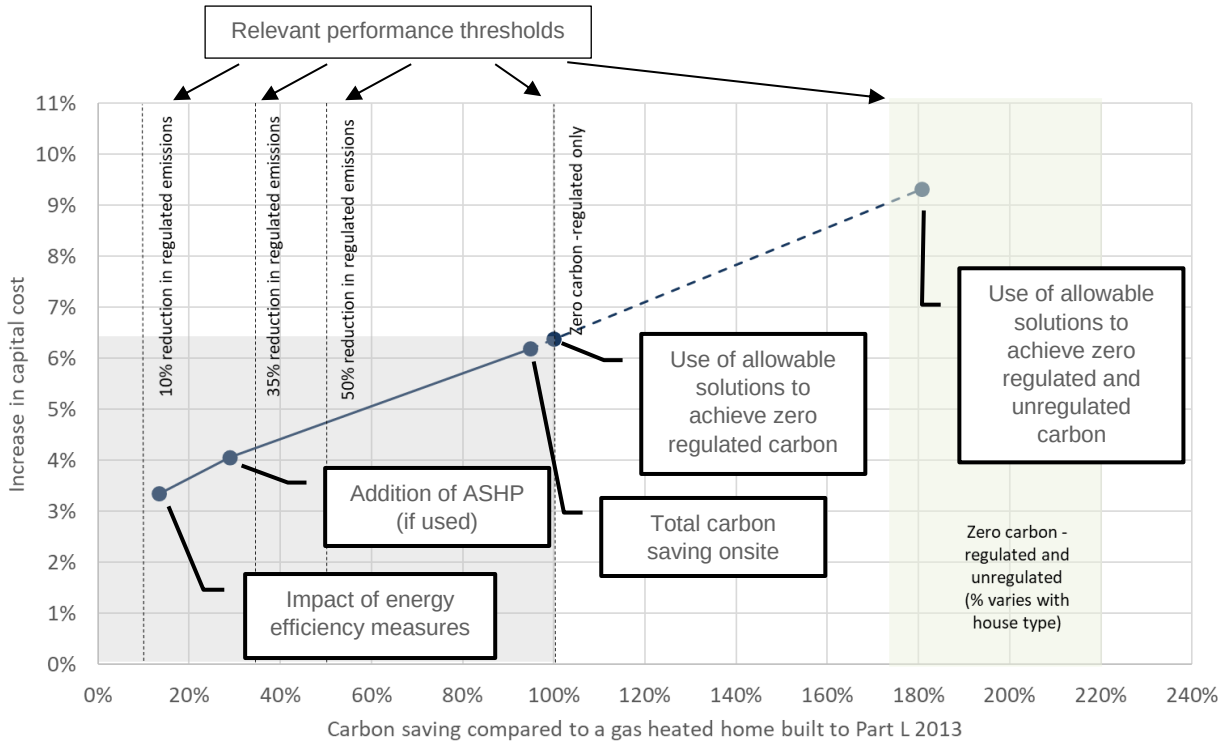
Photovoltaic panels are more cost effective[18] when used in larger arrays, as a result, where these technologies are needed to meet a policy requirement the model used the maximum available array size where this reduced the overall costs of compliance. This approach would also result in more significant savings in energy costs for households, albeit at the expense of a reduction in contributions to an allowable solutions fund. The maximum array area was limited to 40% of ground floor area as previously mentioned, a developer might wish to increase this array area further through careful roof design, or alternatively use less PV and purchase more allowable solutions, this latter strategy might have the effect of increasing the total development costs but the effect should be relatively small unless the option of an array of less than, say, 1kWp were selected.

Each option was modelled using SAP 2012 method and emissions factors with adjustments for the space heating efficiency of ASHP's, where used, as previously described.

Figure 4.1 illustrates the approach taken to presenting the results to aid in interpretation of the study findings.

[18] Where the marginal cost of carbon savings approaches the £95 per tonne used in modelling of allowable solutions

Figure 4.1 Illustration of the approach to presenting study findings



4.1 Policy option 1 – 10% efficiency, 35% onsite and zero carbon

Policy option 1 requires a minimum 10% reduction in carbon emissions through energy efficiency, a minimum total onsite carbon reduction of 35% and the achievement of net zero carbon. Figures 4.2 and 4.3 summarise the cost uplifts for the most cost-effective solutions for achieving compliance with policy option 1 using either gas or ASHP heating systems respectively. Both show cost and performance relative to a baseline of a gas heated home built to the Part L 2013 notional specification.

Figure 4.2 Cost and performance of options to achieve policy option 1 with gas heating

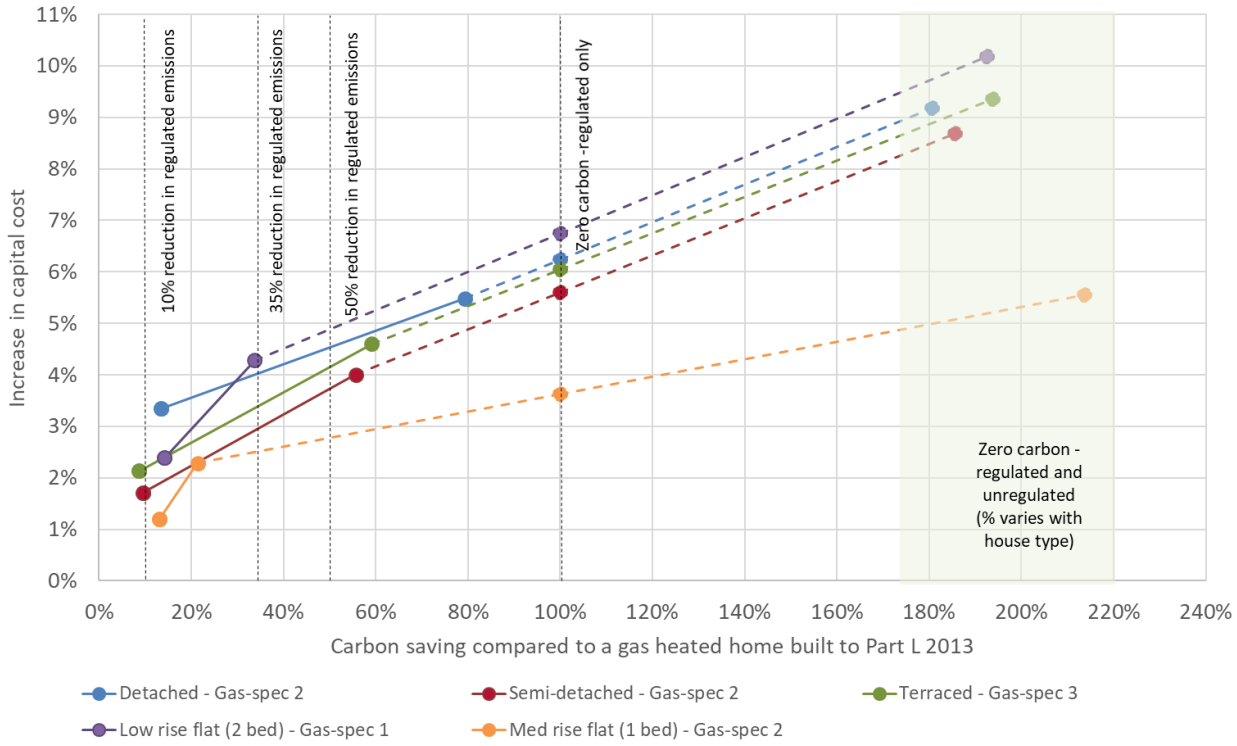


Figure 4.3 Cost and performance of options to achieve policy option 1 with ASHP heating

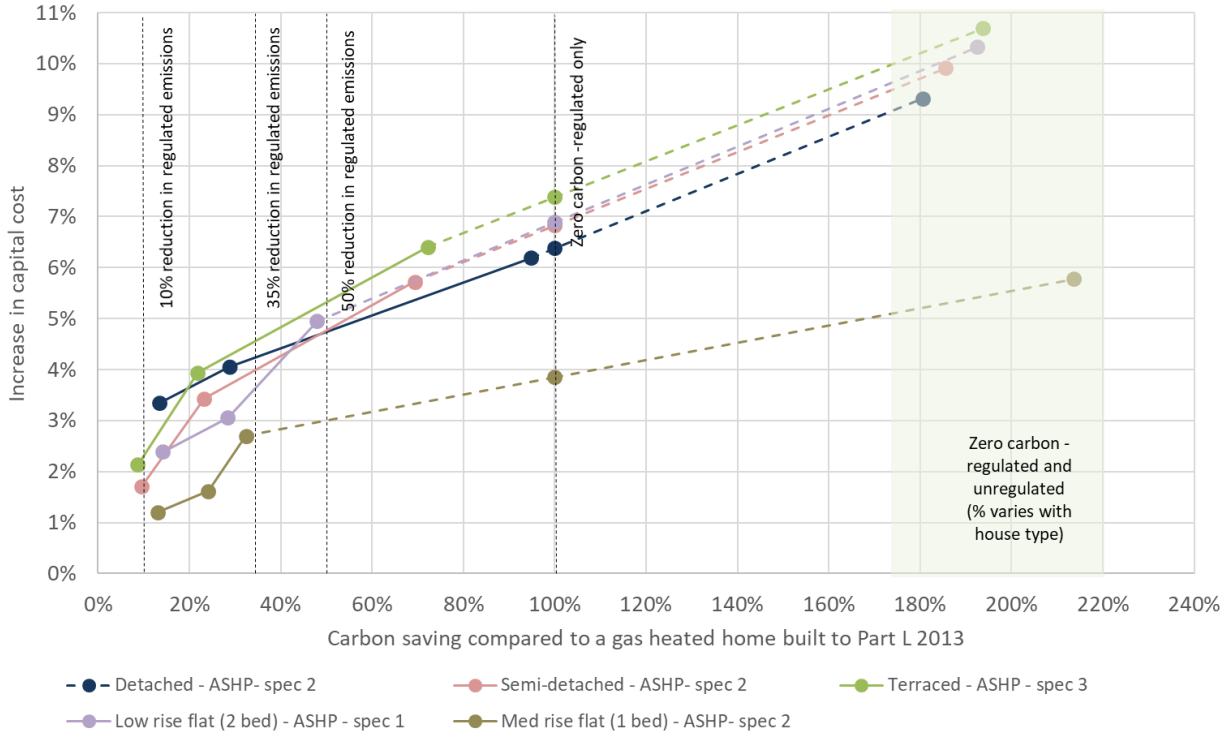


Table 4.1 summarises the costs associated with each option as a percentage of the total build cost, as the £ per m^2 of construction and as a total cost for each home. Cumulative costs are shown for each level of the policy option.

Table 4.1 Summary of cumulative costs with each element of Policy option 1

House type	Energy efficiency					Low carbon heating system (ASHP)				Onsite carbon reduction				Zero regulated carbon			Zero regulated and unregulated carbon		
	Specification	Carbon saving	% uplift	£m²	£ per home	Carbon saving	% uplift	£m2	£ per home	Carbon saving	% uplift	£m²	£ per home	% uplift	£m²	£ per home	% uplift	£m²	£ per home
Gas heated																			
Detached	2	13%	3.3%	£45	£5,300	Not applicable				79%	5.5%	£74	£8,700	6.2%	£84	£9,900	9.2%	£124	£14,500
Semi-detached	2	10%	1.7%	£25	£2,100					56%	4.0%	£58	£4,900	5.6%	£81	£6,800	8.7%	£126	£10,600
Terraced	3	9%	2.1%	£29	£2,400					59%	4.6%	£62	£5,200	6.0%	£82	£6,900	9.4%	£126	£10,600
Low rise flat	2	14%	2.4%	£32	£2,300					34%	4.3%	£58	£4,000	6.7%	£91	£6,400	10.2%	£137	£9,600
Med rise flat*	2	15%	1.2%	£30	£1,500					24%	2.3%	£57	£2,900	3.5%	£87	£4,400	5.4%	£136	£6,800
ASHP heated																			
Detached	2	13%	3.3%	£45	£5,300	29%	4.1%	£55	£6,400	95%	6.2%	£84	£9,800	6.4%	£86	£10,100	9.3%	£126	£14,700
Semi-detached	2	10%	1.7%	£25	£2,100	23%	3.4%	£50	£4,200	69%	5.7%	£83	£7,000	6.8%	£99	£8,300	9.9%	£144	£12,100
Terraced **	3	9%	2.1%	£29	£2,400	22%	3.9%	£53	£4,500	72%	6.4%	£86	£7,300	7.4%	£100	£8,400	10.7%	£144	£12,100
Low rise flat	2	14%	2.4%	£32	£2,300	28%	3.1%	£41	£2,900	48%	4.9%	£67	£4,700	6.9%	£93	£6,500	10.3%	£139	£9,800
Med rise flat**	2	13%	1.2%	£30	£1,500	24%	1.6%	£40	£2,000	32%	2.7%	£67	£3,400	3.8%	£96	£4,800	5.8%	£145	£7,200

* this option is not able to achieve the onsite reduction target with gas heating.

** this option falls very slightly short of the minimum energy efficiency or onsite performance standard. It is expected that in practice the additional 1% onsite reduction could be achieved through a combination of design and / or specification options.

- For a detached home the cost of achieving net zero regulated carbon is just under or just over £10,000 when using either gas or ASHP based heating. The cost of the zero regulated and unregulated carbon policy option is around £14,500 per home. Onsite carbon reductions (energy efficiency and renewable energies) would cost approximately 4% of the capital cost of the notional specification, but it might be expected that a developer would go beyond this standard to achieve further carbon savings onsite as is the case in this scenario.

- For the semi-detached and terraced house options there is a greater difference in the costs of the gas and ASHP scenarios. This is because the additional costs of installing an ASHP and hot water store are higher where the alternative is a gas combi boiler with no water store.

- In the medium rise flat it is difficult to achieve the onsite carbon target with a gas heating system. This is because of the relatively small amount of PV that can be assigned to each flat in the block. Where an ASHP is used for heating the onsite saving is within 3% of the requirement and it is therefore expected that the standard could be met through further refinement of specification options.

- For each home the most cost-effective energy efficiency standard is around 10-15 kWh m^2 more energy efficient than that of the Part L 2013 notional specification.

Key findings and Policy Considerations for Policy Option 1

All dwelling types with gas can achieve net zero carbon for regulated energy for a build cost uplift of around 6% of the current the cost of building to regulations. Purchase of additional allowable solutions to achieve net zero regulated and unregulated emission would result in a cost uplift of between just under 9% and 11% over simply complying with Building Regulations but the additional cost could be under 6% for medium rise flats.

The chart shows that fabric is the most expensive component per unit of carbon saved – as illustrated by the steepness of the line. However, fabric is important for reasons stated previously.

Within the modelling parameters used, all of the lowest cost options use some allowable solutions to achieve the zero carbon standard, although the detached house with ASHP comes close to achieving net zero regulated emissions fully onsite.

The requirement for a minimum level of energy efficiency with this policy option means that only those fabric specifications with high levels of insulation and air tightness can meet the requirement. The modelled specifications that meet the energy efficiency standard include the use of heat recovery ventilation (MVHR) together with improved insulation and air tightness. In practice, it should also be possible to achieve the performance standards in housing with higher insulation levels at the expense of targeting stringent air tightness and using MVHR, for example, by following an approach like the Energiesprong specification. The relative cost effectiveness of pursuing fabric insulation, air tightness and ventilation standards to different extents will vary depending on the developers preferred construction method, the skills of their site teams and their familiarity with the relevant technologies.

In flats, meeting the energy efficiency standard is likely to require the use of MVHR systems together with additional insulation and air tightness.

It is slightly more expensive to achieve these policy requirements with homes heated with an ASHP, this is particularly pronounced for the onsite costs where costs are around half to just under two percent higher). The ASHP options do enable lower carbon emissions onsite and so

some of the additional costs are recouped in the reduced need to pay for allowable solutions. Although the ASHP options meet policy requirements using the SAP2012 standards they perform far better than the gas options when SAP10 emission factors are used (see Section 5).

Policy consideration 6: Policy option 1

Key policy implications from analysis of this policy include:

- An allowable solutions approach is needed to enable zero carbon standards to be achieved
- The adoption of a heat hierarchy that prioritises the use of ASHP will increase development costs until up to date emissions factors are used
- The onsite reduction target should be achievable by each of the housing types assessed and for housing a developer may choose to install more renewable energy on the property in lieu of allowable solutions payments
- An efficiency requirement will be needed if developers are to improve fabric since otherwise it is likely to be cheaper to meet the zero-carbon requirement through PV and Allowable Solutions alone.
- An efficiency requirement of 10% would result in a significant reduction in heat loss from the home but would not necessarily mandate the use of MVHR or the achievement of very high levels of air tightness in houses. Developers would have the flexibility to meet the requirement in a manner that suits their circumstances and product offering.

4.2 Policy option 2 – 10% efficiency, 50% onsite and zero carbon

This option is similar to policy option 1 but includes a minimum requirement of a 50% reduction in onsite carbon emissions.

Figures 4.4 and 4.5 summarise the cost uplifts for the most cost-effective solutions for achieving compliance with policy option 2 using either gas or ASHP heating systems respectively. Both show cost and performance relative to a baseline of a gas heated home built to the Part L 2013 notional specification.

Figure 4.4 Cost and performance of options to achieve policy option 2 with gas heating

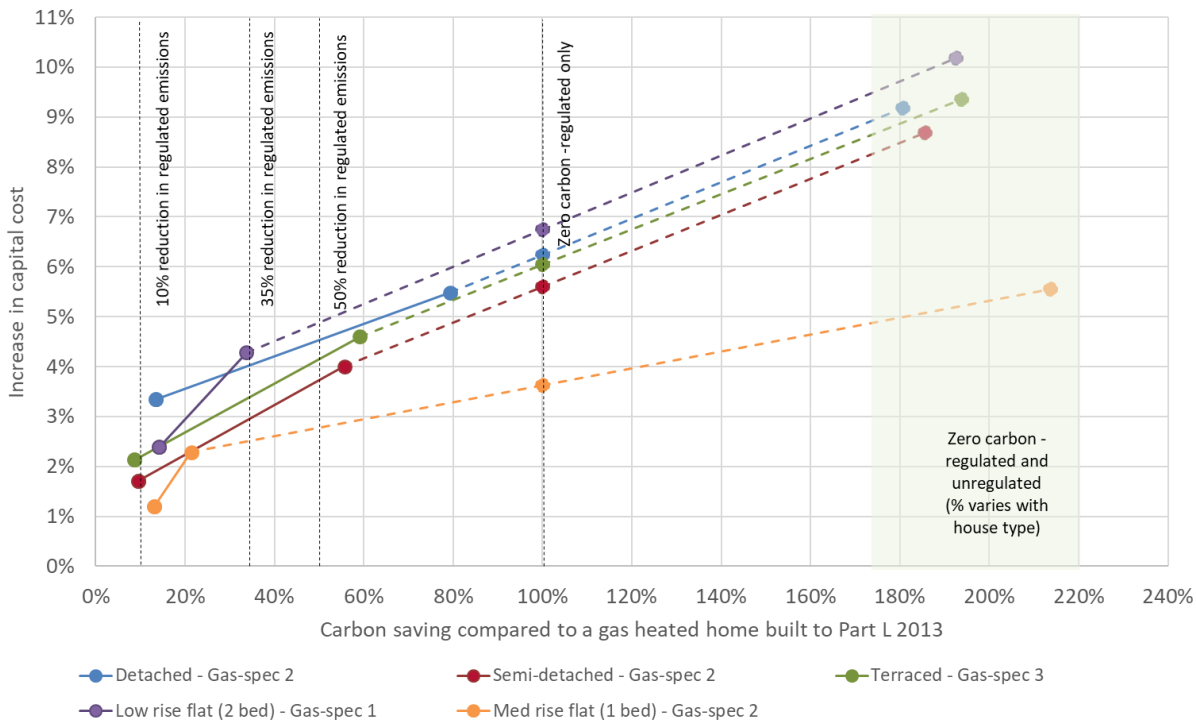


Figure 4.5 Cost and performance of options to achieve policy option 2 with ASHP heating

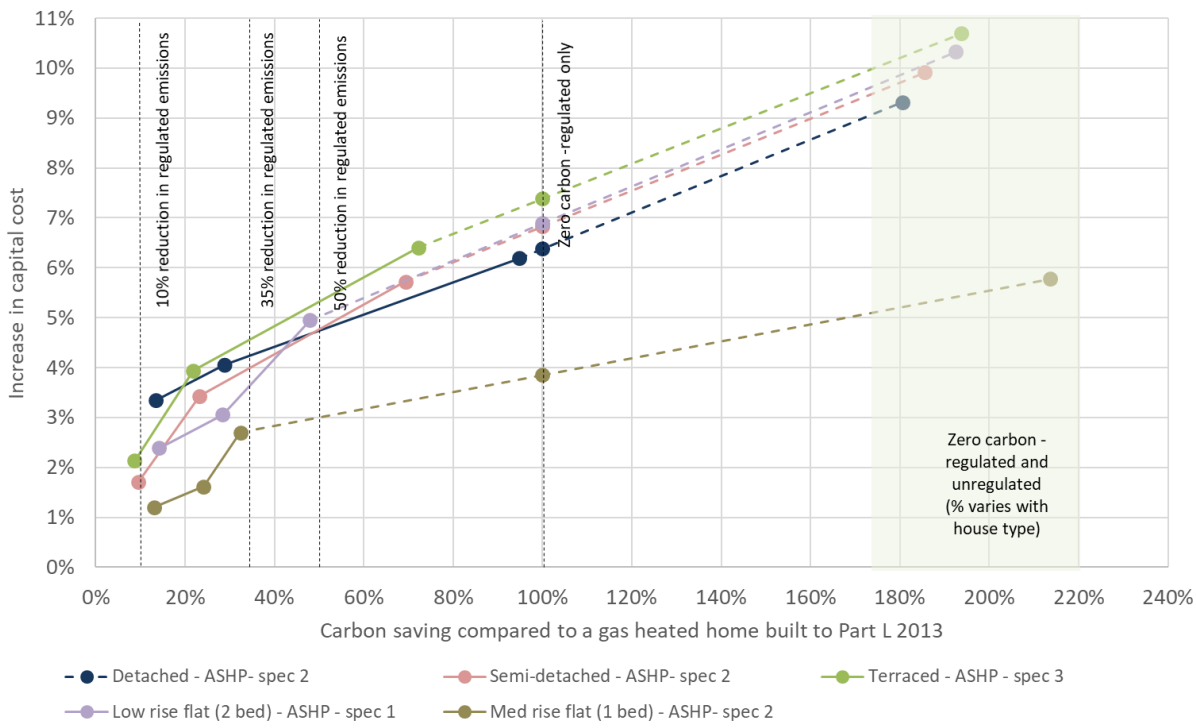


Table 4.2 summarises the costs associated with each option as a percentage of the total build cost, as the £ per m^2 of construction and as a total cost for each home.

Table 4.2 summary of cumulative costs with each element of option 2

House type	Energy efficiency					Low carbon heating system (ASHP)				Onsite carbon reduction				Zero regulated carbon			Zero regulated and unregulated carbon		
	Specification	Carbon saving	% uplift	£m²	£ per home	Carbon saving	% uplift	£m2	£ per home	Carbon saving	% uplift	£m²	£ per home	% uplift	£m²	£ per home	% uplift	£m²	£ per home
Gas heated																			
Detached	2	13%	3.3%	£45	£5,300	Not applicable				79%	5.5%	£74	£8,700	6.2%	£84	£9,900	9.2%	£124	£14,500
Semi-detached	2	10%	1.7%	£25	£2,100					56%	4.0%	£58	£4,900	5.6%	£81	£6,800	8.7%	£126	£10,600
Terraced	3	9%	2.1%	£29	£2,400					59%	4.6%	£62	£5,200	6.0%	£82	£6,900	9.4%	£126	£10,600
Low rise flat*	2	20%	2.6%	£35	£2,500					34%	4.3%	£58	£4,000	6.7%	£91	£6,400	10.2%	£137	£9,600
Med rise flat*	2	15%	1.2%	£30	£1,500					24%	2.3%	£57	£2,900	3.5%	£87	£4,400	5.4%	£136	£6,800
ASHP heated																			
Detached	2	13%	3.3%	£45	£5,300	29%	4.1%	£55	£6,400	95%	6.2%	£84	£9,800	6.4%	£86	£10,100	9.3%	£126	£14,700
Semi-detached	2	10%	1.7%	£25	£2,100	23%	3.4%	£50	£4,200	69%	5.7%	£83	£7,000	6.8%	£99	£8,300	9.9%	£144	£12,100
Terraced**	3	9%	2.1%	£29	£2,400	22%	3.9%	£53	£4,500	72%	6.4%	£86	£7,300	7.4%	£100	£8,400	10.7%	£144	£12,100
Low rise flat**	2	14%	2.4%	£32	£2,300	28%	3.1%	£41	£2,900	48%	4.9%	£67	£4,700	6.9%	£93	£6,500	10.3%	£139	£9,800
Med rise flat*	2	13%	1.2%	£30	£1,500	24%	1.6%	£40	£2,000	32%	2.7%	£67	£3,400	3.8%	£96	£4,800	5.8%	£145	£7,200

* this option is not able to achieve the onsite reduction target.

** this option falls very slightly short of the minimum energy efficiency or overall onsite performance standard. It is expected that in practice the additional efficiency or onsite reduction could be achieved through a combination of design and / or specification options.

The lowest cost solutions for housing archetypes are the same as for Policy option 1 but neither flat archetype can achieve the 50% onsite reduction standard with gas heating and only the low rise (2 bed) flat can achieve this standard when heated with an ASHP.

Key findings and Policy Considerations for Policy Option 2

The technical solutions for option 2 are the same as those for option 1. For housing, developers may choose to exceed the minimum onsite requirement as this is no more expensive than purchasing allowable solutions. For flats it is not possible to achieve the onsite requirement with the options modelled for the medium rise flat or for the low rise flat using gas heating.

Policy Consideration 7: policy option 2

A 50% onsite requirement is technically possible and can be achieved in the houses modelled. However, this policy may be too challenging for flats where the extent of available roof per flat is limited.

4.3 Policy option 3 – 0% efficiency, 35% onsite and zero carbon

Policy option 3 differs from option 1 in that there is no requirement to achieve a minimum level of onsite energy efficiency. Figures 4.6 and 4.7 show the results for this option for gas and ASHP heated homes respectively.

Figure 4.6 Cost and performance of options to achieve policy option 3 with gas heating

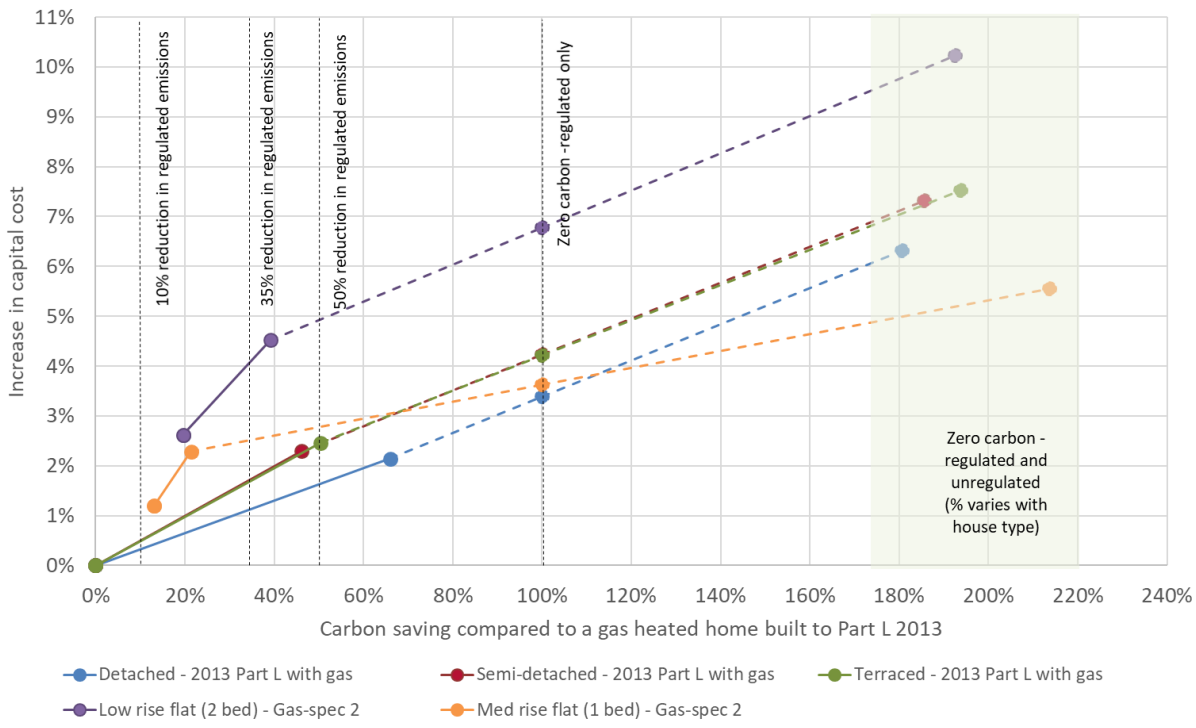


Figure 4.7 Cost and performance of options to achieve policy option 3 with ASHP heating

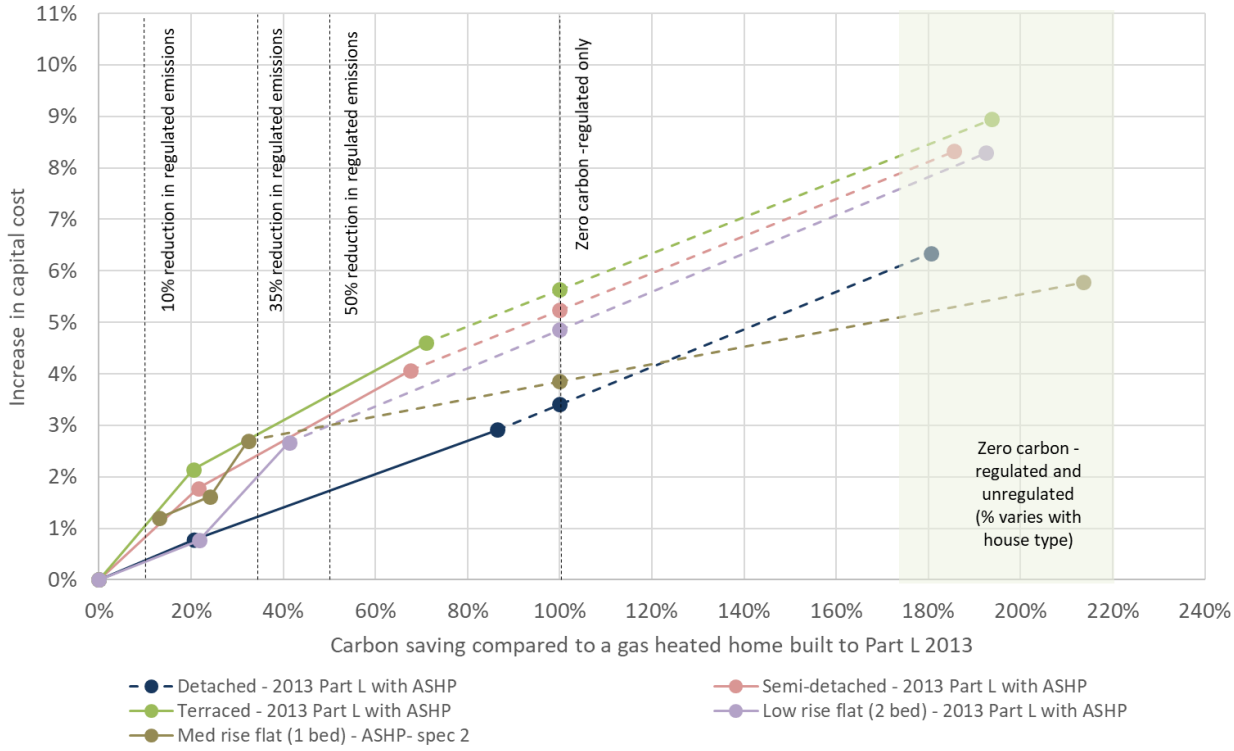


Table 4.3 summarises the costs associated with option 3 as a percentage of the total build cost, as the £ per m^2 of construction and as a total cost for each home.

Table 4.3 summary of cumulative costs with each element of policy option 3

House type	Energy efficiency					Low carbon heating system (ASHP)				Onsite carbon reduction				Zero regulated carbon			Zero regulated and unregulated carbon		
	Specification	Carbon saving	% uplift	£m²	£ per home	Carbon saving	% uplift	£m2	£ per home	Carbon saving	% uplift	£m²	£ per home	% uplift	£m²	£ per home	% uplift	£m²	£ per home
Gas heated																			
Detached	Part L only	0%	0.0%	£0	£0	Not applicable				66%	2.1%	£29	£3,400	3.4%	£46	£5,300	6.3%	£85	£10,000
Semi-detached	Part L only	0%	0.0%	£0	£0					46%	2.3%	£33	£2,800	4.2%	£61	£5,200	7.3%	£106	£8,900
Terraced	Part L only	0%	0.0%	£0	£0					50%	2.5%	£33	£2,800	4.2%	£57	£4,800	7.5%	£102	£8,500
Low rise flat*	1	14%	2.4%	£32	£2,300					34%	4.3%	£58	£4,000	6.7%	£91	£6,400	10.2%	£137	£9,600
Med rise flat**	2	13%	1.2%	£30	£1,500					21%	2.3%	£57	£2,900	3.6%	£91	£4,500	5.6%	£139	£6,900
ASHP heated																			
Detached	Part L only	0%	0.0%	£0	£0	21%	0.8%	£10	£1,200	87%	2.9%	£39	£4,600	3.4%	£46	£5,400	6.3%	£86	£10,000
Semi-detached	Part L only	0%	0.0%	£0	£0	22%	1.8%	£26	£2,200	68%	4.1%	£59	£5,000	5.2%	£76	£6,400	8.3%	£121	£10,100
Terraced	Part L only	0%	0.0%	£0	£0	21%	2.1%	£29	£2,400	71%	4.6%	£62	£5,200	5.6%	£76	£6,400	8.9%	£121	£10,100
Low rise flat	Part L only	0%	0.0%	£0	£0	22%	0.8%	£10	£700	41%	2.7%	£36	£2,500	4.8%	£65	£4,600	8.3%	£112	£7,800
Med rise flat*	2	15%	1.2%	£30	£1,500	24%	1.6%	£40	£2,000	32%	2.7%	£67	£3,400	3.8%	£96	£4,800	5.8%	£145	£7,200

* this option falls very slightly short of the minimum onsite performance standard. It is expected that in practice the additional 1% onsite reduction could be achieved through a combination of design and / or specification options.

** this option is not able to achieve the onsite reduction target.

- The omission of an energy efficiency component to policy option 3 means that the overall costs of meeting the onsite and zero carbon standards is lower. For all the housing options the lowest cost solution does not involve any further energy efficiency beyond the requirements of Part L . For flats there is a need for greater efficiency to enable the onsite target to be achieved at least in the case of the medium rise flat and the low rise flat if heated with gas.

Key findings and Policy Considerations for Policy Option 3

When the requirement for a minimum energy efficiency standard is removed the costs of meeting the regulated and regulated and unregulated zero carbon requirements reduce considerably for houses.

Since fabric improvements are more expensive than PV, this analysis indicates that in most house types, developers would use PV rather than fabric improvements to meet the standard.

There is a different picture for flats, where the costs are the same as for option 1. This is because the limited available PV area per home means that to meet the overall reduction target it is necessary for them to adopt higher levels of energy efficiency.

Whilst a lower construction cost option 3 has drawbacks in that:

- Resident costs will be higher as more energy is used
- Higher energy demand will increase the quantity of low carbon energy generation that is required to decarbonise the electricity grid. Whilst the installation of PV on each home will help with this process it will not, in isolation, provide the necessary low carbon energy to heat the homes at periods of peak demand and when generation levels are low.
- Increased demand for energy (when coupled with electric heating) will place higher peak demand loads on energy infrastructure. The costs of providing this additional capacity will be partly borne by developers but also by other energy consumers, thereby increasing overall energy costs.

Further, the potential to improve energy efficiency after construction is complete is limited and far more expensive. The additional costs of improving energy efficiency in new construction are many times less than achieving the same standards in retrofit. Notwithstanding the practical difficulties associated with retrofitting homes in occupation the costs associated with achieving improved performance standards for any elements other than heating system after construction are likely to be prohibitive for any home built to a Part L 2013 compliant specification. This is because upgrades to the fabric of the building would necessitate significant work with relatively small marginal gain. For example, there is little benefit in applying external or internal wall insulation to achieve only a 0.05 Wm2K or less improvement in U value. Similarly, there would be little benefit in reinsulating a floor to achieve a reduction in heat transfer of 0.02 Wm2K or less. Achieving very high levels of airtightness could possibly be achieved in tandem with, for example, external wall insulation but would be very difficult to deliver without a major programme of fabric works when the home is already completed and occupied.

Achieving these higher performance standards in new construction requires careful design and specification but is far lower cost as the only cost is for the marginal increment in performance standards rather than for a full programme of retrofit work with associated additional, planning, design, construction and redecoration / making good.

Policy consideration 8: policy option 3

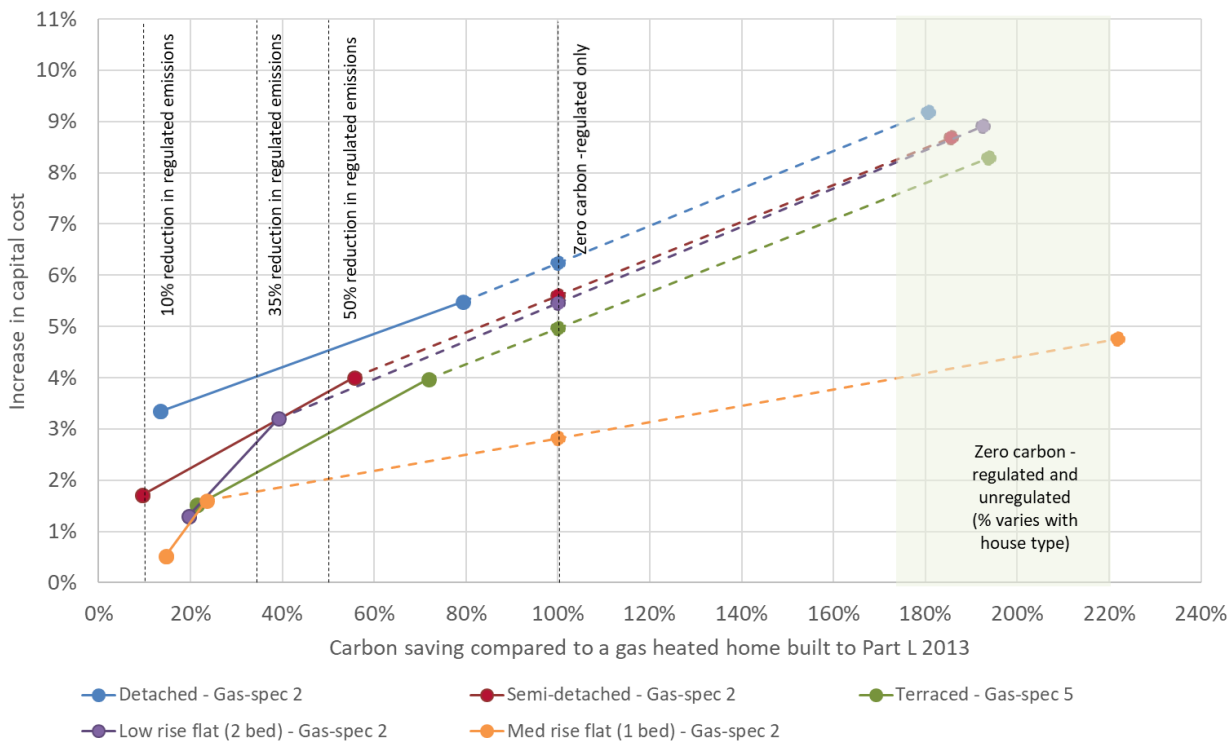
- It is 2-3% of total build costs less expensive to omit the fabric component of a zero-carbon target for most house types

- Flats would be relatively unaffected
- However, there are potential risks from omitting an energy efficiency requirement, principally in the form of higher bills and potential implications for costs and because additional peak and total electrical loads could affect the ability to effectively decarbonise the wider UK energy system.
- If the opportunity to achieve high efficiency standards is missed during new construction it is likely to be prohibitively expensive to achieve these retrospectively. By contrast that additional cost of installing photovoltaics after construction is relatively small in comparison to doing so during the build process.

4.4 Sensitivity analysis: reduced heating system costs

The implications of a scenario where very high levels of energy efficiency enabled reductions in the cost of the internal heat distribution system (radiators and heating) were tested in a sensitivity analysis. The analysis considered the implications of being able to reduce the number of internal radiators and associated pipework by 50% where the highest energy efficiency standard (close to Passivhaus) was used. Figures 4.8 and 4.9 show the impact of this assumption on the costs of meeting policy options 1 and 2[19] for the gas and ASHP heated options respectively. The results are also shown in Table 4.4.

Figure 4.8 Cost and performance of options to achieve policy options 1&2 with gas heating and assuming reduced heating costs in very energy efficient homes



[19], i.e. to the level of 3-4 radiators on each floor[19] This sensitivity would not applicable to option 3 which does not require increased levels of energy efficiency.

Figure 4.9 Cost and performance of options to achieve policy options 1&2 with ASHP heating and assuming reduced heating costs in very energy efficient homes

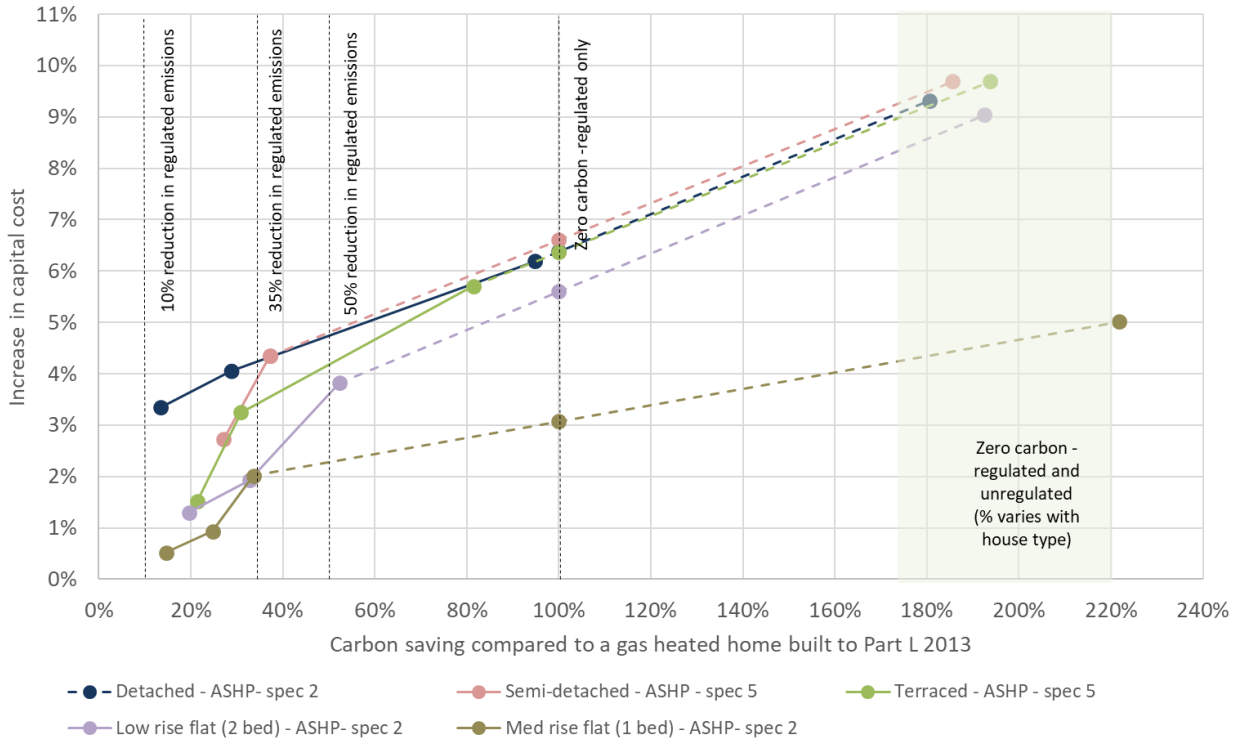


Table 4.3 summary of cumulative costs of meeting policy options 1&2 assuming reduced heating costs in very energy efficient homes

House type	Energy efficiency					Low carbon heating system (ASHP)				Onsite carbon reduction				Zero regulated carbon			Zero regulated and unregulated carbon		
	Specification	Carbon saving	% uplift	£m²	£ per home	Carbon saving	% uplift	£m2	£ per home	Carbon saving	% uplift	£m²	£ per home	% uplift	£m²	£ per home	% uplift	£m²	£ per home
Gas heated																			
Detached	2	13%	3.3%	£45	£5,300	Not applicable				79%	5.5%	£74	£8,700	6.2%	£84	£9,900	9.2%	£124	£14,500
Semi-detached	2	10%	1.7%	£25	£2,100					56%	4.0%	£58	£4,900	5.6%	£81	£6,800	8.7%	£126	£10,600
Terraced	5	21%	1.5%	£20	£1,700					72%	4.0%	£54	£4,500	5.0%	£67	£5,600	8.3%	£112	£9,400
Low rise flat*	2	20%	1.3%	£18	£1,200					39%	3.2%	£43	£3,000	5.5%	£74	£5,200	8.9%	£120	£8,400
Med rise flat**	2	15%	0.5%	£13	£600					24%	1.6%	£40	£2,000	2.8%	£70	£3,500	4.7%	£119	£5,900
ASHP heated																			
Detached	5	13%	3.3%	£45	£5,300	29%	4.1%	£55	£6,400	95%	6.2%	£84	£9,800	6.4%	£86	£10,100	9.3%	£126	£14,700
Semi-detached	5	27%	2.7%	£40	£3,300	37%	4.3%	£63	£5,300	37%	4.3%	£63	£5,300	6.6%	£96	£8,000	9.7%	£141	£11,800
Terraced	5	21%	1.5%	£20	£1,700	31%	3.2%	£44	£3,700	81%	5.7%	£77	£6,500	6.4%	£86	£7,200	9.7%	£131	£11,000
Low rise flat	2	20%	1.3%	£18	£1,200	33%	1.9%	£26	£1,800	52%	3.8%	£52	£3,600	5.6%	£76	£5,300	9.0%	£122	£8,500
Med rise flat*	2	15%	0.5%	£13	£600	25%	0.9%	£23	£1,200	34%	2.0%	£50	£2,500	3.1%	£77	£3,800	5.0%	£125	£6,300

* this option falls very slightly short of the minimum onsite performance standard. It is expected that in practice the additional 1% onsite reduction could be achieved through a combination of design and / or specification options.

** this option is not able to achieve the onsite reduction target.

This analysis shows that with gas heating the energy efficiency of each specification is unchanged compared to the previous analysis (Figures 4.2 and 4.4). However, with an ASHP providing the heating, the use of a highly efficient fabric Spec 5 becomes lower cost for both the semi-detached and terraced houses. The energy efficiency standard for the flats is unchanged but was already at the highest option available.

This option is considered as a sensitivity as it presents an alternative means of meeting policy requirements but would a more significant departure from current housebuilding practice. The analysis indicates that for homes that have a reasonably efficient form[20], the pursuit of a highly efficient fabric which enables savings in the internal heating system could be a lower cost way of complying with policy standards.

4.5 Less ambitious carbon reduction options and existing policy baseline

Policy Options 1-3 are all assessed against a comparator of a Part L 2013 home, however many authorities already have a range of sustainable buildings policies which are influencing current development in the region. Existing policies might include:

- ‘Merton rule’ requirements for using renewable energy to reduce carbon emissions for example by between 15 and 20% of regulated energy consumption or for 20% of both regulated and unregulated energy use[21]
- Reducing operational emissions by 19% overall, following the 2015 Written Ministerial Statement HCWS488 stating that energy efficiency improvements should be limited to those equivalent to meeting the Code for Sustainable Homes level 4 standard.
- A requirement for 10% carbon reduction through energy efficiency as a component of an overall 19% reduction.

Since these policy standards are already being delivered, an uplift to a higher standard (e.g. zero carbon) could be considered from a baseline of existing policy requirements rather than the regulatory minimum.

Figure 4.10 shows the cost implications of meeting ‘Merton Rule’ requirements for detached and semi-detached houses and low-rise flats. Compliant renewable energy measures include the use of ASHP’s and PV panels and where needed to achieve the target improved energy efficiency.

[20] i.e. a relatively low ratio of external walls to floor area
[21] This is broadly equivalent to 35-45% of regulated energy depending on home type if following, SAP 2012 methods, unregulated energy represents between 80 and 120% of regulated energy consumption.

Figure 4.10 Cost and performance of options to achieve 'Merton Rule' requirements

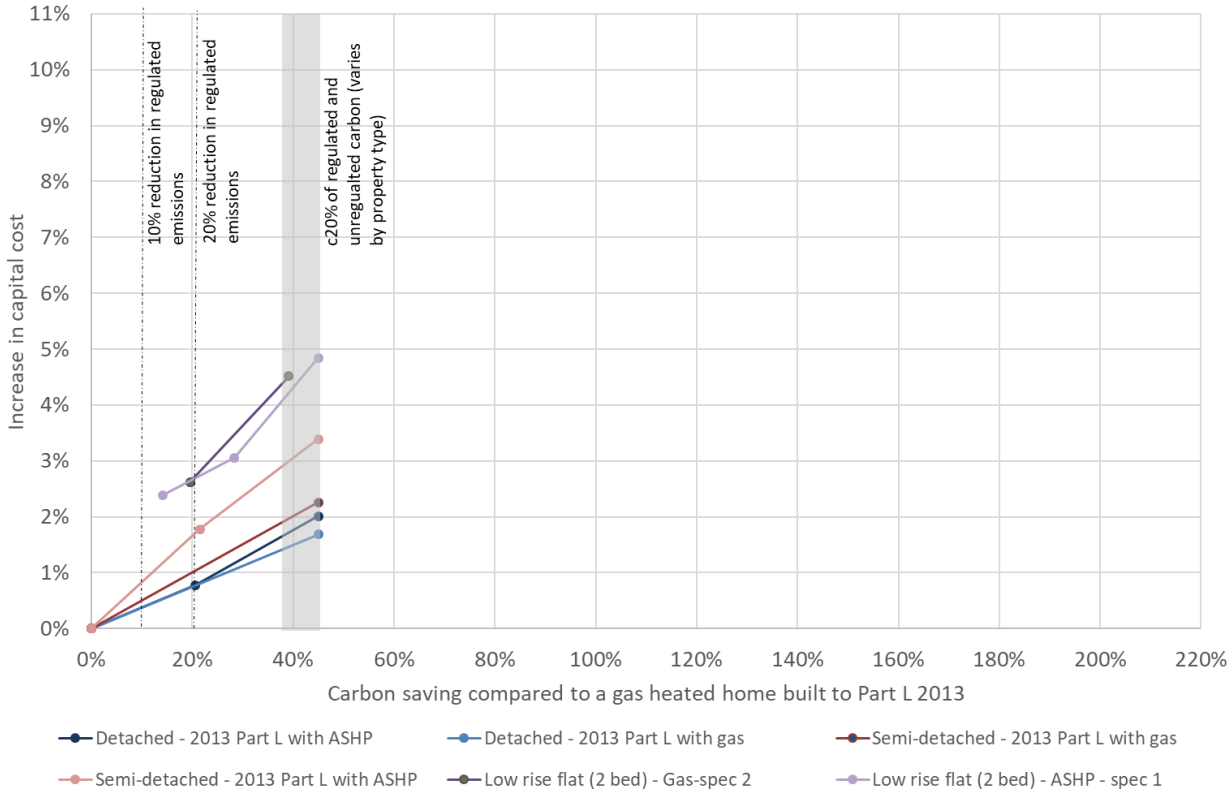


Figure 4.11 shows the costs of reducing emissions by 19% onsite with no requirement for energy efficiency beyond the Part L 2013 notional specification (assuming gas heating), while Figure 4.12 show these results together with a requirement for a 10% carbon reduction through energy efficiency.

Figure 4.11 Cost and performance of options to achieve 19% improvement on Part L 2013

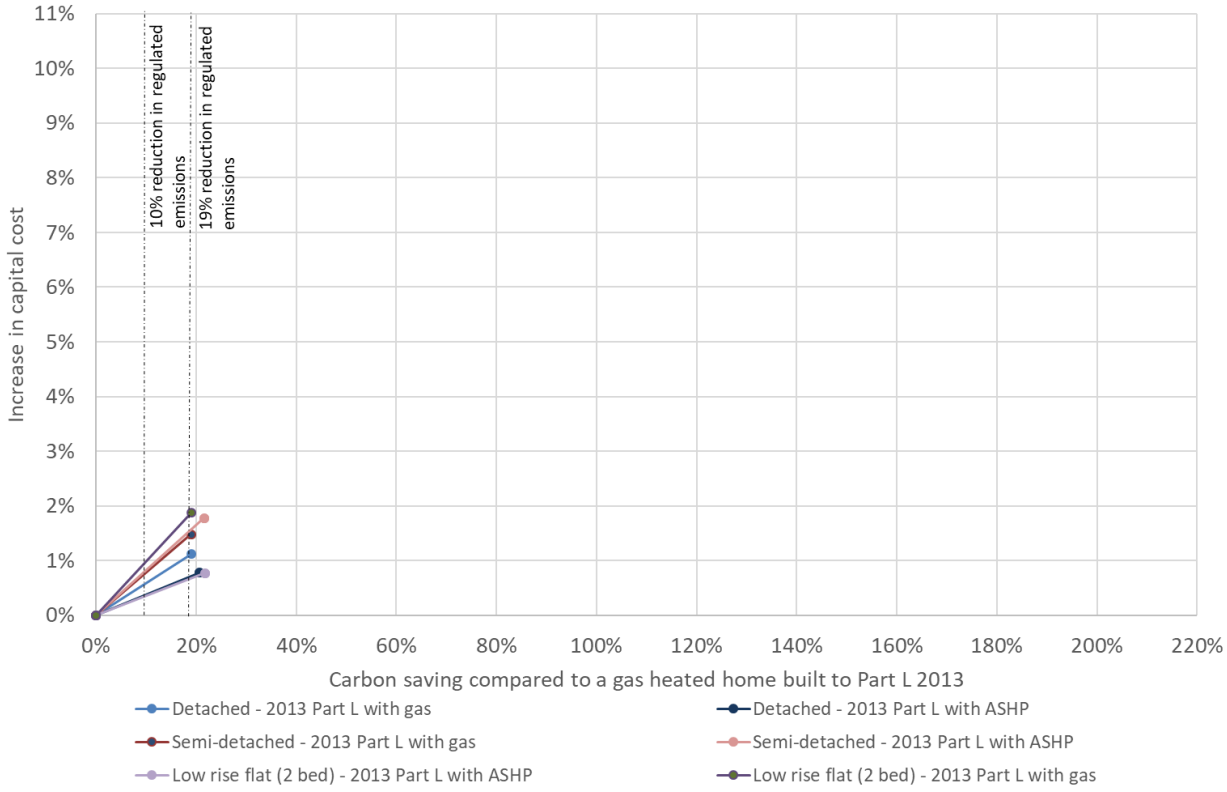
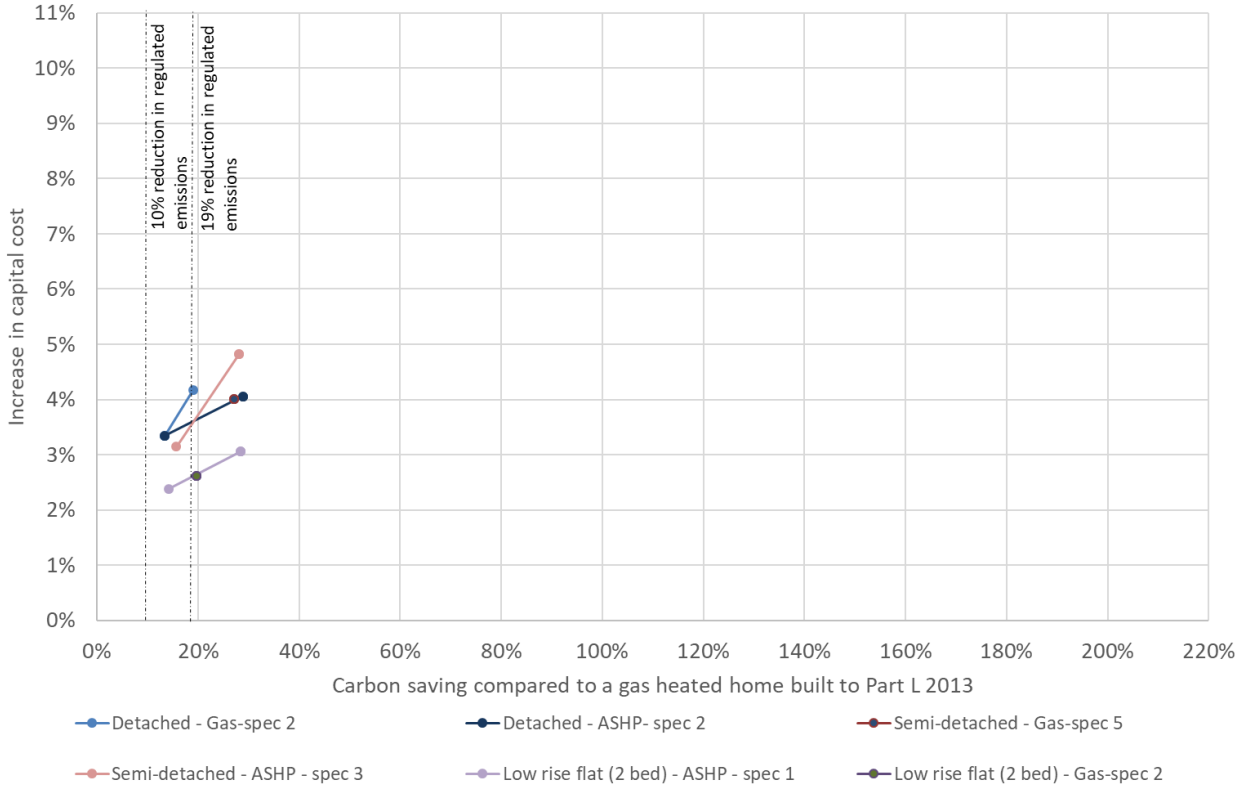


Figure 4.12 Cost and performance of options to achieve 19% improvement on Part L 2013 and 10% carbon reduction from energy efficiency



The introduction of a 10% energy efficiency requirement in addition to the overall 19% onsite requirement increases costs for houses, as with this requirement the most cost-effective options involve maximising the energy efficiency of the home and using a smaller heating system to achieve more than the minimum 10% carbon reduction and thereby avoiding the need for installing renewables to achieve the overall 19% carbon saving. Hence, in some scenarios there are only dots on Figure 4.12, representing the position after improving energy efficiency.

Policy consideration 9: lower performance standards

- The options above could be considered for development scales or locations where full zero carbon is challenging.
- Since many areas have existing policy requirements which are currently being delivered, any cost uplift arising from new and more challenging policy requirements (such as zero carbon) could be considered against the baseline of existing policy.
- The introduction of a requirement for a 10% fabric improvement on its own could drive a high standard of fabric improvement, which is the most important element to implement at the new build stage.

5. Decarbonisation: A consideration for future policy

Over recent years the mix of electricity generation sources used to provide electricity through the national grid has changed significantly. This includes an increase in the contribution of renewable energy sources from under 5% in 2004 to over 30% in 2018[22] and an increase in the use of gas over coal as the main fossil fuel for power generation. This trend is set to continue in the coming decades as further renewable and low carbon electricity sources are deployed. This is leading to falling "emissions factors" for electricity; the amount of CO2 emitted per unit of power generated.

5.1 Implications of decarbonisation for approaches to carbon reduction

An important implication of the decarbonisation of the UK electricity supply mix is that the carbon emissions associated with residential electricity use are in practice lower than those included within the SAP 2012 methodology and they are likely to fall further in the future. Therefore, new homes will have lower overall carbon emissions per unit of electricity consumption than that currently shown using the SAP 2012 method.

SAP is being revised to take account of decarbonisation of electricity and other changes that have occurred since 2012. The next version will be SAP 10, which has been published in draft but may yet change, is yet to be confirmed, and will only come into effect when Part L of the Building Regulations is updated, expected 2019.

The recently published SAP10 method reflects decarbonisation by using emission factors for electricity of 0.23 $kgCO_2e$ per kWh, a 55% reduction on the 0.519 $kgCO_2e$ per kWh factor used in SAP 2012. This is almost at parity with the gas emissions factor of 0.216 $kgCO_2e$ per kWh.

The impact of grid decarbonisation is important for several reasons:

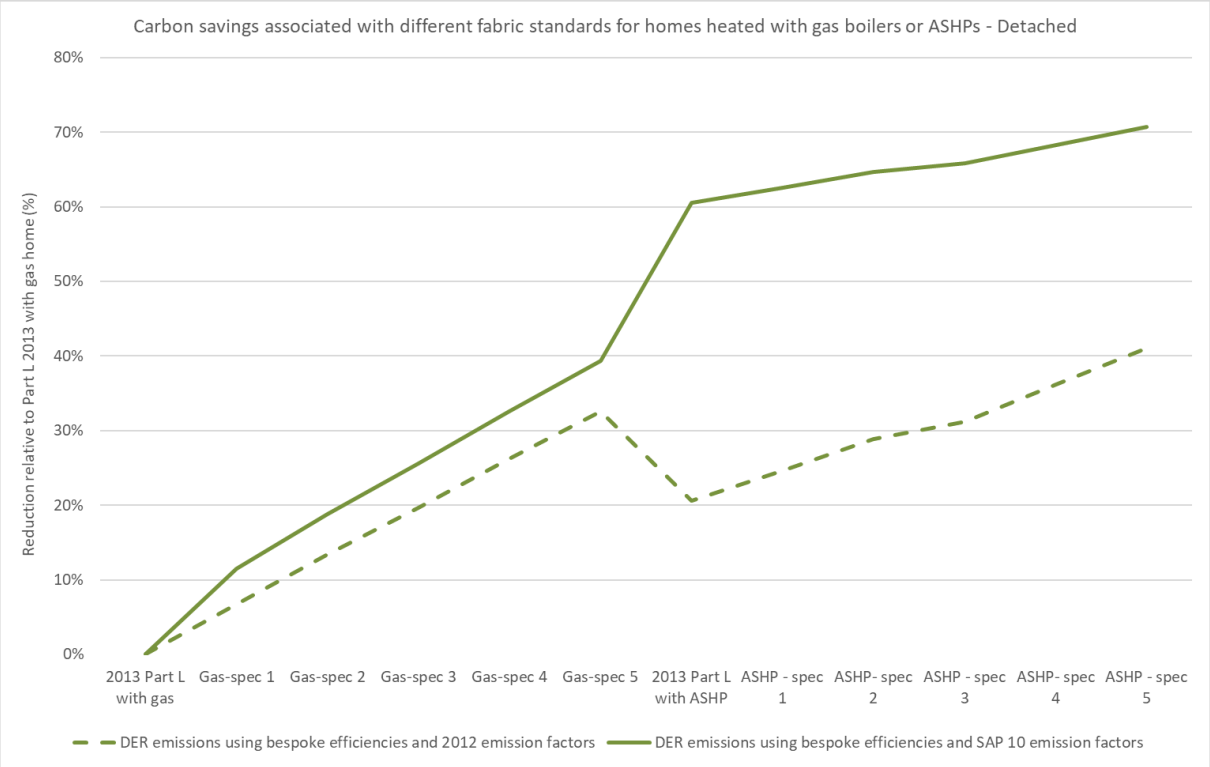
- Electrically heated homes have lower carbon emissions.
- ASHP will be a significantly less carbon intensive source of heating, since they use a small amount of electricity to generate a large amount of heat[23]. Emissions per unit of heat output from an ASHP will be around a third of those from even a highly efficient gas boiler. This means that ASHPs, currently constituting less than 1% of the market for heating systems may become a lot more common. Total carbon emissions from all homes (including those heated by gas) will be lower because of reduced emissions associated with unregulated energy (largely electricity) and regulated electricity use for lighting, pumps and fans.
- The amount of carbon saved from generating electricity using PV will reduce as the displaced grid energy will have lower carbon intensity. This means that the cost effectiveness of PV as a carbon saving technology will fall, albeit it will still help to reduce household energy costs. This will not increase costs of homes heated electrically, since the amount of carbon to reduce will decline at the same rate as the ability of PV to reduce it. However, for gas heated homes, because the gas emissions factor will not decrease, PV will become less effective at offsetting emissions from gas. This will be another driver for ASHP, especially if there are challenging carbon reduction targets.
- The amount of carbon saved by fabric improvements will also decline where homes are electrically heated. However, reducing demand for electric heating through fabric improvements is important for reducing demands on the electricity grid and avoiding associated costs of grid reinforcement. By reducing the amount of power used for heating in the evenings when people are home, when energy production from photovoltaic panels is low, new homes can help to minimise the additional peak demand that needs to be

[22] Energy Trends, June 2018. Business Energy and Industrial Strategy.
[23] This study assumes an efficiency factor of 300%.

served and thereby help to reduce the costs of the transition to low carbon power. This will become increasingly important if renewable electricity in the grid is to continue to increase up to 100%.

The costs of allowable solutions payments required to achieve zero regulated carbon, or zero regulated and unregulated carbon emissions will fall as the total quantity of residual carbon to be addressed will be smaller. The impact of changing carbon emissions factors to those in SAP 10 for each fabric standard with both gas and ASHP heating is shown in Figure 5.1 using the example of a detached house and with the higher 'bespoke' ASHP efficiency of 300% for space heating. The analysis excludes the use of PV or allowable solutions to show more clearly the effect on heating systems and fabric.

Figure 5.1 Impact of using SAP 10 rather than SAP 2012 emission factors on carbon savings



This analysis illustrates the savings in carbon emissions for all options, but in particular the significant impact on the performance of specifications using an ASHP for heating. With SAP 10, ASHP heated homes demonstrate a c.60-70% reduction in emissions compared to a gas heated Part L 2013 compliant equivalent, greater than the savings of Specification 5 fabric on a gas heated home. The scale of carbon savings associated with electrification of heating is likely to increase in the future as the carbon intensity of the supplied electricity reduces further.

The impact of changing emission factors for electricity will only be seen in the SAP process when a new version of SAP is adopted for use in Building Regulations. Until this happens the carbon emissions of homes, particularly those heated with heat pumps will be overestimated[24]. For example, this analysis shows that a Part L compliant semi-detached house under SAP 2012

[24] Notwithstanding the effects of any performance gap, whereby actual energy use is higher than that projected at design stage

produces around 18 $kgCO_2e$ per m^2. Under SAP 10 efficiency factors, this falls to around 16$kgCO_2e$ per $m^2$and if an ASHP is used it falls further to 6.5 $kgCO_2e$ per m^2.

5.2 Updates to SAP and Part L

It is too soon to gauge the full effect of the introduction of SAP 10 or a similarly updated assessment method. While the electricity emission factor clearly has a major impact on the carbon performance of new homes, it is only one of several variables influencing the performance of homes when assessed using a new version of SAP.

SAP 10 lists the following material changes in modelling methods over the SAP 2012 version:

- Updated fuel prices, CO2 emissions and primary energy factors
- Adjustments to the calculation of hot water consumption to take account of shower type
- Updated calculation of lighting energy to allow for new lighting technologies
- Revised treatment of distribution loss factors associated with communal heating networks
- Updated air flow rates associated with chimneys and flues
- Refined assessment of summer internal temperatures
- Revised treatment of mechanical ventilation system heat recovery and aerodynamic performance
- Provision of additional flow temperature options for heat pumps and condensing boilers
- Revised self-use factor for electricity generated by PV systems to allow for the effects of battery storage –
- Addition of the ability to include solar thermal space heating
- Adjustment to the assumed standard heating pattern

The full implications of the above changes are unclear as SAP10 compliant modelling software has not been released. However, the number and nature of the changes included suggest that understanding the potential future performance of homes under a SAP10 methodology is more complex than simply changing the electricity emission factor for results modelled using SAP 2012. Further changes, beyond SAP 10 may be contained within the revised Part L. For example, the threshold for Part L compliance may be raised.

Because of the potentially significant changes in the assessment method, and potentially in the regulatory environment, it is recommended that policy requirements are revisited if the assessment method and regulatory requirement are updated.

This does not mean that the principles of seeking to minimise energy demand, use low carbon heating sources and generate renewable energy onsite will change only that the specific nature of the requirements and the baseline performance will be recalibrated.

Figures 5.2 and 5.3 illustrate the scale of reduction in costs associated with each zero-carbon option for gas and ASHP heated homes. The actual performance of a home modelled using the full new assessment method will differ from that shown here. In Figure 5.3 the minimum onsite targets can be achieved without the need for PV as part of the specification.

Figure 5.2, illustration of the scale of costs associated policy option 1 with gas heating and SAP 10 emission factors

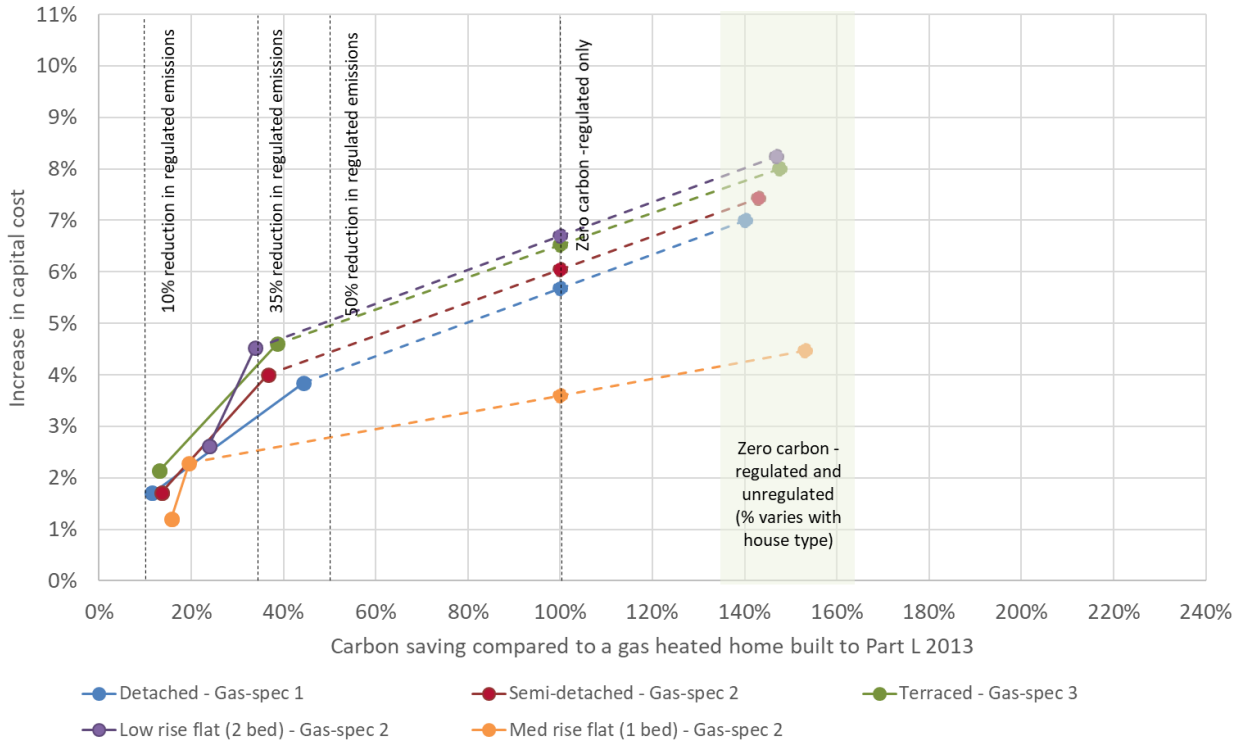
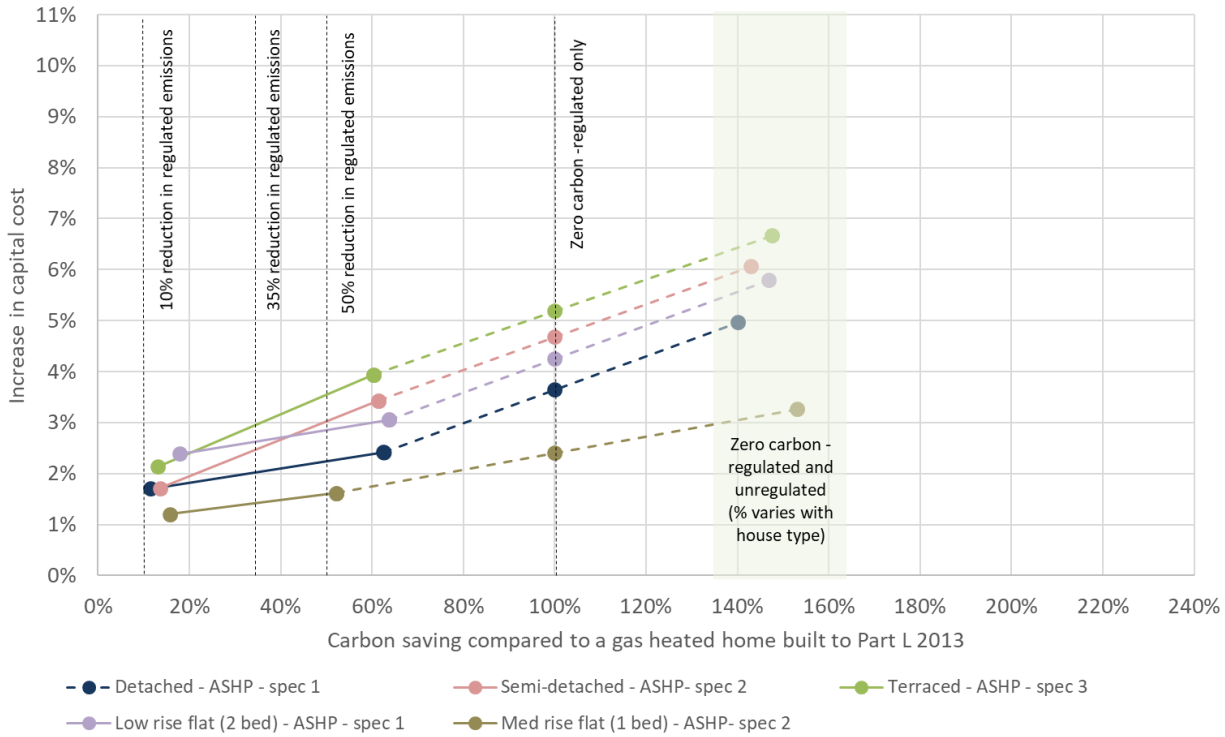


Figure 5.3, illustration of the scale of costs associated policy option 1 with ASHP heating and SAP 10 emission factors



Figures 5.2 and 5.3 show that both gas and ASHP heated homes can achieve policy option 1 using SAP 10 emission factors for all home types except the medium rise flat. However, the scale of onsite carbon reduction is far higher for those homes heated with ASHP and the overall costs of meeting the zero carbon standards are also lower. The impact of the change in emission factors means that overall costs of meeting zero carbon standards are lower, with the percentage cost uplift for zero regulated and unregulated carbon emissions between c.2 and c.4% lower than for the equivalent homes modelled using SAP 2012 emission factors.

Policy consideration: impact of decarbonisation

It is recommended that the targets are revisited when Part L is revised since there will be a profound impact on how developers can meet the target. If policy aims to maximise onsite energy performance and set the highest viable standard, the new target should be set at a point where the cost of compliance remains the same despite the changing conditions. In this way, the figures used to represent the cost of the current policy in the viability test will still represent the cost to developers and so viability will remain unchanged even though the target has changed..

Options and considerations include:

- Achieving zero carbon will become less expensive with SAP 10 emission factors – falling by between 2 and 4% depending on dwelling type. This could mean that a more challenging target could be set at the same cost to developers.
- Similar targets (e.g. 10% fabric, 35% onsite, 100% through AS) could be retained, but using a baseline of a home heated with an ASHP rather than gas as the benchmark, this would represent a further tightening of standards both for energy efficiency and onsite performance. This is because heating energy is a smaller portion of overall energy use when heat pumps are utilised and if the ASHP is used as the reference point, the carbon savings that would have been associated with its adoption will have to be delivered via other technologies.
- Definition of a much higher target for onsite carbon reductions against a gas heated Part L 2013 compliant home, so developers need to use onsite measures other than simply ASHP to meet the target. This would reflect the potential for a ASHP heated home to achieve a c.60% carbon saving in comparison to an equivalent gas heated home
- Definition of new targets that reflect any changes made in any new Part L standard, which might take account of the points above.
- A requirement for zero regulated or zero regulated and unregulated carbon emissions would be unaffected by changes in the SAP method, since the end point would still be a 100% reduction, albeit the total quantity of carbon to be addressed would be materially lower and therefore allowable solutions costs would reduce considerably

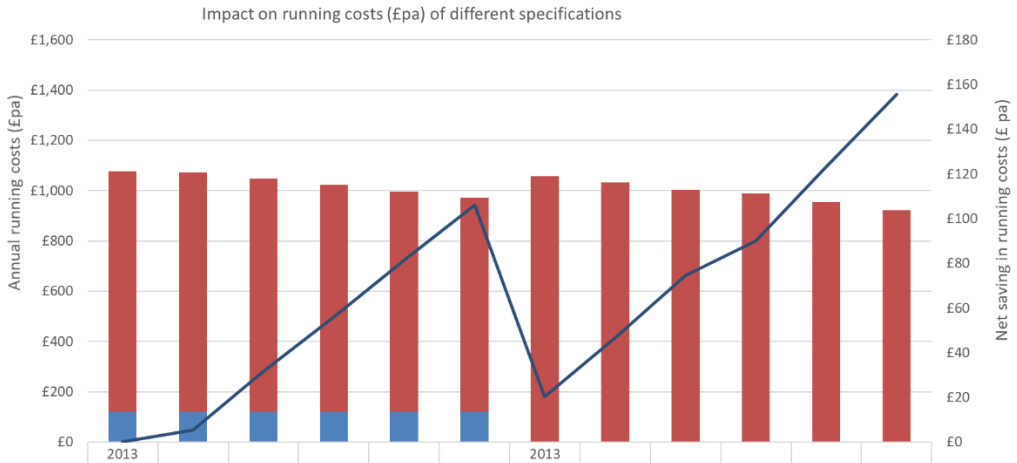
A switch from gas to ASHP may be driven by decarbonisation however it is possible that even if ASHP are the cheaper options developers may still choose to install gas because that is current practice. For this reason, a renewable heat policy may still be required to support the shift from gas to renewable heat.

6. Costs for residents

6.1 Running costs

The impact of different policy options for homeowners is an important consideration for new homes as while the carbon in electricity may be reducing its cost is not yet following this same trajectory. Figure 13 shows the projected energy costs of each home in the first year after completion and if built to each of the fabric and heating system options considered in this study. This figure does not include any income from photovoltaics. Onsite PV would provide further annual savings in the region of £90 per kW installed assuming 50% exported and 50% used to offset grid consumption.

Figure 13 Impact on running costs in year 1 for the detached house



	2013 Part L with gas	Gas-spec 1	Gas-spec 2	Gas-spec 3	Gas-spec 4	Gas-spec 5	2013 Part L with ASHP	ASHP - spec 1	ASHP-spec 2	ASHP - spec 3	ASHP-spec 4	ASHP - spec 5
Total	£1,078	£1,073	£1,047	£1,022	£997	£972	£1,058	£1,032	£1,004	£988	£955	£923
Net energy bills	£958	£953	£927	£902	£877	£852	£1,058	£1,032	£1,004	£988	£955	£923
Gas standing charge	£120	£120	£120	£120	£120	£120	£0	£0	£0	£0	£0	£0
Net saving in running costs (£ pa)	£0	£5	£32	£56	£81	£106	£20	£46	£75	£90	£123	£156

All of the lower carbon options deliver a cost saving in comparison to a Part L 2013 compliant gas heated home. This is achieved through improved energy efficiency (for gas heated homes), or for the ASHP based options through the avoidance of a standing charge for gas supply as the cost of regulated energy consumption for each ASHP option is slightly higher than for equivalent gas heated properties. The most energy efficient options achieve savings in running costs of c.£100-£150 per year for the detached house. For other property types the overall saving is smaller reflecting the reduced size and energy demand of these properties. They do nonetheless follow a similar pattern and each lower carbon option has lower running costs compared to the gas heated Part L 2013 compliant reference home.

7. Passivhaus

The Passivhaus standard signifies that a home is highly energy efficient with very low heating and overall energy demand. Passivhaus accreditation is achieved using a specific assessment methodology that is different to the SAP method used for building regulations and the performance of the property is tested in detail prior to certification. Certified Passivhaus projects have already been delivered across the West of England area including in Bristol, Weston-Super-Mare, Cheltenham, Cirencester and Devizes. There are now more than 1,000 certified Passivhaus' units in the UK[25] and over 65,000 worldwide.

Achieving the Passivhaus Standard in the UK typically involves:

- Accurate design modelling using the Passive House Planning Package (PHPP)
- Low levels of heat loss, either by using high levels of insulation or by having a built form that is inherently energy efficient (i.e. it has a high floor area to external surface area).
- High performance windows with insulated frames, these enable Passivhaus' to ensure that the internal surface of all external walls is maintained at a comfortable level while also avoiding down drafts
- High levels of airtightness (0.6 air changes per hour at 50 Pascals air pressure) with ventilation provided in the winter using mechanical ventilation with highly efficient heat recovery (in warmer weather windows can also be opened)
- Virtually thermal bridge free construction

A core attribute of a Passivhaus home is that it's space heating requirement is no more than 15kWh per m^2 as calculated using the PHPP method[26]. There are equivalent requirements for cooling loads and that primary energy consumption is no more than 120kWh m^2. Beyond the 'classic' Passivhaus certification are two further standards 'plus' and 'premium' these higher standards require that the home achieves a lower renewable primary energy[27] consumption and generate enough (or more) renewable energy to meet all the needs of the home taking into account energy losses that might occur if the energy were between periods of high generation and periods of high demand.

The very low heating requirement of Passivhaus' mean that it is theoretically possible for the home to be heated entirely from solar gain, the heat given off by occupants and through warming the air supplied to each room via the mechanical ventilation system. However, although a Passivhaus does not in theory require radiator-based heating system, they typically include a small number of radiators to enable households to better control local temperature and to provide reassurance to residents that have not lived in this sort of home previously.

The Passivhaus standard is assessed at the level of a whole building (i.e. an entire terrace of houses, or block of flats) and as a result the specifications required to meet the standard vary considerably depending on the form of the development. For an 'efficient form factor[28]' of building e.g. a terrace of 7-8 homes or a block of flats, the external wall performance required to meet Passivhaus requirements can be less insulating than those typically used for homes that simply comply with Building Regulations, while for detached houses levels of insulation are

[25] The Passivhaus Trust Project Gallery (as of September 2018)
[26] PHPP is a more complex assessment method than SAP and utilises additional inputs on the specification in generating the estimate of energy consumption.
[27] The renewable primary energy factor of energy consumption takes into account when energy is required relative to the regional availability of renewable energy at that time.
[28] Form factor is a measures of surface area to volume ratio. Large buildings that are cuboid or rectangular are more efficient than a building that is smaller or with a more complex form, since these have more external area, from which heat can escape, relative to their internal floor area.

typically far higher than normal. Although there are some variations in specification, all Passivhaus' projects achieve very high levels of airtightness (less than $1m^3m^2hr$) and are fitted with triple glazed windows and whole house ventilation and heat recovery systems.

An important component of Passivhaus certification is that the performance of the completed home is rigorously assessed against the design standards. Where the in-use performance of new homes has been reviewed[29], the performance of certified Passivhaus' were shown to be very close to, or in cases below, those predicted during design. These findings contrast with the observed gap between design and in use performance for other houses. It is not possible to draw definitive conclusions from the limited available data or to identify the reasons why Passivhaus' seem to have less performance gap than other homes. Possible causes could be the design philosophy, the use of PHPP software or the rigour of the certification process.

Passivhaus projects have the potential to deliver high quality comfortable, low carbon homes with low running costs. To assess the cost implications of building to Passivhaus specifications several Passivhaus developers were contacted and information sought on the specifications used and construction methods for different home types. A range of examples of certified Passivhaus homes were identified using traditional masonry, timber and other construction methods such as clay blocks. The design of the homes varied from contemporary to traditional and included blocks of flats, terraces and detached homes.

Cost allowances for the Spec 5 options for each house type are reasonable approximations of the costs of building to a Passivhaus specification. However, there are two important caveats:

- Certified Passivhaus projects would require a certification process and additional oversight and information management to ensure compliance this is estimated at between £4,000 and £8,000 per building. As certification is carried out at the level of the building envelope, i.e. a block of flats or terrace of homes or single house, it is reasonable to allow say, £4,000 for a single new detached house down to £500-750 for a flat in a block.
- Building level certification means that energy performance is averaged across the homes that comprise the Passivhaus. As a result, where a building has a very energy efficient form, i.e. a long terrace or a block of flats it is significantly easier to achieve Passivhaus compliance with a less well insulated external envelope. For example, in a Passivhaus project in South West England, it has been possible to achieve a certifiable home with uninsulated external walls with U values of around 0.25 Wm^2K. Whilst the ability to average at the whole building level could result in cost savings, it does mean that the more exposed units in a development (top floor corner flats or end terrace houses) may have significantly worse energy performance than might be implied by the Passivhaus standard. To date there is no evidence that these homes perform unsatisfactorily, and they are still likely to be well above typical Part L 2013 homes in terms of their overall performance.

The influence of form factor on the costs of compliance together with the economies of scale where certification is undertaken for terraces, flats or larger overall developments means that Passivhaus compliance costs will be significantly lower for larger developments in comparison to single homes.

Although Passivhaus homes are highly energy efficient, if domestic hot water and any residual space heating is provided using gas then the carbon emissions of the home will still be higher than a home built to the Part L 2013 notional specification with an ASHP, as shown previously in

[29] Innovate UK, 2016. Building Performance Evaluation Programme: Findings from domestic projects.

Figure 5.1[30]. Therefore, to get the maximum carbon benefit from building to this specification, domestic hot water should be supplied using a low carbon heat source such as a heat pump or an alternative renewable energy source.

Policy consideration: Passivhaus' should still use low carbon heat

Although Passivhaus' are highly thermally efficient, if their residual heating and their hot water demand is met using a gas boiler and without renewable energies then their carbon emissions could be higher than less efficient homes. A heating hierarchy that requires use of low carbon / renewable sources of energy for heating and in particular hot water would maximise the carbon benefits of building to certified Passivhaus standards.

Whilst the specifics of design, finish and other variables will influence overall costs it is estimated that the additional cost for a certified Passivhaus incorporating an ASHP over a Part L 2013 notional specification with gas heating is approximately £12k for a detached house to around £2.5-3k for a low rise flat. Table 7.1 summarises the build-up of the additional costs for different home types, the actual cost implications of certified Passivhaus will vary according to the form factor of a building and the ability of the developer's supply chain to deliver the detail of the standard requirements including through product selection, construction detailing and commissioning. Whilst achieving the necessary attention to detail and compliance with the design may not theoretically cost more for an experienced developer, it will require additional site supervision and other costs for those first engaging in the process.

Table 7.1 Indicative cumulative costs over Part L 2013 for certified Passivhaus'

House type	Passivhaus specification			With ASHP rather than gas boiler			Total including certification		
	%	£m^2	£ per home	%	£m^2	£ per home	%	£m^2	£ per home
Detached (117m^2)	4.4%	£59	£6,900	5.1%	£68	£8,000	7.6%	£103	£12,000
Terraced houses (2*end-terrace and 4* mid-terrace, 84m^2 per home)	3.0%	£43	£3,600	4.6%	£67	£5,600	5.8%	£85	£7,100
Flats (low rise c.32 units at an average size of 70m^2)	1.4%	£19	£1,300	2.1%	£29	£2,000	2.9%	£39	£2,750

It should be noted that the costs of delivering this standard vary according to the efficiency of the building's form factor and that constructions are often simplified (eg rendered finishes to solid wall constructions) to help reduce thermal bridging and ease the achievement of high standards of air tightness. These design solutions, while cost effective, are not always consistent with local vernacular or other design considerations. Further, the costs of certification will vary according to the extent to which common details and specifications are applied across a project. It might be expected that his element of certification costs would fall over time if a developer were to use a common supply chain and design details on multiple projects.

Given the scale of additional costs and a policy objective to incentivise this form of development, it could be argued that where developers are committing to the Passivhaus standard with an ASHP, some elements of the zero carbon policy could be waived for certified Passivhaus'. While a Passivhaus without PV or allowable solutions would have higher theoretical carbon emissions

[30] Assuming SAP 10 emission factors and comparing a home with a 15kWh m^2 heat loss and a gas boiler with that meeting Part L1a 2013 but with an ASHP

than a ‘zero carbon’ home built to Part L 2013 with an ASHP, PV and allowable solutions, it could be argued that the Passivhaus solution provides for longer term savings and a reduced performance gap together with the potential to retrofit PV later. In contrast it would not be practicable to retrofit a new home to Passivhaus standards.

8. Development scale, location and high-rise flats

This report considers typical costs for medium sized developments of housing and low / medium rise flats on sites that are unconstrained and without abnormalities. There are a range of factors that might result in construction costs being higher or lower than those presented here.

8.1 Development scale

The scale of development and, perhaps more importantly, the size of the developer will influence construction costs. There is not a straight forward relationship between size and costs as while larger organisations will be able to achieve economies of scale in purchasing, they are also likely to have higher overheads and more complex supply chains. Building Cost Information Service (BCIS) data suggest that one off housing is typically around 10-15% more expensive than multi plot developments and it might be expected that high volume housing would be less expensive than standard housing. Therefore, a range of 20% (+/- 10%) is reasonable on average, albeit with potential for higher discrepancies for specific items.

This range takes no account of variations in design, specification or quality of finishes that might exist between standard housing and more 'bespoke' one off homes. The overall cost uplifts for more bespoke homes may be higher - if they have more complex detailing or lower - if the home is larger and therefore has an improved external wall to floor ratio or where there it has a higher cost of finishes which reduces the uplift associated with improved insulation, PV or allowable solutions.

Viability studies will explore this in more detail

8.2 Location

Construction costs vary significantly around the UK, being highest in London and lowest in Northern Ireland and then Wales. Construction costs in the South West and West Midlands BCIS regions are close to the national average[31]. However, within any given location costs may vary for a range of factors including site access constraints, ground conditions, uneven topography, etc.

BCIS indices suggest that site constraints and access limitations can each impose a cost premium of around 5% on a project. The impact of ground conditions, topography, contamination or other abnormal factors can be highly variable.

Policy consideration: cost variables

While there are a great many influences on project construction costs, in practice, few of these factors should influence the proportionate cost uplift associated with building to low carbon standards. However, they may affect the overall development cost and thereby its viability and ability to support additional planning related costs.

8.3 High rise flats (>8 storeys)

High rise flat blocks were not explicitly considered in this study. It is likely that these sorts of development would be confined to relatively few locations and may be subject to area specific planning policies.

[31] BCIS regional cost indices.

The potential solutions for high rise blocks may be similar to those identified for medium rise blocks but there would be a further reduction in the available roof space for PV per flat thereby reducing the scale of onsite carbon savings that can be achieved.

Combined heat and power may be proposed for high rise blocks being assessed using the SAP 2012 methodology, although these would perform well using this protocol their 'real world' emissions (i.e. using current emission factors such as SAP 10) would be higher than if heat pump-based systems were employed. The use of heat pumps in high rise apartments could involve centralised systems with heat interface units for individual units, or in the case of ground source systems, could include localised pumps connected to a water circuit.

Given the scale of a typical high-rise block (or development of multiple blocks) it would be proportionate to expect an energy strategy that explicitly demonstrates how relevant area specific energy policies are being achieved and that these should include a requirement to ensure that representative current (or future weighted) emission factors are used as the basis for selecting the proposed solution.

Policy consideration: high rise flats

CHP is currently a relatively common solution for achieving carbon savings in higher rise developments but is not expected to deliver carbon savings when current or future emission factors are applied. Requesting that energy strategies for higher rise developments demonstrate carbon savings using SAP 10 emission factors would help these schemes to deliver carbon reductions in practice.

SECTION 2: NON-DOMESTIC

9. Non-domestic buildings

Potential standards that might be applied to non-domestic buildings in the West of England have been assessed by a review of recent literature on the subject considering both the potential and costs for reductions in energy use and carbon emissions and the implications of setting BREEAM ratings encompassing a wider range of sustainable buildings topics.

As with domestic buildings, the review considers the potential for energy efficiency, total onsite carbon reductions and net zero carbon standards (including the use of allowable solutions). The policy option considered is for a 15% reduction in carbon emissions from energy efficiency, a total onsite reduction of 35% and the achievement of zero regulated carbon emissions using allowable solutions, all in comparison to the emissions from a Part L 2013 compliance building with gas heating. The analysis assumes the current emission factors for electricity used within the Simplified Building Energy Model (SBEM) method, same range of issues relating to changing emissions factors and their implications for future performance apply to SBEM as to SAP.

9.1 Energy efficiency

Recent studies by Buro Happold[32] and AECOM[33] (both supported by Currie & Brown) for the Greater London Authority consider the potential and associated costs associated with achieving carbon reductions in non-domestic buildings. These studies considered the implications of setting tighter energy efficiency standards for non-domestic buildings as part of the formulation of the draft new London plan. In addition, work by Buro Happold (with Currie & Brown) for the Old Oak Park Royal Development Corporation considers specifically how energy and carbon savings can be achieved in higher rise and mixed-use developments[34].

Key findings from these studies include:

- The correlation between 'energy efficiency / carbon performance (excluding PV and heat networks) and capital cost is weak[32] or absent[34] with a range of factors influencing both cost and performance including:
    - building form,
    - glazing ratio
    - 'good passive design' that balances glazing area and energy demands
- Energy use in non-domestic buildings is highly variable by building type and design aspiration. The cost and potential for achieving savings beyond the requirements of Part L2013 will therefore depend on building type and design decisions. For example, the nature of demand heating, cooling and lighting energy demand will be influenced by the intended use, the extent and orientation of glazing and any associated shading, and plan depth. Substantial energy efficiency savings are typically achievable in office and retail buildings, but other building types such as schools and particularly hotels may find it more difficult to achieve energy efficiency savings because of the specific nature of their demand, eg the dominance of hot water supply as an energy source in hotels[33]
- Efficient lighting and control systems are a major contributor to energy efficiency in office and retail spaces with the potential to deliver substantial savings in lighting energy demand compared to the that required by Part L 2013. Substantial energy efficiency savings can be achieved purely with highly efficient lighting (i.e. LED) and controls, in

[32] Buro Happold, 2017. Driving Energy Efficiency savings through the London Plan - Data Analysis. www.london.gov.uk
[33] AECOM, 2017a. GLA energy efficiency target – development case studies. www.london.gov.uk
[34] Buro Happold, 2018. Energy, daylight and overheating study in tall buildings. www.london.gov.uk

some situations these could be sufficient to achieve savings of 10-15% or more on the requirements of Part L 2013[35] . More efficient lights and controls are still more expensive than traditional systems (approximately a further £20m^2 depending on design) but are becoming standard in new buildings as developers and occupiers realise their significant performance benefits and reduced maintenance and energy costs.

- Cost uplift associated with energy efficiency measures varies considerably because of differing building designs. The Part L Notional specification was set at £0 but in practice there is a substantial variation in the costs of building to this specification depending on design considerations. The uplift associated with achieving a 15% energy efficiency target was between £37 and £59 m^2 which for when compared with overall development costs of between £2,000 and £3,000 m^2 is under 2% of the capital cost.
- Nearly 60% of non-domestic developments in London achieve a 10% energy efficiency (LEAN) saving with a little under half achieving a saving of 15% in comparison to Part L 2013[32].

In 2017, the average energy efficiency saving in non-domestic buildings in London was 19.2% beyond the requirements of building regulations[35], this suggests that while certain buildings may not be able to achieve a 15% requirement it is widely achievable in new non-domestic buildings.

Policy consideration; energy efficiency
Most buildings can achieve 10-15% energy efficiency improvements on current regulations, but there are some buildings that might find this standard more difficult due to the energy associated with their type and operational demand, for example hotels.

9.2 Overall carbon onsite savings

Achieving an overall 35% reduction in carbon emissions compared to Part L 2013 after the application of energy efficiency measures would entail the use of low carbon technologies and use of renewable energy. As with energy efficiency there is the potential for a substantial variation in the ability of different buildings to achieve the necessary savings.

In London, overall carbon reductions have been achieved in many buildings using CHP and / or connection to district heat networks. These solutions may be less widely applicable in less urban areas across England and the reduction in future carbon savings associated with CHP means that this solution will become less effective in reducing emissions , and that the carbon intensity of heat delivered via heat networks will need to reduce if they are to remain carbon-competitive with alternative options. Analysis of other solutions, such as heat pumps[36], suggests that, using current SBEM emission factors, the potential carbon savings from these technologies may insufficient to achieve an overall 35% reduction in onside carbon emissions and that a combination of heat pumps and other renewable energy sources (eg PV) might be required. If revised emission factors, e.g. in line with those in SAP 10, were adopted then the use of heat pumps, together with energy efficiency measures should be sufficient to enable an onsite target of 35% to be achieved.

The ability of non-domestic buildings to meet a 35% reduction target will be influenced by a range of factors. For example, an air-conditioned office project might be able to secure savings of 25% or more through energy efficiency, which when combined with a heat pump or connection to a low carbon heat source and potentially use of PV could easily meet a 35% reduction in carbon

[35] GLA, 2018. Energy Monitoring Report: Monitoring the implementation of London Plan energy policies in 2017. www.london.gov.uk
[36] Etude, 2018. Low Carbon Heat: Heat Pumps in London. www.london.gov.uk

emissions on site and for a cost uplift of a few % on top of the initial cost. Conversely a high-rise hotel might struggle to achieve the 35% target without the use of CHP which would deliver far less real carbon savings than those estimated by SBEM.

Currie & Brown's work with BRE[37] on the costs of BREEAM ratings for an air-conditioned office considered how both BREEAM and London Plan energy targets could be achieved. A series of energy models were developed to comply with the London Plan with a 35% improvement over minimum energy performance requirements necessary for Part L2A 2013 while also meeting the minimum requirements for an Excellent rating for BREEAM UK New Construction 2014 under Ene 01. The capital cost of achieving London plan compliance was around a 1% increase on that of the base specification[38].

Policy consideration: onsite savings
Achieving 35% reduction onsite is achievable for non-domestic buildings, but in some cases current emission factors might result in the use of CHP, likely future emission factors would enable a 35% target to be achieved using heat pumps together with efficient systems and renewable energies. If a heating hierarchy were applied that discouraged the use of CHP or other combustion technologies, then it might be necessary to also allow developers to present energy strategies that use new SAP10 emission factors when demonstrating the carbon savings delivered by their proposals.

9.3 Use of allowable solutions to achieve net zero carbon

Consideration of the additional costs of allowable solutions to meet a net zero carbon standard reflects only the regulated emissions of a non-domestic building. If unregulated emissions were to be included, then these would need to be calculated specifically for each project using a method such as CIBSE's TM54[39]. Unregulated loads could vary very considerably between building types and intended usage and could be greater than those associated with regulated energy use.

If the target emission rate for a new non-domestic building is between 15 (e.g. naturally-ventilated building) and 40 (e.g. an air-conditioned office) kgCO_2e m^2, then the approximate costs of allowable solutions to offset a residual 65% of regulated emissions (after the onsite target has been achieved) would be between £42 and £114m^2, or between approximately 2 and 4% of typical capital costs using an allowable solutions cost of £95 per tonne of CO_2e.

9.4 BREEAM rating

Currie & Brown's research with BRE[40][41], together with previous studies for the British Constructional Steelwork Institute show that, if delivered efficiently by experienced design and construction teams the additional costs of meeting BREEAM (the 2011 standard) Excellent ratings are in the order of a 1-2% of capital costs for most buildings but can be higher, in the order of 3-5% for some buildings (such as healthcare buildings) and locations. The most significant costs associated with achieving higher BREEAM ratings are often associated with meeting minimum energy requirements. This means that where a planning requirement also

[37] BRE, 2017. Delivering Sustainable Buildings: Savings and Payback – Office Case Study for BREEAM UK New Construction 2014.
[38] The case study project was a relatively high specification and large London office, the cost uplift for smaller and lower cost developments may be higher.
[39] CIBSE, 2013. TM54: Evaluating operational energy performance of buildings at the design stage.
[40] BRE, 2014. Delivering Sustainable Buildings: Savings and Payback.
[41] BRE, 2017. Briefing Paper Delivering Sustainable Buildings: Savings and Payback - Office Case Study for BREEAM UK New Construction 2014

exists for carbon / energy efficiency measures beyond the requirements of building regulations then the net impact of an additional BREEAM requirement would be reduced.

Where a contractor is inexperienced in delivering BREEAM then it is possible for additional costs to be incurred in setting up processes to ensure that their site management and supply chain activities are BREEAM compliant. Similarly, for very small projects the costs of assessment and certification, which do not scale linearly with project size, may result in disproportionately higher costs. For example, assessment costs might be 0.1% or less of the cost of a 10,000m^2 office but around 1% of the costs of a 1,000m^2 retail unit.

BRE have recently introduced the BREEAM 2018 standard which includes a range of new or amended requirements. Some of these new criteria are deemed to be cost-free albeit they may require additional consultant's input and considerations at early design stage. BREEAM 2018 is a recently introduced standard and evidence of sufficient data on it implications is not yet available for a substantial cost analysis. However, Currie & Brown's initial review suggests that whilst the 2018 standard requires more time input from the project team its implications for capital costs are relatively small.

Policy consideration: BREEAM
While the costs of BREEAM ratings are typically in the range of a few percent of capital cost, the implications for specific buildings, development locations (eg greenfield sites, away from transport links and amenities) may be higher and the costs of the certification itself become considerable for smaller developments. A size threshold may help to reduce costs for smaller projects.

9.5 Summary

There is a huge variation in the form and use of non-domestic buildings and this results in a wide range of energy demands and varying potential for efficiencies. If higher standards were set at a level that could be definitively achieved by all non-domestic buildings, it is likely that the standards would be too lax for most circumstances. Therefore, it is sensible to set standards at a level that are challenging to most projects but to be flexible for other projects which can demonstrate that through their best endeavours the necessary standards cannot be achieved.

Table 9.1 summarises the cost uplifts of the potential standards to reduce carbon emissions. As stated previously there will inevitably be variation around these levels depending on the type and design of non-domestic building being proposed so these uplifts should be taken as indicative of scale only.

Table 9.1 – Indicative cost uplifts of the potential standards to reduce carbon emissions

Standards	Target	Percentage of construction cost
Energy Efficiency	Minimum carbon reduction of 15%	2%
On site saving	Total carbon reduction of 35%	1%
Allowable solutions	Offset 65% of regulated CO_2 emissions	2-4%
BREEAM	BREEAM Excellent rating	1-2%

A standard of a 15% carbon saving through energy efficiency together with an overall 35% onsite carbon reduction and the use of allowable solutions to achieve net zero regulated carbon emissions is likely to result in a cost uplift of in the order of 5-7% of capital cost depending on project type, size and other factors. The additional cost of BREEAM Excellent certification may be a further 1-2% for measures not associated with delivering energy requirements. In many

buildings this additional cost could be under 1% subject to its location, the base design and experience of the design and construction team.

10. Conclusions and policy considerations

The analysis presented in this report suggests that it is possible to achieve net zero regulated carbon emissions from a combination of energy efficiency on site carbon reductions and allowable solutions for an additional capital cost of between 5-7% for homes and non-domestic buildings. Achieving net zero regulated and unregulated emission is likely to result in a cost impact of 7-11% for homes.

In conducting the analysis, a range of relevant policy considerations were identified that are relevant to the development of planning standards:

Housing

a. SAP version - Assumptions in the currently operational SAP method (SAP2012) are now several years old and do not reflect current understanding of the carbon emissions associated with the supply of electricity. Revised emission factors were published in the SAP10 methodology and these have a substantial impact on the estimated carbon emissions and impact of new development. For consistency with current regulations and to enable developers to use a common method for both building regulations and planning, the policy options are defined against SAP2012 standards.
b. ASHP Efficiencies - Default efficiencies for ASHP within SAP2012 are lower than those believed to be achieved in practice and so assessments of the performance of these technologies could be based on higher assumed levels of heating efficiency. However, to achieve these levels in practice it is vitally important that the whole heating system (including radiators / underfloor heating etc) is appropriately specified, installed and commissioned. Therefore, any adoption of these higher efficiencies should be in parallel to a requirement for specific evidence as to how these points would be addressed.
c. Photovoltaics costs - Photovoltaics form a substantial portion of the overall costs of meeting the considered policy options. The assumptions used in this study are based around the development of a robust regional delivery process akin to the buying club solutions seen elsewhere. Without such an approach the costs of adopting meeting policy options may be higher and might result in greater use of allowable solutions and less PV installation.
d. Support for storage - Whilst not an explicit policy option support for measures to reduce peak demand for electricity are likely to be beneficial provided they are supported by a robust and transparent methodology. The adoption of an energy efficiency standard addresses this in part, further support might include provision of the option to include energy storage solutions within any regional ‘renewables buying club’.
e. Need for allowable solutions - Achieving net zero carbon for regulated energy with the options considered requires the use of allowable solutions
f. Role of energy efficiency - Achieving carbon savings beyond Part L 2013 via further energy efficiency is more expensive than using renewable energy or allowable solutions but would help to reduce household bills and reduce demand on power generation and supply infrastructure
g. Onsite reduction target - A 35% onsite target is likely to be achievable for each of the dwelling types considered in the study but a higher 50% target could be difficult to achieve in flats, especially medium and higher rise.
h. Adopting energy efficiency as a lower cost option - It may be possible to reduce the costs of policy compliance by adopting very high levels of energy efficiency and reducing the extent of internal heating systems.
i. Existing policies are already in place in many areas - Many planning authorities are already successfully delivering a range of low carbon policy requirements, the additional costs of meeting net zero carbon policy options will be less than those of building only to

the regulatory minimum. Further the costs impact of these policies when introduced was very likely to be higher than those in 2018 as the cost of technologies such as PV have fallen substantially and relatively consistently over the last decade.

j. Impact of grid decarbonisation - A policy that combines energy efficiency and low carbon heat will deliver carbon savings using current SAP 2012 emission factors but is even more effective when current real emission factors are considered. Further, some solutions that would not be prioritised in a heat hierarchy would perform poorly if updated emission factors were applied (eg CHP).
k. Changes to modelling methods - A new version of SAP is likely to include a wide range of methodological changes as well as updated emission factors it would therefore be prudent to review the specifics of a policy target using the revised methodology when this is available.
l. Passivhaus – Passivhaus certification provides clear evidence that a home or non-residential building has been built to high standards of efficiency and thermal comfort. Given the need for some heating and hot water consumption, it is important that low carbon heating / hot water systems are applied in line with a heat hierarchy to get the most carbon saving benefit from these buildings.
m. Variations in costs – construction costs vary for a wide range of factors. The proportionate impact of the considered policy options may not vary considerably but there may be a variation in absolute costs based on the size of development and developer. It is also the case that the targeted development plots and offered housing products will vary and so land values and sales prices will also vary between development locations and scales.
n. High rise flats – current energy solutions for high rise flats often include CHP systems, these may not perform as well as other technical solutions in a situation where electricity emission factors are reduced. It may be worth requiring that developers demonstrate that their proposals meet policy options using SAP10 emission factors to avoid unintended consequences associated with the use of unrepresentative information on the carbon impact of electricity.

Non-domestic buildings

o. Energy efficiency – there is a high degree of variation in the energy use and potential for carbon savings in non-domestic buildings nonetheless there is evidence from recent studies that savings of 10-15% are achievable and in London the average level of energy efficiency saving achieved in non-domestic buildings was 19.2% beyond the requirements of Part L 2013.
p. Onsite carbon savings – notwithstanding the variation between building types, most non-domestic buildings should be able to meet a 35% reduction target. However, if a heating hierarchy is applied that favours non-fossil fuelled heating then it may be necessary to adopt SAP 10 emission factors (or equivalent) to demonstrate the real benefits of heat pumps and other solutions.
q. Net zero carbon - for regulated emissions the total costs of meeting net zero carbon standard with a 15% energy efficiency requirement and a 35% onsite requirement should be in the range of 5-7% of the capital cost for a building regulations compliant home assuming allowable solutions cost £95 per tonne. However, if unregulated emission were included the additional costs could vary very considerably depending on the type of use. BREEAM Excellent would add 1-2% more to the cost.

Appendices

Appendix A - House types

The table below provides basic dimensional information on each modelled house type. Areas and energy performance for flats are averaged across a 4 (low rise) or 8 (medium rise) storey block.

	Detached	Semi	Terraced	1B Flat	2B Flat
AREAS (sqm)					
Party wall	0.0	41.8	41.8	28.1	29.2
Exposed wall	156.3	93.8	52.0	18.0	41.3
Semi-exposed wall	0.0	0.0	0.0	24.0	12.1
Roof - Main	58.1	41.8	41.8	50.0	70.1
Roof - Bay window	0.8	0.8	0.8	0.0	0.0
Floor	58.9	42.6	42.6	50.0	70.1
TFA	117.1	84.4	84.4	50.0	70.1
Total window area	26.2	14.6	14.6	9.8	13.8
Total door area	2.1	2.1	2.1	2.1	2.1
HEIGHTS (m)					
Storey - ground	2.4	2.4	2.4	2.4	2.4

Appendix B - Description of fabric and services specifications

The specifications modelled for each house type are shown below. Only two enhanced options were modelled for the two flat scenarios as the base build form was already highly energy efficient.

Detached house

Building Element Description		Required performance					
		Part L Notional	Spec 1	Spec 2	Spec 3	Spec 4	Spec 5
Walls	Exposed (W/m².K)	0.18	0.18	0.17	0.15	0.15	0.13
Floors	Ground Floor (W/m².K)	0.13	0.15	0.11	0.11	0.11	0.11
Roofs	Exposed Roof (W/m².K)	0.13	0.11	0.11	0.11	0.11	0.11
Doors	U-value (W/m².K)	1.0	1.2	1.0	1.0	1.0	1.0
Windows	U-value (W/m².K)	1.4	1.4	1.2	0.8	0.8	0.8
Ventilation	Type	Nat Vent	MVHR	MVHR	MVHR	MVHR	MVHR
Air Permeability	(m³/h.m² @50pa)	5.0	3.0	3.0	3.0	2.0	1.0
Thermal Bridging	Y-value	0.05	0.05	0.05	0.05	0.04	0.04

Semi-detached house

Building Element Description		Required performance					
		Part L Notional	Spec 1	Spec 2	Spec 3	Spec 4	Spec 5
Walls	Exposed (W/m²K)	0.18	0.18	0.18	0.16	0.15	0.16
Floors	Ground Floor (W/m².K)	0.13	0.15	0.13	0.12	0.11	0.11
Roofs	Exposed Roof (W/m².K)	0.13	0.11	0.13	0.11	0.11	0.11
Doors	U-value (W/m².K)	1.0	1.2	1.0	1.0	1.0	1.0
Windows	U-value (W/m².K)	1.4	1.2	1.4	1.2	0.8	0.8
Ventilation	Type	Nat Vent	Nat Vent	MVHR	MVHR	MVHR	MVHR
Air Permeability	(m³/h.m² @50pa)	5.0	4.5	3.0	3.0	3.0	2.0
Thermal Bridging	Y-value	0.05	0.04	0.07	0.07	0.07	0.04

Terraced house

Building Element Description		Required performance					
		Part L Notional			Spec 3	Spec 4	Spec 5
Walls	Exposed (W/m²K)	0.18			0.18	0.18	0.16
Floors	Ground Floor (W/m².K)	0.13			0.13	0.11	0.11
Roofs	Exposed Roof (W/m².K)	0.13			0.13	0.11	0.11
Doors	U-value (W/m².K)	1.0			1.2	1.0	1.0
Windows	U-value (W/m².K)	1.4			1.3	1.2	1.2
Ventilation	Type	Nat Vent			MVHR	MVHR	MVHR
Air Permeability	(m³/h.m² @50pa)	5.0			5.0	4.0	2.0
Thermal Bridging	Y-value	0.05			0.08	0.07	0.05

Low rise flat

Building Element Description				
		Part L Notional	Spec 1	Spec 2
Walls	Exposed (W/m²K)	0.18	0.18	0.18
	Semi exposed (W/m².K)	0.21	0.21	0.21
Floors	Ground Floor (W/m².K)	0.13	0.15	0.15
Roofs	Exposed Roof (W/m².K)	0.13	0.11	0.11
Windows	U-value (W/m².K)	1.0	1.4	1.4
Ventilation	Type	1.4	1.2	1.2
Air Permeability	(m³/h.m² @50pa)	5.0	5.0	3.0
Thermal Bridging	Y-value	Nat Vent	MVHR	MVHR

Medium rise flat

Building Element Description		Part L Notional	Spec 1	Spec 2
Walls	Exposed (W/m².K)	0.18	0.18	0.18
	Semi exposed (W/m².K)	0.21	0.21	0.21
Floors	Ground Floor (W/m².K)	0.13	0.15	0.13
Roofs	Exposed Roof (W/m².K)	0.13	0.13	0.13
Windows	U-value (W/m².K)	1.0	1.4	1.4
Ventilation	Type	1.4	1.4	1.4
Air Permeability	(m³/h.m² @50pa)	5.0	4.0	4.0
Thermal Bridging	Y-value	Nat Vent	MVHR	MVHR

Appendix C - Cost data

Element	Performance	Unit	Total Cost
External Wall			
Blockwork cavity with mineral wool insulation Includes: ▪ Brickwork outer leaf ▪ Wall ties ▪ Cavity closers and trays ▪ Lintels ▪ Mineral wool ▪ Lightweight concrete blockwork ▪ 13mm dense plaster ▪ Paint	0.21W/m².K	£/m2	219
	0.18 W/m².K		221
	0.17 W/m².K		221
	0.16 W/m².K		221
	0.15 W/m².K		224
	0.14 W/m².K		225
	0.13 W/m².K		230
	0.12 W/m².K		230
Semi-exposed wall (MW)			
Blockwork cavity with mineral wool insulation Includes: ▪ Brickwork outer leaf ▪ Wall ties ▪ Cavity closers and trays ▪ Lintels ▪ Mineral wool ▪ Lightweight concrete blockwork ▪ 13mm dense plaster ▪ Paint	0.21W/m².K	£/m2	146
	0.18 W/m².K		148
	0.16 W/m².K		148
	0.15 W/m².K		151
	0.14 W/m².K		152
	0.13 W/m².K		157
	0.12 W/m².K		158
Ground / Exposed Floor			
Includes: ▪ Screed ▪ Rigid PIR insulation board ▪ Edge insulation ▪ Damp proof membrane	0.15 W/m².K	£/m2	146
	0.14 W/m².K		149
	0.13 W/m².K		152
	0.12 W/m².K		154
	0.11W/m².K		157
Exposed Roof - Insulation at Joists			
Includes: ▪ Tiling ▪ Counter battens ▪ Breather membrane ▪ Timber rafters / trusses ▪ Mineral wool between ceiling joists ▪ Mineral wool over ceiling joists ▪ Vapour control layer ▪ Plasterboard, skim and paint	0.15 W/m².K	£/m2	175
	0.14 W/m².K		176
	0.13 W/m².K		185
	0.12 W/m².K		186
	0.11W/m².K		187
Windows			
uPVC double or triple glazed units	1.4 W/m².K	£/m2	240
	1.3 W/m².K		270
	1.2 W/m².K		300
	1 W/m².K		330
	0.8 W/m².K		360

Element	Performance	Unit	Total Cost
Ventilation			
Natural ventilation includes for trickle ventilation and intermittent extract fans in kitchens and wet rooms	Nat Vent	£per home	480
MVHR includes the MVHR unit, fitting and power supply and supply and extract ducting.	MVHR		1,835-2,360
Design Air Permeability			
Use of tapes around junctions and wet plaster finish with close attention to detail. Increasing levels of air tightness require additional tapes / airtight boards or membranes and additional of performance.	6 m³/hm² at 50Pa	£/m2	0
	5 m³/hm² at 50Pa		2
	4 m³/hm² at 50Pa		4
	3 m³/hm² at 50Pa		5
	2 m³/hm² at 50Pa		6
	1 m³/hm² at 50Pa		8
Photovoltaics			
Photovoltaics fixed		£per install	740
Photovoltaics variable		£per kWp installed	1,100
Heating and hot water system			
Detached, semi/terraced houses and low rise flat Individual condensing gas boiler, hot water store (detached only), supply, hot water distribution and radiators		£per home	7,750-5,500-5,600
Medium rise flat Communal condensing gas boiler, hot water store, distribution, heat interface unit, in flat water distribution and radiators			8,900
Detached, semi/terraced houses and low rise flat Individual ASHP, hot water store, supply, hot water distribution and radiators (sized for low temperature supply)			9,200-8,000-6,400
Medium rise flat Communal ASHP, hot water store, distribution, heat interface unit, in flat water distribution and radiators (sized for low temperature supply)			10,000

Appendix D - Other analyses

Cost and carbon savings for each specification option

Figure D.1 Cost uplift and energy and carbon savings with different modelling assumptions – detached house

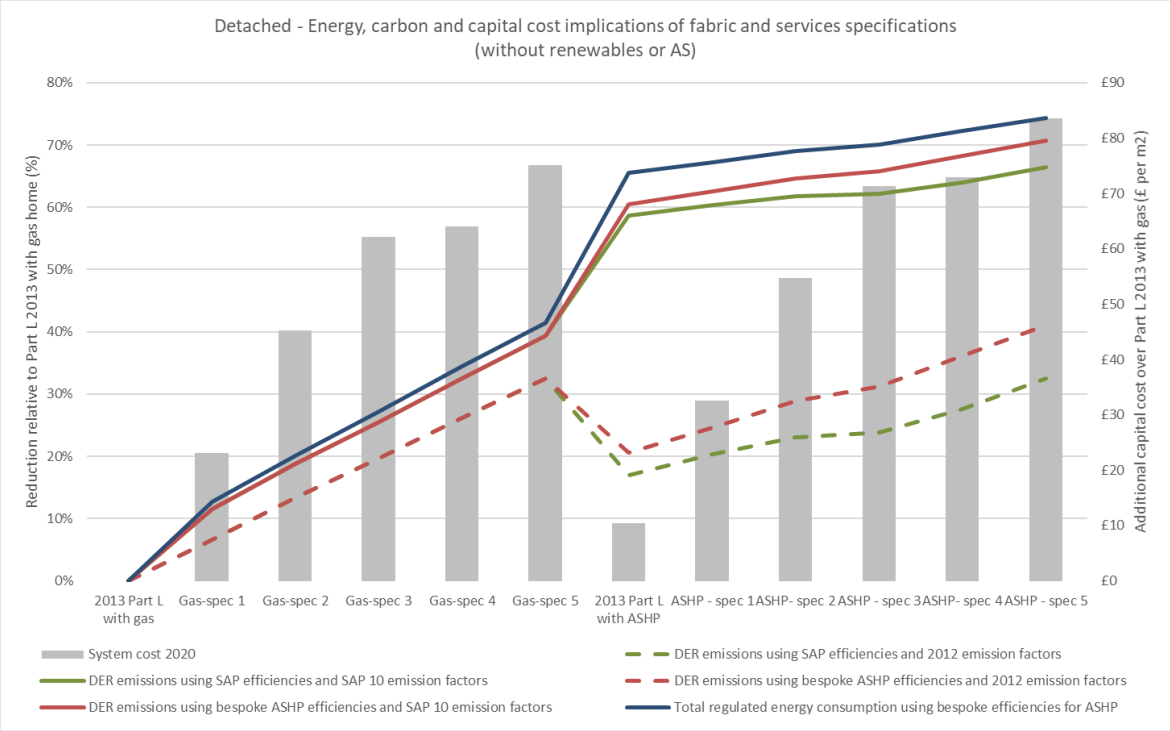


Figure D.2 Cost uplift and energy and carbon savings with different modelling assumptions – semi-detached house

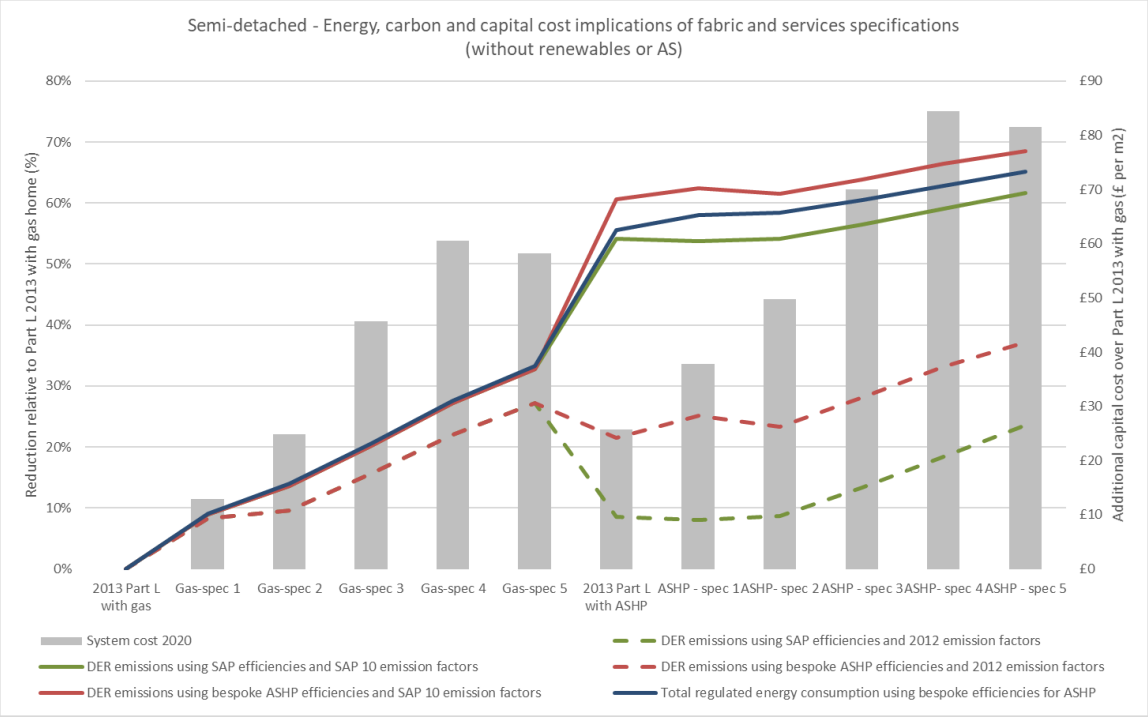


Figure D.3 Cost uplift and energy and carbon savings with different modelling assumptions – terraced house

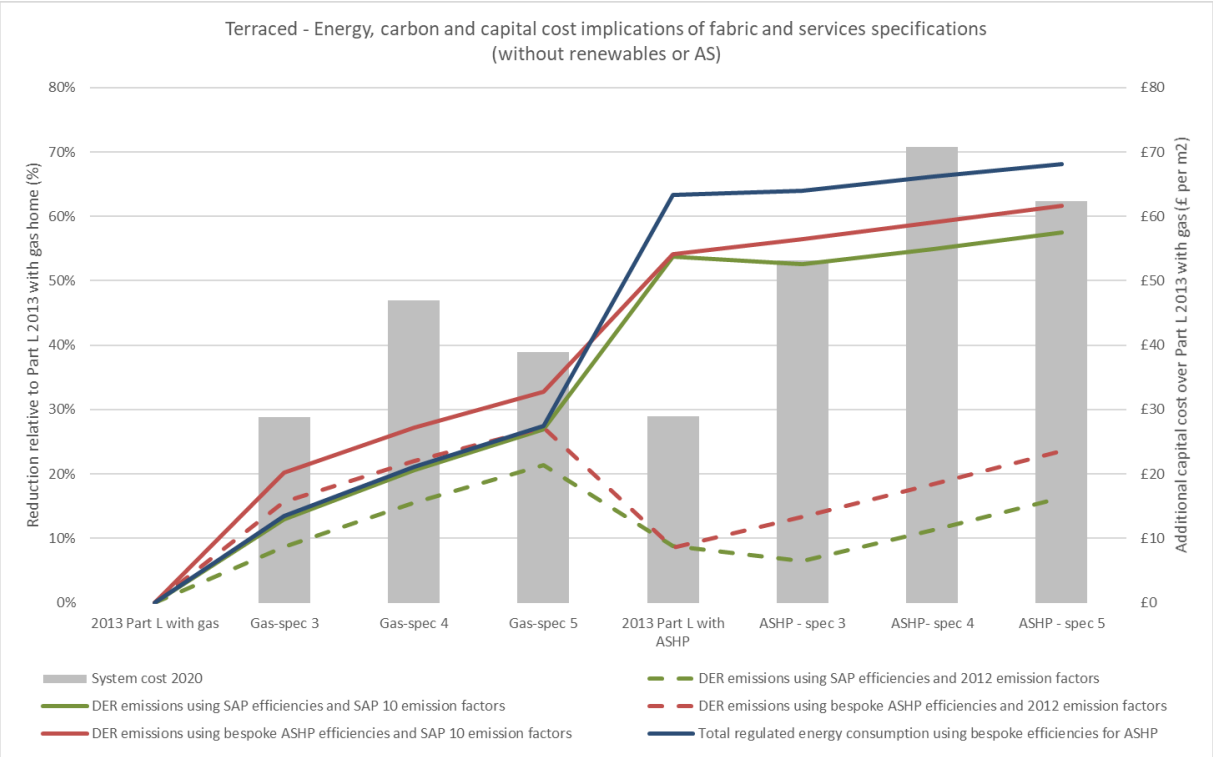
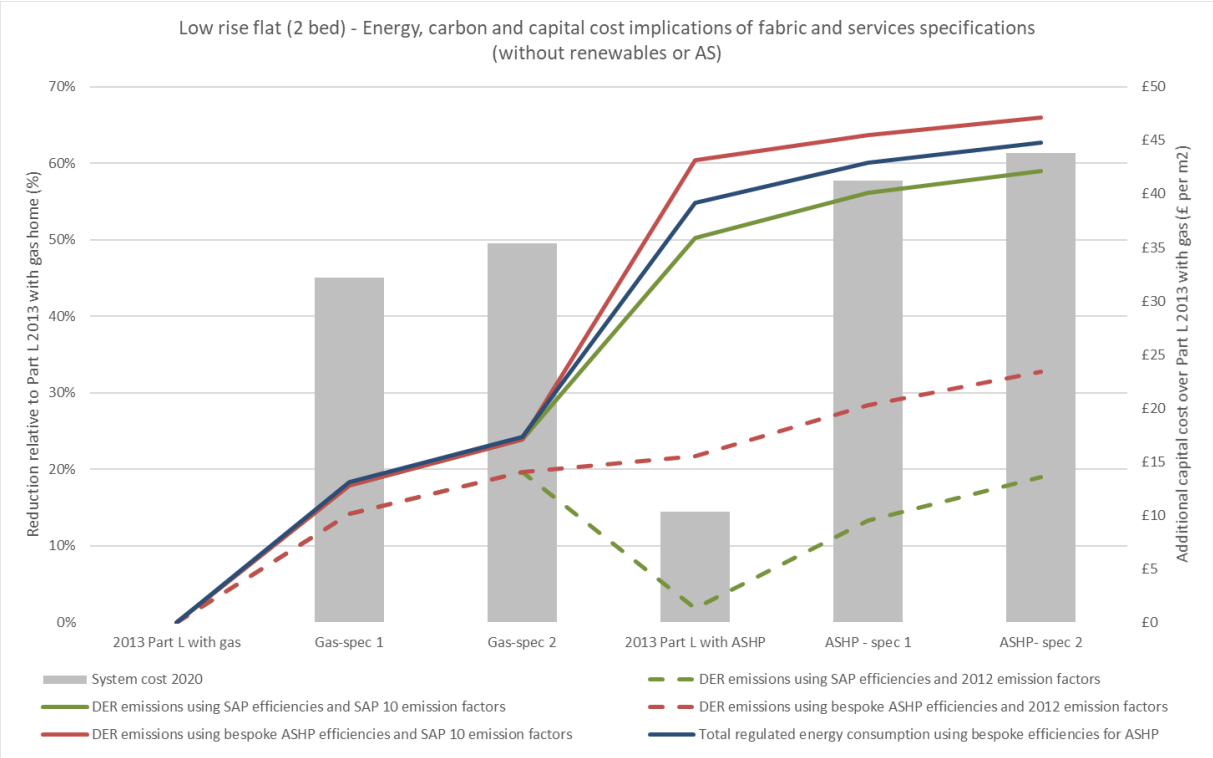


Figure D.4 Cost uplift and energy and carbon savings with different modelling assumptions – low rise flat



Impact of increasing area available for PV to100% of floor area on Policy Option 1

Figure D.5 Meeting policy option 1 with PV area up to 100% of floor area (gas heating)

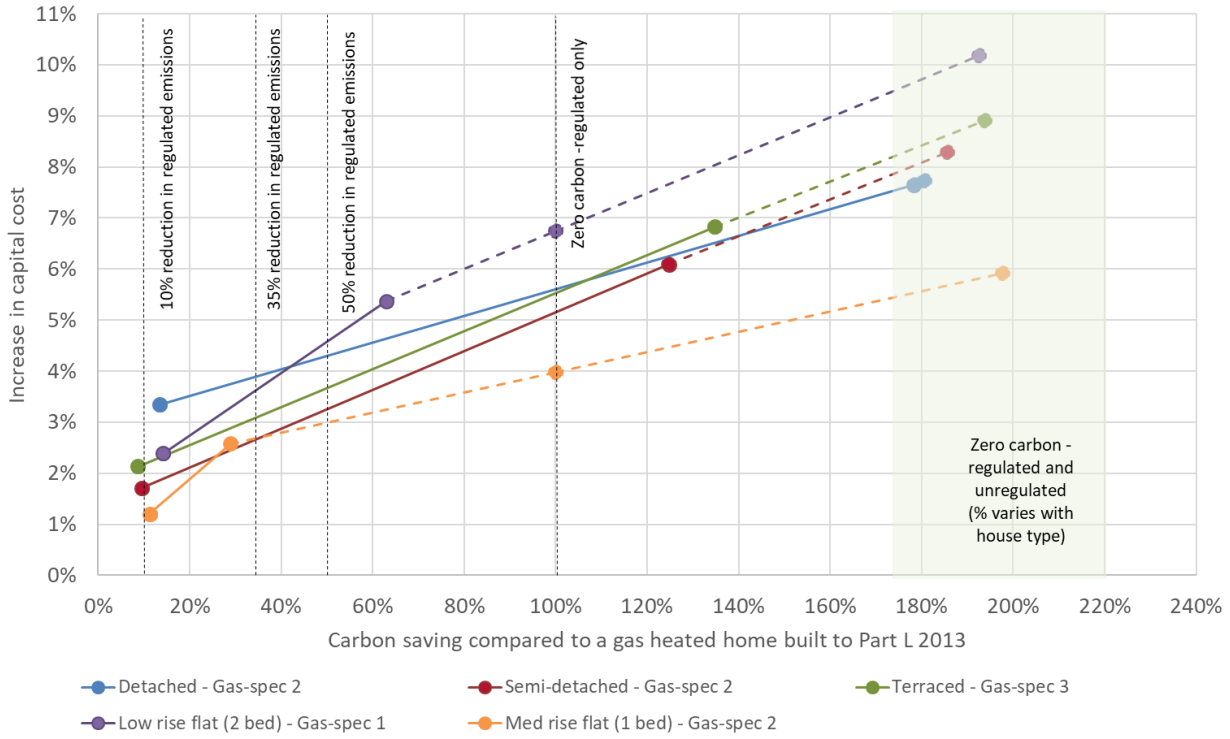
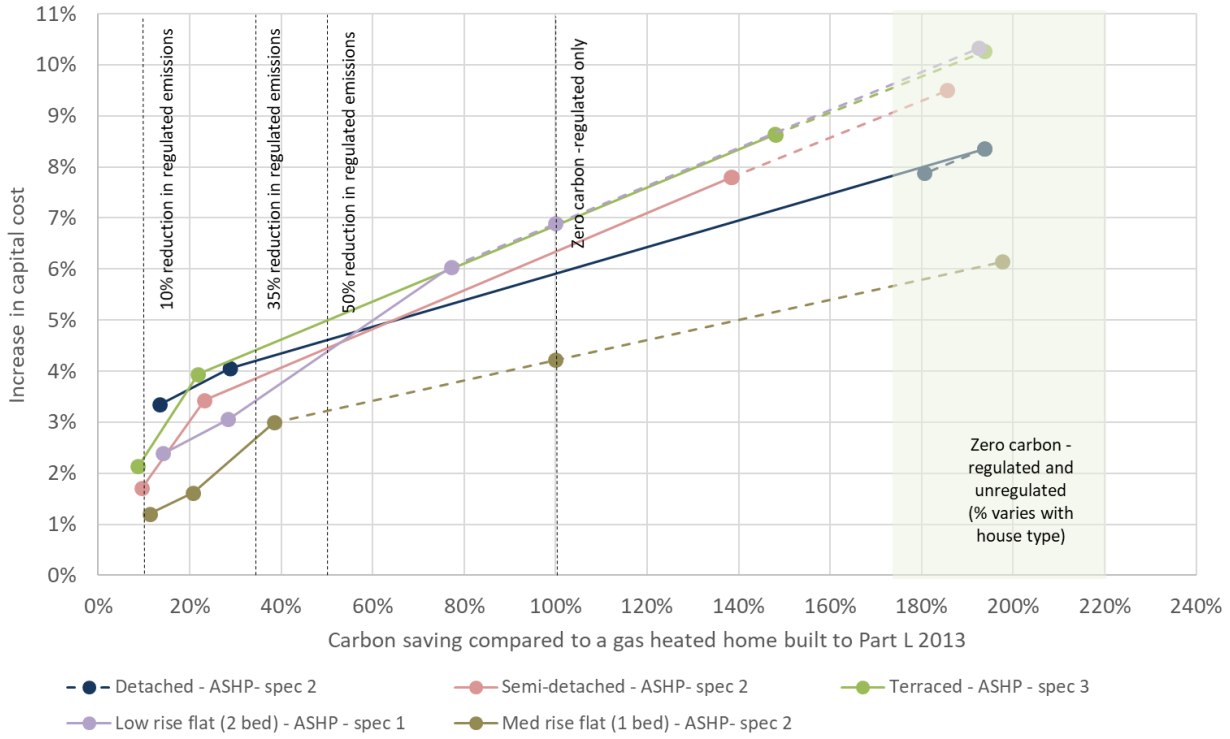


Figure D.6 Meeting policy option 1 with PV area up to 100% of floor area (ASHP heating)



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