Improvements to Energy Standards for New Buildings within Scottish Building Regulations 2021: Modelling Report

Domestic Buildings

July 2020, with July 2021 amendments

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Executive Summary

1. The aim of this project was to assess and identify potential improvements in energy and emissions performance for new domestic and non-domestic buildings constructed in Scotland set via Standard 6.1 (carbon dioxide emissions). This was to inform the setting of targets within the next set of energy standards, programmed for implementation in 2021. This report focuses on the project findings for new domestic buildings.

2. Improvements to the current notional (reference) building were identified based on a review of current practice in Scotland and other relevant literature. The relative cost-effectiveness and feasibility of these improved measures were assessed. Based on this, two new alternative standards (“Option 1” and “Option 2”) were proposed. Their benefits and costs were assessed at an individual building and national level.

3. Option 1 comprises improvements to the fabric efficiency of the notional building and the inclusion of waste water heat recovery. Option 2 includes further improvements, including triple glazing and the adoption of mechanical ventilation with heat recovery. Developers can build to alternative specifications as long as they meet, or improve upon, the performance of the notional building.

4. For both options, it is proposed that the notional building is based on gas heating plus photovoltaics (PV), with typically an increase in the array size compared to the current notional building. An exception is proposed if a heat pump is used in the actual building, where an air source heat pump (ASHP) is included and the PV element removed in the notional building. This would simplify the current approach where the fuel in the notional building depends on that included in the actual building. This is to help avoid heat pumps being able to meet the gas heating targets with relaxation in other elements of specification, including fabric energy efficiency.

5. Options 1 and 2 are estimated to reduce carbon emissions by 32% and 57% respectively across the build mix. This was evaluated using the SAP 10.1 methodology, including SAP 10.1 carbon emission factors, across 7 building archetypes, based upon current build levels and fuel mix in Scotland. This compares to a recommendation in the 2007 Sullivan Report to achieve aggregate emission reductions equating to at least 27.5% on 2015 standards.

6. It is estimated that Options 1 and 2 for a semi-detached home, as an example, will increase the capital costs by 4% and 7% respectively if gas heating plus PV is used. This cost is reduced if ASHP is used, increasing the capital cost by 3% and 6% respectively, providing encouragement to lower carbon fuels. In general, it is estimated that the capital cost is lower for an ASHP for individual homes but higher for flats.

7. The national cost benefit analysis shows that Option 1 results in a net benefit of £46m whilst Option 2 results in a net cost of £250m. This difference is driven by the incremental capital, renewal and maintenance costs for Option 2 being nearly double those for Option 1 and this negates the greater savings in energy use from Option 1.

8. The Scottish Government proposes that primary energy becomes the main target metric. This analysis demonstrated the benefit in retaining the carbon dioxide equivalent emissions target as an additional metric to encourage a move to lower carbon fuels.

Introduction

1.1 Project aims

9. The overall aim of this project was to assess and identify the potential for further improvement in energy and emissions performance for new domestic and non-domestic buildings constructed in Scotland set via Standard 6.1 (carbon dioxide emissions) and supporting guidance within The Scottish Government's Building Standards Technical Handbooks. This was to inform the setting of targets within the next set of energy standards, programmed for implementation in 2021. This report focuses on the project findings for new domestic buildings.

10. Standard 6.1 of the Scottish Building Regulations (Scottish Government, 2004) specifies that for new domestic and non-domestic buildings:

    "Every building must be designed and constructed in such a way that:

    a. the energy performance is estimated in accordance with a methodology of calculation approved under regulation 7(a) of the Energy Performance of Buildings (Scotland) Regulations 2008, and
    b. the energy performance of the building is capable of reducing carbon dioxide emissions."

    The accompanying technical handbooks (Scottish Government, 2019a) provide guidance on achieving this standard.

11. The two key outputs required from the project were:

    - Revised notional building(s) for application within the 2021 standards. The Scottish Government has indicated that this should be based on a single fuel type, and that in the next (2024) revision the intention is to move to low carbon heating systems, so the 2021 specification should be in this context. It was recognised that there may need to be a variation of a core notional building specification for different building types to reflect the practicality of a particular level of improvement for different building types (e.g. high-rise flats).
    - Illustration of the costs and benefits of the options assessed for the revised notional building. This should inform a subsequent business and regulatory impact assessment to be undertaken by the client. It should include assessing the national cost impact taking into account the capital and life cycle costs (e.g. maintenance and asset replacement), and the national benefit impact taking into account any change in energy demand and carbon emissions, and pricing this according to UK Government. The impact assessment should be undertaken in accordance with The Green Book and accompanying supplementary guidance 'valuation of energy use and greenhouse gas emissions for appraisal' (HM Treasury, 2018).

1.2 Policy context

1.2.1 National climate change targets

12. The recent UK Climate Change Act amendment committed Scotland to a target of net zero emissions of all greenhouse gases by 2045 (HM Government, 2019). This reflects the Committee on Climate Change's report on achieving net zero, which stated that Scotland has proportionately greater potential for emissions removal than the UK overall and can credibly adopt a more ambitious target of net zero greenhouse gas emissions by 2045 (compared to 2050 for England) (Committee on Climate Change, 2019a). The Scottish Government has also adopted a new target to reduce emissions by 75% by 2030 compared to 1990 levels (Scottish Government, 2019b).

1.2.2 Programme for Government 2019-20

13. To achieve net zero emissions, it will be necessary to significantly reduce (or eliminate) carbon emissions from the operation of buildings. Currently, the majority of emissions in buildings, particularly for residential buildings, are from the use of higher carbon fossil fuels to heat buildings. Hence, it is a priority to install low carbon heating sources. Photovoltaics are not a substitute for low-carbon heat; carbon savings associated with this generation will decline as the grid decarbonises. In the Programme for Government 2019-20, Scottish Ministers have committed to the decarbonisation of heat in new homes from 2024 and consideration of similar actions for new non-domestic buildings from that date (Scottish Government, 2019c):

> "Our consultation… on new building regulations will include measures to improve energy efficiency… and we will work with stakeholders to develop regulations to ensure that new homes from 2024 must use renewable or low carbon heat. Similarly, our ambition is to phase in renewable and low carbon heating systems for new non-domestic buildings consented from 2024. We will work with the construction, property and commercial development sectors to identify and support good practice to inform the development of standards on how we can achieve this".

14. There are several points of note relating to this:

- Energy efficiency: It is important to minimise the energy demand from new buildings. High efficiency standards complement low carbon heating through lower demand for low carbon energy, and lower running costs. Reduced peak energy demands also reduce the impact on energy supply and distribution infrastructure. There are potentially significant capital cost savings in terms of distribution pipework and heat emitter costs in buildings, arising from reduced space heating demand.
- Potential adverse impacts: Care needs to be taken to ensure that higher fabric standards and ventilation specifications do not lead to poor indoor air quality through under-ventilation or summer overheating, and avoid higher energy demand through installation of active cooling.
- Renewable and low carbon heating: The 2021 revision of the standards should provide a trajectory to low carbon heat in all new buildings. Recent work for the

UK and Welsh Governments on their energy standards (MHCLG, 2019f; Welsh Government, 2019b) suggests that it is possible to set reasonable but stringent notional buildings based on fossil fuels (e.g. gas) which encourage the installation of low carbon heating now (e.g. heat pumps) as with grid decarbonisation, it results in lower capital costs for compliance. Minimum fabric and services efficiency standards will need to be carefully considered, particularly in this case.

- Consideration of future-proofing: The asset life of the building fabric means that it is likely to still be in place come 2045 and it is relatively expensive to retrofit. This suggests standards for building fabric should be set at a level that they do not require costly energy-efficiency retrofit to meet these future targets. Similar consideration should also be given the building services as although they have a shorter asset-life, systems may well still be in-use come 2045, albeit the expectation is that there will need to be a transformation across the building stock to move to low carbon heating. There may be measures which would provide benefits now, and make it easier to install heat pumps or district heating in future, such as low flow temperature heating systems being installed in new homes.

1.2.3 Scottish energy strategy

15. It is noted that these changes should be viewed within the context of the Scotland's energy strategy (Scottish Government, 2017b). This set out the vision for the future energy system in Scotland including prioritising energy efficiency and renewable and low carbon solutions. It also set a particular aim of stimulating the deployment of district and communal heating as means of supplying low carbon heat. This was made clear at the start of the decade in the 2020 Routemap for Renewable Energy in Scotland (Scottish Government, 2011) which included a target for 1.5TWh of heat demand to be delivered by district or community heating by 2020. More recently, this ambition to increase deployment of district heating was made clear in the Scottish Government's second consultation on district heating regulation and local heat and energy efficiency strategies (Scottish Government, 2017a). As a result, an aspect of the current project was to assess the implications of new standards on the feasibility and viability of connecting to heat networks.

1.2.4 Scottish low carbon building standards strategy and review

16. In 2007, Scottish Ministers convened an expert panel to advise on the development of a low carbon building standards strategy to increase energy efficiency and reduce carbon emissions. This resulted in the Sullivan Report – a low carbon building standards strategy for Scotland (Scottish Building Standards Agency, 2007). Key recommendations included the following:

- Net zero carbon buildings (i.e. space and water heating, lighting and ventilation) by 2016/2017, if practical.
- Two intermediate stages on the way to net zero carbon buildings, one change in energy standards in 2010 (low carbon buildings) and another in 2013 (very low carbon buildings).
- The 2010 change in energy standards for non-domestic buildings should deliver carbon dioxide savings of 50% more than 2007 standards. The 2010 change in

energy standards for domestic buildings should deliver carbon dioxide savings of 30% more than 2007 standards.

- The 2013 change in energy standards for non-domestic buildings should deliver carbon dioxide savings of 75% more than 2007 standards. The 2013 change in energy standards for domestic buildings should deliver carbon dioxide savings of 60% more than 2007 standards.

17. In May 2013 Scottish Ministers reconvened the Sullivan panel with a view to revisiting some of their original recommendations, including those above, taking account of the impact of the economic downturn on the construction sector. Whilst maintaining the level of ambition, the 2013 update report (Building Standards Division, 2013) recommended a more moderate pace of change. However, the improvement standards recommended in the original Sullivan Report act as a benchmark for this current review. The carbon dioxide emissions savings from the proposed improved notional buildings have been compared against the recommendations from the Sullivan Report.

18. The current review of the energy standards in the Scottish Building Regulations had already commenced prior to the start of this project. Scottish Ministers designated energy efficiency as a national infrastructure priority in 2015. They noted that whilst new buildings constructed to current building standards already achieve a good level of energy efficiency, they wish to explore options to build upon the progress made to date in providing energy efficient buildings with reduced carbon emissions. Hence, they called for a review of the building regulations and the energy standards that apply to both domestic and non-domestic buildings.

19. As a first step, a public consultation was undertaken to seek the views of stakeholders on the impact the 2015 energy standards had, or continue to have, on industry in designing and constructing buildings (Scottish Government, 2018). The consultation asked stakeholders about the challenges faced in meeting the 2015 standards and how they were overcome. It also consultation asked for feedback on practical opportunities to further improve the energy performance of buildings. These responses have informed the current project.

1.2.5 Energy Performance of Buildings Directive

20. The Energy Performance of Buildings Directive set a number of requirements for EU Member States that also needed to be considered in this project. The Directive places a requirement on Member States to review the minimum energy performance requirements set for buildings at intervals not exceeding 5 years. It also sets a requirement for minimum energy performance standards for new buildings to be ‘nearly zero energy’. In particular, by 31 December 2020, all new buildings should be nearly zero-energy buildings; and after 31 December 2018, new buildings occupied and owned by public authorities should be nearly zero-energy buildings. The 2018 call for evidence to support this Building Standards review stated that “UK work in this area is on-going and proposals will be developed for Ministers to consider in the context of Scotland’s position in Europe, post-exit” (Scottish Government, 2018).

21. The 2018 amended Energy Performance of Buildings Directive called for member states to express the energy performance of buildings by a numeric indicator of primary energy use for the purpose of reporting and as the principal metric for the setting of minimum energy performance requirements. This differs from the current metric for

performance for the energy standards of carbon dioxide equivalent emissions. The Scottish Government indicated the intention to retain the carbon dioxide equivalent emissions target as an additional metric, in the context of its overall carbon emission targets, and this has been explored a part of the project.

22. It should be noted that there are other European requirements that impact on new build standards. For example, the recently amended Energy Performance of Buildings Directive introduces a requirement for self-regulated devices and the Energy Efficiency Directives sets minimum standards for building services. Whilst it is expected that such requirements are unlikely to impact on the notional buildings themselves, they are likely to impact more on other parts of Standard 6.

1.3 Policy and research implications

23. The research undertaken as part of the project, the proposals made for the notional building, and the findings from the cost benefit assessment may raise issues which have implications for policy or strategy beyond Building Standards Section 6, or which require further research or action. Key implications have been highlighted in the report.

24. In particular, wider work outside the scope of Building Standards Section 6 will be required to facilitate the transition to low carbon heating systems, and to support an increase in localised embedded renewable energy generation more generally. This is in the context of 2021 and future standards, and of current electricity grid constraints and a drive for future electrification across different sectors. Supportive measures are also likely to be needed to facilitate other future changes in construction practices associated with improvements to standards set by the notional building. Particularly relevant concerns and some suggestions for how to address these are discussed in sections 1.7.2, 1.9 and 1.10.6 of this report.

25. Changes to Section 6 may also require, or benefit from, a review of some of the guidance in other areas of the Technical Handbooks, for example parts of Section 7. Additionally, work is likely to be required outside of this review to help ensure that indoor air quality and overheating (discussed in section 1.8 of this report) – or other sustainability risks – do not impact negatively on new homes in Scotland. There are also various decisions on Section 6 amendments outside of the scope of the current project which the Scottish Government's Building Standards Division will need to consider, such as changes to minimum elemental performance standards.

Task 1: Establish Current Baseline

26. Task 1 of the analysis was to establish the current baseline situation for new buildings in Scotland. To achieve this involved three main stages of analysis:

    1. Estimating a national annual build profile, based on defined building types/sub-types.
    2. Energy modelling of these building sub-types, including identification of current (2015) Building Standards compliant specifications.

27. This section of the report sets out the evidence and rationale for the approach taken. It also summarises key assumptions and results.

1.4 Establishing the national annual build profile for new buildings

28. The first stage of the process was the identification of a suitable number of evidence-based building types and sub-types. ‘Building types’ refer to the function of the building (detached house, mid-floor flat etc.). ‘Building sub-types’ represent distinct combinations of building type, heating fuel/technology and ventilation strategy. The selected sub-types should be representative of the buildings constructed in Scotland over the last few years.

29. To derive the building sub-types analysis was undertaken of an extract of the Energy Performance Certificate (EPC) database for new domestic buildings provided by the Scottish Government. This included information relating to certificates issued over the period from January 2016 to December 2018. A total of 53,495 EPC records were included in the analysis.[1] This analysis and the resulting sub-types are described below.

30. The EPC database contains information on each individual property, including building type, heating fuel/technology and total floor area (other parameters such as fabric U-values, and further information on building services are discussed later in section 0). This information was used to identify the numbers of different building sub-types and their proportions within the database extract. A summary is shown in Table 1.4a below.

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[1] Data was excluded where certificates were pre-2016 (19 records, of total provided by Scottish Government), where the fields ‘Part 1 Construction Year/Age Band’ were pre-2014 (1754 records, including many likely relating to conversions of buildings), or where the average wall U-value was greater than or equal to 0.6 (95 records. These cases were all also missing airtightness test data and most also had poor performance elsewhere e.g. single glazing).

Table 1.4a: Proportions of all building types in EPC database extract, split by heating fuel

Building Type	Biomass	DHN	Electric	Mains gas	Oil	LPG	LNG	TOTAL
House	0%	0%	0%	0%	0%	0%	0%	**0%**
Basement flat	0%	0%	0%	0%	0%	0%	0%	**0%**
Detached bungalow	0%	0%	1%	1%	1%	0%	0%	**3%**
Detached house	0%	0%	3%	27%	2%	0%	0%	**33%**
Detached maisonette	0%	0%	0%	0%	0%	0%	0%	**0%**
Enclosed end-terrace house	0%	0%	0%	0%	0%	0%	0%	**0%**
Enclosed end-terrace maisonette	0%	0%	0%	0%	0%	0%	0%	**0%**
Enclosed mid-terrace maisonette	0%	0%	0%	0%	0%	0%	0%	**0%**
End-terrace bungalow	0%	0%	0%	0%	0%	0%	0%	**0%**
End-terrace flat	0%	0%	0%	0%	0%	0%	0%	**0%**
End-terrace house	0%	0%	0%	7%	0%	0%	0%	**8%**
End-terrace maisonette	0%	0%	0%	0%	0%	0%	0%	**0%**
Ground-floor flat	0%	0%	1%	8%	0%	0%	0%	**10%**
Ground-floor maisonette	0%	0%	0%	0%	0%	0%	0%	**0%**
Mid-floor flat	0%	1%	1%	9%	0%	0%	0%	**11%**
Mid-floor maisonette	0%	0%	0%	0%	0%	0%	0%	**0%**
Mid-terrace bungalow	0%	0%	0%	0%	0%	0%	0%	**0%**
Mid-terrace house	0%	0%	0%	7%	0%	0%	0%	**8%**
Mid-terrace maisonette	0%	0%	0%	0%	0%	0%	0%	**0%**
Semi-detached bungalow	0%	0%	1%	1%	0%	0%	0%	**1%**
Semi-detached flat	0%	0%	0%	0%	0%	0%	0%	**0%**
Semi-detached house	0%	0%	1%	13%	0%	0%	0%	**15%**
Semi-detached maisonette	0%	0%	0%	0%	0%	0%	0%	**0%**
Top-floor flat	0%	1%	1%	8%	0%	0%	0%	**10%**
Top-floor maisonette	0%	0%	0%	0%	0%	0%	0%	**0%**
TOTAL	**0%**	**3%**	**10%**	**84%**	**3%**	**1%**	**0%**	**100%**

Notes Percentages do not all add up to 100 due to rounding.
Source AECOM analysis of *EPC database extract 2016-18 SAP new build* (provided by Scottish Government, December 2019)

31. The sub-types which represent more than or equal to 5% of the total building stock in the database extract are highlighted in green in Table 1.4a. Those representing more than 0.5% but less than 5% are highlighted in yellow.

32. For derivation of the national build profile for the purpose of this project, it is sufficient to focus on the most common sub-types as these will allow sufficient determination of the impact of any changes to Building Standards – additional sensitivity analyses can be undertaken later if necessary on less common, but important, sub-types.

33. As a first step, those sub-types representing over 5% of the total were proposed for definite inclusion. This resulted in the following 6 sub-types which represents around 80% of the build mix:

- Detached house, gas
- Semi-detached house, gas
- Mid-terrace house, gas
- Ground-floor flat, gas
- Mid-floor flat, gas
- Top-floor flat, gas

34. The semi-detached house sub-type represents records identified as ‘semi-detached house’ or ‘end-terrace house’ in the database, as these forms are equivalent and their average floor areas were very similar.

35. The remaining building sub-types were also considered where they represented over 0.5% of the buildings in the database extract. The most significant remaining sub-types were electric-heated; accounting for 10% of the database entries in total. Within this, detached homes were the most prevalent (3% of all records). However, as the electric-heated sub-types covered a range of built forms, a semi-detached house was chosen as being more representative of electric-heated homes overall. Whilst the average total floor area for electric-heated homes was found to be around 120m^2 (excluding outliers >300m2), the distribution of the floor areas was skewed towards the lower end of the range – the median value was just under 100m^2. Of the electric-heated homes, around 70% have an air source heat pump (ASHP) as their main heating source, with a further 5% having other types of heat pump. Therefore this sub-type is assumed to be heated by an ASHP.

36. As the total number of LPG-heated homes, oil-heated homes and homes connected to a heat network were each under 3% these were excluded from the build profile. However, heat networks are planned to be the subject of sensitivity analysis under Task 3 (see section 1.15); potentially along with either direct electric[2] or oil-heated homes.

37. This gives a revised list of seven sub-types in total, shown in Table 1.4b. The middle column shows the adjusted proposed baseline build mix proportions, based on the EPC proportions but scaled up to total 100%. The final column uses these adjusted proportions and a total annual build figure of 18,207 homes per year to estimate baseline numbers of completed homes by sub-type per year. The total annual build figure is based on Housing Statistics for Scotland data on completions across all sectors for the calendar years 2016-2018, from which an average has been taken.

[2] Likely to be based on storage heaters, as the second most common main electric heating type in the database extract (after ASHP) was electric storage heaters (around 15% of electric-heated homes).

Table 1.4b: Seven building sub-types selected for analysis

Building Sub-types	Proportion of EPC database buildings	Proportion of baseline build mix	Annual build numbers
Detached house, gas	27%	30%	5,521
Semi-detached house, gas	21%	23%	4,158
Mid-terrace house, gas	7%	8%	1,467
Ground-floor flat, gas	8%	9%	1,706
Mid-floor flat, gas	9%	9%	1,706
Top-floor flat, gas	8%	9%	1,706
Semi-detached house, ASHP	10%	11%	1,943
TOTAL	**90%**	**100%**	**18,207**

Notes Percentages do not add up to totals due to rounding.
The figures for semi-detached house, ASHP are based on the total number of electric-heated homes of any built form.
The 'proportion of baseline build mix' figures for the flats have been adjusted to be of equal proportions, to represent a 3-storey block of flats. The total number of flat blocks built per year is calculated as 1706*3/12, which assumes a 3-storey block with 4 flats per storey.

Source AECOM analysis of *EPC database extract 2016-18 SAP new build* (provided by Scottish Government, December 2019)
Scottish Government, *Housing Statistics for Scotland – All sector new build (completions)*, September 2019 (data for calendar years 2016-2018 used to derive an average annual total build rate)

38. The ventilation strategy was also considered as a determining factor for identifying different sub-types for analysis. From the EPC records, the particular ventilation type could not be determined, as the main ventilation field ('Mechanical Ventilation') only had three options: 'mechanical, extract only', 'mechanical, supply and extract', or blank (assumed to be naturally ventilated homes). As the first option only accounted for 20 of the 53,495 analysed records, it is reasonable to assume that the 'mechanical, supply and extract' option (accounting for around 45% of all records) covers various types of mechanical ventilation, not just Mechanical Ventilation with Heat Recovery (MVHR) but also including mechanical extract ventilation (MEV).[3] Feedback from developers via Homes for Scotland suggested that MVHR was not commonly specified, supporting this assumption. Overall, there appeared to be a downwards trend for mechanical vent across the registration years for all dwelling types (though data only covered three years), and a move to natural ventilation. Looking at 2018 registrations only, natural ventilation accounted for the following proportions of each building sub-type: mains gas detached 50%, semi-detached 57%, mid-terrace 56%, flats 76%, and ASHP semi-detached 78%.

[3] Air permeability rates were also included in the database. Analysis of these two fields in combination showed that only around 3% of all records had both 'mechanical, supply and extract' selected and air permeability rates of under 4 (in this case, it could reasonably be assumed that MVHR is being specified). This low figure was somewhat surprising, but as noted above feedback from developers in Scotland confirmed that MVHR was not commonly specified in new build Scottish homes.

39. The EPC database extract provided good evidence for including natural ventilation sub-types across the range of built forms and heating types. Including building sub-types for the mains gas houses cases based on MEV was additionally considered. Feedback from Homes for Scotland also suggested that where mechanical ventilation is specified, decentralised MEV (dMEV) is more commonly used in houses (and centralised MEV in flats). Therefore a dMEV case was tested using SAP 9.92 software, based on the mains gas semi-detached sub-type and using the specifications set out in section 0, but with dMEV, and the PV array size being reduced slightly to achieve compliance within 1% of the Target Emission Rate (TER). It was found that results did not differ substantially from the natural ventilation case. The adjustment to achieve compliance within 1% of the TER meant that the Dwelling Emission Rate (DER) would be the same as the natural ventilation case, using SAP 9.92 carbon emission factors. Using SAP 9.92 energy results but applying SAP 10.1 carbon emission factors and primary energy factors led to the dMEV case DER being 4% lower than the natural ventilation case, and the Dwelling Primary Energy Rate (DPER) being 2% lower for dMEV. It was also expected that capital costs for the two cases would be similar. Therefore it was agreed with Scottish Government that separate dMEV sub-types were not needed for inclusion in the baseline scenario.

40. Data on representative building floor areas for each of the building sub-types selected for analysis was required to inform energy modelling and costing. The EPC database extract was interrogated for this information, and Table 1.4c shows the average total floor areas (TFA) found for each sub-type.

Table 1.4c: Building sub-type average total floor areas (TFA), based on EPC database extract

<table>
<tr><th>Building Sub-type</th><th>Average TFA in EPC database* (m²)</th><th>Proposed TFA in modelling (m²)</th><th>Basis for model</th></tr>
<tr><td>Detached house, gas</td><td>142</td><td>141</td><td>England/Wales Part L 2020 detached house, adjusted</td></tr>
<tr><td>Semi-detached house, gas or ASHP</td><td>87</td><td rowspan="2">84</td><td rowspan="2">England/Wales Part L 2020 terraced house</td></tr>
<tr><td>Mid-terrace house, gas</td><td>86</td></tr>
<tr><td>Ground-floor flat, gas</td><td>68</td><td rowspan="3">70</td><td rowspan="3">England/Wales Part L 2020 large flat</td></tr>
<tr><td>Mid-floor flat, gas</td><td>70</td></tr>
<tr><td>Top-floor flat, gas</td><td>71</td></tr>
</table>

Notes Outliers which might skew results have been excluded from this analysis, as follows: TFA > 300m² for detached houses (under 3% of all detached houses), TFA > 150m² for semi-detached houses (under 3% of all semi-detached and end-terrace houses). No adjustments made for mid-terrace houses or flats as excluding outliers made little difference to results.

Source AECOM analysis of *EPC database extract 2016-18 SAP new build* (provided by Scottish Government, December 2019)

41. Table 1.4c also shows the TFAs used in the modelling. These have been based on existing models where possible (i.e. those available either from previous modelling to inform the 2015 revision of Building Standards for new dwellings in Scotland, or those used for the recent Part L 2020 modelling in England/Wales). Models have been selected based on their TFAs being within 5% of the averages found in the EPC

database extract. Where this was not possible (i.e. in the case of the detached house) it is proposed that an existing model is scaled for use in the analysis.

42. For flats, the distribution of TFAs was also looked at in case there would be a significant advantage to modelling two different flat sizes. However, analysis did not strongly support a case for this, suggesting that the single size is reasonably representative of flats constructed in Scotland (the median flat TFA was also around 70m^2). Additionally, previous work on Part L 2020 in England and Wales can be used to inform consideration of where constraints might apply in flats for particular solutions (e.g. heat pump sizing for smaller flat sizes).

43. Table 1.4d summarises key dimensions for the building forms used in the analysis.

Table 1.4d: Building type summary of key dimensions

AREAS (m^2)	Detached	Semi-detached	Mid-terrace	Flat - Ground	Flat - Mid	Flat - Top
Party wall	0	42	84	29	29	29
Exposed wall	172	94	52	41	41	41
Semi-exposed wall	0	0	0	12	12	12
Roof – Main	70	42	42	0	0	70
Roof – Bay window	1	1	1	0	0	0
Ground floor	71	43	43	70	0	0
TFA	141	84	84	70	70	70
Upper floor (1st)	70	42	42	0	0	0
Total window area	28.8	14.6	12.8	13.8	13.8	13.8
Window area – North	*3.0*	*0.0*	*0.0*	*7.9*	*7.9*	*7.9*
Window area – East	*15.3*	*7.6*	*7.6*	*0.0*	*0.0*	*0.0*
Window area – South	*1.7*	*1.8*	*0.0*	*0.0*	*0.0*	*0.0*
Window area – West	*8.7*	*5.2*	*5.2*	*5.9*	*5.9*	*5.9*
Total as % of TFA	*20%*	*17%*	*15%*	*20%*	*20%*	*20%*
Opaque door area	4.3	2.1	2.1	2.1	2.1	2.1
Zone 1	19	20	20	24	24	24
Zone 1 as % of TFA	*13%*	*24%*	*24%*	*35%*	*35%*	*35%*

Notes Some figures do not add up to totals due to rounding.

Zone 1 areas as proportions of TFA are similar to the averages for the equivalent dwelling types in the EPC database (where they are as follows: detached 16%, semi-detached 21%, mid-terrace 23%, flat 35%).

For the flat building types, some results will be presented in terms of a block of flats (assumed to consist of 12 flats in total; 3 storeys of 4 flats each; assumption agreed with Scottish Government).

Window areas include glazed doors. Were solid doors included in addition, the % of TFA calculations would be closer to 25% (as in the notional dwelling), though still slightly under 20% for the semi-detached and mid-terrace dwelling types.

Source Floor plans and elevations for England/Wales dwelling types, with scaled adjustments where required to meet TFAs.

1.5 Energy modelling of building sub-types

1.5.1 2015 compliant specifications – introduction

44. The EPC database extract was reviewed to find typical specifications to inform 2015 Building Standards compliant models. These models form the basis of the counterfactual/baseline assessment. The method used for the analysis and results found are set out below.

45. The same exclusions were made from the database as described in Section 1.4 above (with the same 53,495 EPC records being included in the analysis). For analysis of fabric U-values, for each element type records were additionally excluded where the average U-values in the database exceeded the maximum area-weighted average values set in the Scottish Technical Handbook – Domestic, Table 6.3, column (a) (Scottish Government, 2019).

46. For elements of the specification where numerical values were applicable (e.g. U-values), the analysis focussed on median values. It also looked at interquartile ranges in these cases. For non-numerical data (e.g. heating control types), the most common entries were focussed on. A guiding principle was that the 2015 notional building specifications set out in Table 6.1 of the Technical Handbook (Scottish Government, 2019) for the relevant fuel types (mains gas, electricity) would be adopted unless there was evidence to suggest that common practice involved significant deviation from the specification (e.g. for U-values, if the notional building value was outside the interquartile range). Where data was not available in the EPC database, notional building values were adopted.

47. Published responses to the Scottish Government's recent review of energy standards: call for evidence were also used to inform the analysis (Scottish Government, 2018). In particular, they were used to sense-check overall compliance strategies and to inform changes required to specifications where the EPC database analysis would otherwise have led to non-compliant models. The main area where this was the case was in relation to solar PV.

48. The findings are summarised in the sub-sections and tables below, covering fabric (section 1.5.2, Table 1.5a), ventilation (section 1.5.3, Table 1.5d), heating (section 1.5.4, Table 1.5e and Table 1.5f), lighting (section 1.5.5, Table 1.5g), and PV (section 1.5.6, Table 1.5h). The three data columns in each of the tables respectively show the proposed Building Standards 2015 compliant specification; the 2015 notional building specification; and the values found in the EPC database.

1.5.2 2015 compliant specifications – fabric

49. For building fabric, where data was available in the EPC database extract, the findings suggested that the specifications in the 2015 notional building are a good representation of common practice for new build homes. Therefore no changes to the notional building specification are proposed, except for window areas/orientation to reflect the building forms being modelled. Details are shown in Table 1.5a.

Table 1.5a: Building Standards 2015 compliant specifications – fabric

Element	Proposed 2015 Compliant Specification	2015 Notional	EPC Database
External Wall U-value	0.17	0.17	0.17 is within 25th-75th percentiles. Median is 0.19 (0.18 for flats).
Corridor Wall U-value	0.17	0.17	-
Party Wall U-value	0.0	0.0	0.0 is most common value (>90% of homes).
Floor U-value	0.15	0.15	0.15 is median value.
Roof U-value	0.11	0.11	0.11 is median value.
Window U-value	1.4	1.4	Not available
Window g-value	0.63	0.63	Not available
Door U-value	1.4	1.4	Not available
y-value	0.08	0.08	Not available
Thermal Mass Parameter	As actual	As actual	Not available
Window overshading	Average	Average	Not available
Window orientation	Based on floor plans and England/Wales assumptions	E/W	Not available
Exposed window, door, rooflight area	Based on floor plans	25% TFA (or, if less, total exposed façade area)	Not available

Notes As explained above, where EPC data was missing, 2015 notional values have been taken.
For window orientation/area details, see Table 1.4d above.
Units for U-values and y-values are W/m^2K.

Source AECOM analysis of *EPC database extract 2016-18 SAP new build* (provided by Scottish Government, December 2019); Scottish Technical Handbook – Domestic, Table 6.1 (Scottish Government, 2019)

50. For the Thermal Mass Parameter (TMP), the values for the building types have been calculated based on the dwelling dimensions and the assumptions set out in Table 1.5b. Timber framed walls have been assumed as this is the prevalent construction in Scotland.[4] The resulting values are shown in Table 1.5c.

Table 1.5b: TMP calculation construction assumptions

Element	Construction
Heat loss floors	Slab on ground, screed over insulation
Party floors / roofs	Timber I-joists, carpeted
Intermediate floors / roofs	Plasterboard ceiling, carpeted chipboard floor
Heat loss walls	Timber framed, one layer of plasterboard
Party walls	Twin timber frame, double plasterboard both sides
Internal walls	Plasterboard on timber frame
Heat loss roofs	Plasterboard, insulated at ceiling level

[4] Data suggests that over 80% of new build homes in Scotland have a timber frame (for example NHBC, *Housing Market Report No. 298*, July 2017, Table QS15).

Source AECOM assumptions

Table 1.5c: TMP calculated values by building type

Building type	TMP (kJ/m²K)
Detached house	102
Semi-detached house	109
Mid-terrace house	115
Flat - Ground	142
Flat - Mid	62
Flat - Top	71

Source AECOM calculations and thermal mass assumptions for different construction elements used in SAP.

1.5.3 2015 compliant specifications – ventilation

51. For ventilation, the main proposed change compared to the 2015 notional building is to the air permeability rate, as analysis showed that the notional value was outside the interquartile range for EPC database entries. The number of sheltered sides is also proposed to be varied, based on built form. Details are shown in Table 1.5d.

Table 1.5d: Building Standards 2015 compliant specifications – ventilation

Element	Proposed 2015 Compliant Specification	2015 Notional	EPC Database
Ventilation type	Intermittent extract fans with trickle vents	Intermittent extract fans with trickle vents	Non-mechanical is most common type
Air permeability rate (m³/m².h @50Pa)	5.0	7.0	5.0 is median value, interquartile range 4.0-5.0.
No. of extract fans	4 for houses; 3 for flats (as per 2015 notional)	4 for dwellings with TFA>80m^2, 3 for smaller dwellings	Not available
No. of sheltered sides	Based on built form (0 for detached, 1 for semi-detached, 2 for mid-terrace and flats)	2	Not available
No. of chimneys/open flues	0	0	Not available

Notes As explained above, where EPC data was missing, 2015 notional values have been taken. For more detailed analysis of data on ventilation types/strategies in the EPC database, see Section 1.4 above.

Source AECOM analysis of *EPC database extract 2016-18 SAP new build* (provided by Scottish Government, December 2019)
Scottish Technical Handbook – Domestic, Table 6.1 (Scottish Government, 2019)

1.5.4 2015 compliant specifications – heating

52. For heating, mains gas heating and electric (ASHP) space and water heating specifications are considered separately. Details are shown in Table 1.5e and Table 1.5f.

53. For mains gas, the main proposed change compared to the 2015 notional building is the exclusion of waste water heat recovery (WWHR), as EPC database analysis showed that this was installed in only a small proportion of cases.

54. Other more minor changes include the assumption of combi boilers for all building types except detached houses, based on EPC database analysis. The hot water cylinder size for the detached house is also proposed to be varied for costing purposes, based on assumptions made in England and Wales Part L 2020 work, but with the assumption that the declared loss factor specified in the 2015 notional is met. For showers, a new data entry field is required for SAP 10 – here the assumed value has been based on the maximum fittings consumption optional requirement level for showers in Approved Document G in England, Table 2.2 (HM Government, 2016). This is the same assumption as used in Part L 2020 modelling work for England and Wales. It was used as an equivalent value could not be found in the Scottish Technical Handbook – Domestic section 3.27.2. For heating flow temperatures, categories have also changed in SAP 10.1 and an assumption of >55°C has been made based on AECOM's understanding of common practice and the assumption used in Part L 2020 modelling work for England and Wales.

Table 1.5e: Building Standards 2015 compliant specifications – gas cases

Element	Proposed 2015 Compliant Specification	2015 Notional	EPC Database
Space Heating Source	Condensing gas boiler	Condensing gas boiler	Condensing gas boiler most common
Emitters	Radiators (standard size)	Radiators (standard size)	Radiators in nearly all cases
Efficiencies (SEDBUK)	89.0%	89.0%	Not available
Flow temperatures	>55°C	55°C (e.g. radiators as emitters); max. category in SAP 9.92 is >45°C	Majority >45°C (max. category)
Controls	Time and temperature zone control, interlock, ErP Class V controls, delayed start	Time and temperature zone control, interlock, weather compensation, delayed start	Time and temperature zone control most common; no data on other items
FGHR?	None	None	FGHR in about 10% of mains gas cases
Pump details	2013 or later, in heated space	Not specified - assume same	2013 or later most common, no data on location
Flue type	Balanced, fan-assisted	Balanced, fan-assisted	Balanced in nearly all cases
Boiler type/size	Detached: 18kW system/regular Semi/Mid/Flat: 24kW combi	System/regular for all dwelling types	Boiler+cylinder in majority of detached houses, combi in majority of other dwelling types
Domestic Hot Water Source	As for space heating	As for space heating	As for space heating
Hot water cylinder size (where applicable)	200l, detached house only	150l, all dwelling types	Not available
Hot water cylinder declared loss factor (where applicable)	1.89 kWh/day	1.89 kWh/day	Not available

Element	Proposed 2015 Compliant Specification	2015 Notional	EPC Database
Primary circuit loss assumptions (where applicable)	Cylinder thermostat, separate timer, fully insulated primary pipework	Cylinder thermostat, separate timer, fully insulated primary pipework	Not available
Shower flow rate (l/min)	8	n/a	n/a
No. of showers	2 for all building types	n/a	n/a
No. of baths	1 for all building types	n/a	n/a
WWHR?	None	Instantaneous, 45% efficiency, 2 showers if TFA>100m², otherwise 1 shower	WWHR in only 4% of mains gas homes (only 3% in 2018)
Secondary heating	None	None	Secondary heating very uncommon
Electricity tariff	Standard	Not specified - assume standard though	Nearly all on standard tariff

Notes As explained above, where EPC data was missing, 2015 notional values have been taken.
Boiler efficiencies will be adjusted for relevant control types and flow temperatures as required.
For SAP 9.92, weather compensation provides a +3% improvement (checked in example Scotland TER worksheet as not specified in 2015 notional building) resulting in a data entry of 92.0%; in SAP 10.1 Table D1 the improvement is only +0.7% for design flow temperatures over 55°C resulting in a data entry of 89.7%.
See text above table for discussion of hot water cylinder assumptions.
The numbers of showers and baths have been based on building type floor plans. The shower flow rate corresponds to the maximum value in Section 7 Aspect Silver level 4. These assumptions are required for SAP 10.1 only.
For SAP 10.1 modelling, it is assumed that water use is below 125 litres per person per day (data entry not required for Scotland in SAP 9.92).

Source AECOM analysis of *EPC database extract 2016-18 SAP new build* (provided by Scottish Government, December 2019)
Scottish Technical Handbook – Domestic, Table 6.1 (Scottish Government, 2019)

55. For the ASHP case, the main proposed changes compared to the 2015 notional building are the use of the heat pump to provide water heating as well as space heating (instead of electric immersion only); exclusion of secondary space heating; and exclusion of waste water heat recovery (WWHR). These changes are based on the specifications in the majority of ASHP entries in the EPC database analysis.

Table 1.5f: Building Standards 2015 compliant specifications – ASHP case

	Proposed 2015 Compliant Specification	2015 Notional	EPC Database
Space Heating Source	ASHP	ASHP	ASHP most common electric heating type
Emitters	Radiators (assume large size)	Radiators (assume large size)	Radiators most common emitter type
Efficiencies (Seasonal Performance Factor, SPF)	170%	175.1%	Not available
Flow temperatures	Assumption not required; use efficiency	55°C	>45°C most common temperature
Controls	Time and temperature zone control	Time and temperature zone control	Time and temperature zone control most common
Domestic Hot Water Source	As for space heating, including electric immersion	Electric immersion only	From main most common in majority of cases
Hot water cylinder size (where applicable)	150l	150l, all dwelling types	Not available
Hot water cylinder declared loss factor (where applicable)	1.89 kWh/day	1.89 kWh/day	Not available
Primary circuit loss assumptions (where applicable)	Cylinder thermostat, separate timer, fully insulated primary pipework	Cylinder thermostat, separate timer, fully insulated primary pipework	Majority have cylinder thermostat, other data not available
Shower flow rate (l/min)	8	n/a	n/a
No. of showers	2 for all building types	n/a	n/
No. of baths	1 for all building types	n/a	n/a
WWHR?	None	Instantaneous, 45% efficiency, 2 showers if TFA>100m², otherwise 1 shower	No WWHR in nearly all ASHP cases
Secondary heating	None	10% electric	No secondary heating in majority of ASHP cases (around 75%)
Electricity tariff	Standard	Not specified - assume standard	Majority on standard tariff (around 90%)

Notes As explained above, where EPC data was missing, 2015 notional values have been taken. ASHP efficiency based on SAP default as a specific value cannot be specified in SAP 9.92 or SAP 10.1, and as value is close to notional and ASHP case over-complies. It should be noted however that the Domestic Building Services Compliance Guide (Scottish Government Building Standards Division, 2014) sets a minimum Coefficient of Performance (CoP) of 2.5 for space heating and of 2.0 for water heating (SAP efficiencies are based on the Season Performance Factor (SPF), which is not directly comparable. The CoP is a measure of instantaneous efficiency, whereas the SPF is a measure of average efficiency across the year taking account of the varying temperature conditions but importantly also considering energy use of auxiliary components such as circulation pumps and direct electric heating (where present)[5]. Scottish Government confirmed their preference to model the default efficiency however rather than

[5] https://www.bregroup.com/heatpumpefficiency/background

adjusting other specification elements. See discussion of overall specification in section 1.5.8 below.

The numbers of showers and baths have been based on building type floor plans.

Source AECOM analysis of *EPC database extract 2016-18 SAP new build* (provided by Scottish Government, December 2019)

Scottish Technical Handbook – Domestic, Table 6.1 (Scottish Government, 2019)

1.5.5 2015 compliant specifications – lighting

56. Nearly all records in the EPC database had 100% low energy lighting. However more detail is needed for SAP10; the proposed assumptions are shown in Table 1.5g.

Table 1.5g: Building Standards 2015 compliant specifications – lighting

	Proposed 2015 Compliant Specification	2015 Notional	EPC Database
Fixed lighting capacity (lm)	185 x TFA	n/a	n/a
Efficacy (lm/W)	80	n/a - 100% low-energy lighting assumed	100% low energy lighting in nearly all cases

Notes The fixed lighting capacity is based on the SAP10.1 Appendix L default calculation where there is no fixed lighting/amount is unknown, and is what was suggested by BRE for Appendix R (notional building) in England.

The lighting efficacy is based on an AECOM suggestion for an improved minimum standard reflecting good practice.

Source AECOM analysis of *EPC database extract 2016-18 SAP new build* (provided by Scottish Government, December 2019)

Scottish Technical Handbook – Domestic, Table 6.1 (Scottish Government, 2019)

BRE, SAP10.1 Appendix L (BRE, 2019)

1.5.6 2015 compliant specifications – solar PV

57. Solar PV is included in the 2015 notional building, but was only found in about 30% of all records for flats and 20% of all records for houses in the EPC database across the 3-year period. However, when looking at 2018 registrations and mains gas heated homes only, PV is installed in around 50% of flats and 40% of houses.

58. The other elements of the proposed 2015 notional building specifications set out in the sections above were modelled for the building sub-types. It was found that without PV, the mains gas cases would be significantly under-compliant.

59. From this, and based on other findings (for example, the large number of cases in the EPC database extract where maximum U-values were exceeded), it is reasonable to suppose that many of the database entries are not compliant with 2015 Building Standards, but were assessed under earlier standards.[6]

[6] Looking at 2018 registrations only for all specification was considered, but this was not found to make a significant difference to U-values, for example.

60. Due to the cases being under-compliant other sources of evidence were reviewed; in particular the published responses to the recent consultation on energy standards (Scottish Government, 2018). These did not provide strong evidence for improving other elements of the 2015 compliant specification, but provided a good evidence base for the inclusion of solar PV. Quotes from a selection of the responses are included below:

- “Generally, the industry has adapted to the 2015 Technical Standards, by a combination of improving fabric and services specification and the addition of renewable technologies.” – Professional membership body (architecture)
- "most developers will be installing PV to comply with Section 6." – Warranty provider
- "the use of renewable energy has also increased, usually photovoltaic panels are recommended to aid compliance with the standards.” – SAP software provider
- “To meet the current guidance we did not improve our building fabric. We merely added PV.” – Housing developer
- "Major housebuilders and developers now recognise solar PV as one of the most effective and affordable methods to meet building regulation demands, as well as the multitude of benefits it brings to homeowners. Our members estimate as much as 70% of new developments now includes solar PV" – Renewable energy trade association

61. Based on the above, it is proposed to include PV in the gas-heated 2015 compliant cases. A summary of the proposed PV modelling specifications for gas-heated building sub-types is shown in Table 1.5h, where it is compared to the 2015 notional and the EPC database findings for main gas heated homes where PV was installed. The draft modelled array sizes (based on SAP 9.92 modelling of the other specification assumptions set out above) are shown in Table 1.5i.

Table 1.5h: Building Standards 2015 compliant specifications – solar PV

	Proposed 2015 Compliant Specification	2015 Notional	EPC Database
PV calculation	Initially based on EPC database averages, but adjusted to achieve compliance within 1% of TER	kWp = 1% of building TFA	n/a
Region	UK average	UK average	Not available
Roof area required (m^2/kWp)	6.5	8.3	n/a
Overshading factor	1.0 (none/very little)	1.0 (none/very little)	Majority none/very little (around 95%)
Orientation	SW	SW	Over 75% orientated between SE and SW
Pitch	30°	30°	Majority at 30° (around 80%)
% exported to grid	Calculated in SAP	Calculated in SAP	Calculated in SAP

Notes The 2015 notional building PV array size is subject to following limit: not exceeding 30% of roof area (divided by no. of storeys in block for flats), based on 30° roof pitch and 0.12kWp/m^2 PV area.

The proposed m²/kWp assumption has been updated from the notional building value based on AECOM's understanding of standard current performance. The proposed value is the same as that used in modelling for Part L 2020 in England and Wales. It is used to help inform costing.

Source AECOM analysis of *EPC database extract 2016-18 SAP new build* (provided by Scottish Government, December 2019)
Scottish Technical Handbook – Domestic, Table 6.1 (Scottish Government, 2019)

Table 1.5i: Building Standards 2015 compliant specifications – solar PV array sizes

PV array sizes (kWp)	Proposed 2015 Compliant Specification	2015 Notional	EPC Database
Detached house, mains gas	1.61	1.17	Mean 1.51 where installed, median 1.38, interquartile range 1.10-1.75
Semi-detached house, mains gas	0.95	0.84	Mean 0.97 where installed, median 0.83, interquartile range 0.75-1.10
Mid-terrace house, mains gas	0.95	0.84	Mean 0.84 where installed, median 0.80, interquartile range 0.75-1.04
Flat, mains gas	0.85	0.70	Mean 0.62 where installed, median 0.50, interquartile range 0.50-0.75
Block of flats, mains gas	10.20	8.40	-
Semi-detached house, ASHP	n/a	n/a	Majority of ASHP-heated homes did not have PV

Notes PV array sizes have been based on achieving compliance just below the TER.
The array size for the flats is at the upper limit based on the 2015 roof area limit (but this is based on 2015 assumptions of panel performance/roof area required, and it should be noted that there have been improvements in the performance of PV panels compared to 2015 assumptions).

Source AECOM modelling in SAP9.92.

62. As noted in Table 1.5i, for the ASHP-heated case no PV is assumed, as in the notional building (and in the majority of ASHP-heated homes in the EPC database).

1.5.7 Viability and cost-effectiveness considerations

63. The viability and cost-effectiveness of the specifications identified for the 2015 compliant building sub-types was considered. As the specifications were in general closely aligned with the median values or most common system configurations found in the EPC database, or otherwise with responses provided to the 2018 call for evidence consultation, this provided strong evidence for viability.

64. Specific development constraints in some situations would influence different specifications in practice from those set out above. The feasibility of mains gas for heating depends on the availability of a gas supply. In some circumstances the viability of PV generation may be limited – for example due to constraints on orientation or over-shading, or on the electricity grid. In both of these cases, the ASHP specification provides an example of an alternative compliance case, and the EPC database

evidence indicates ASHP is installed in a significant proportion of new build homes (around 7% of homes analysed in database extract).

65. The use of specifications supported by the EPC database analysis and 2018 consultation responses provided evidence for cost-effectiveness as well as viability, as developers would not commonly adopt non cost-effective solutions to compliance. There are of course other cost-effective solutions available (an example of which might be waste water heat recovery), but it was considered most important to reflect current common practice in the baseline. A review of the specification items and overall strategies set out above did not flag significant concerns on their cost-effectiveness based on AECOM's understanding of cost data, impact on energy/carbon reductions, and the 2015 compliance targets, though some commentary on PV and ASHP is provided below.

66. Previous work on cost-optimal standards for the UK (MHCLG, 2019c) showed that where PV is being installed, larger array sizes are more cost-effective than smaller ones (in the absence of targets which may tend to limit sizes for compliance reasons). Where suitably-orientated roof-space is available, some developers may be choosing to put larger PV array on houses, in particular, and to relax other specification elements such as fabric – as suggested by one of the responses to the 2018 consultation cited in paragraph 60 above. However, although the sizes modelled for the houses are not large, they are still a minimum of 1kWp, and they are based on EPC database evidence. This item of the specification should be reviewed in the analysis of 2021 standards.

67. In the modelled 2015 ASHP case, the specification over-complies meaning there is potential for more cost-effective solutions from a capital cost perspective, particularly if more efficient heat pumps are installed in practice. For example, the fabric specifications could be relaxed to the maximum limits set in Table 6.5 of the Technical Handbook (Scottish Government, 2019a), though this would have negative impacts on occupants including increased fuel bills. The rationale for the specifications modelled is discussed in section 1.5.8 below. The potentially unintended implications of compliance flexibility for ASHP-heated homes should also be considered as part of the analysis of 2021 standards.

1.5.8 Modelling using SAP 9.92

68. The seven building sub-types set out in Table 1.4b were modelled with the 2015 compliant specifications set out in Table 1.5a to Table 1.5i. Initially, the current version of the National Calculation Methodology for domestic buildings, the Standard Assessment Procedure version 9.92 (SAP 9.92), was used (BRE, 2014). This is the version used for checking compliance with Building Standards 2015. Modelling was undertaken using Stroma's FSAP2012 software, which implements the SAP 9.92 methodology.

69. The main purpose of modelling the building types using SAP 9.92 was to check compliance with Building Standards 2015. The modelling informed the specifications set out above. The Scottish Government had requested that for each model the Dwelling Emission Rate (DER) would be within 1% of the Target Emission Rate (TER). In the gas-heated cases, this was achieved through the specifications set out above, and with adjusting the PV array sizes as required whilst keeping within reasonable limits (final

modelled values are shown in Table 1.5i). For the flats, compliance was checked based on block-averaging rather than on individual units.

70. However the ASHP-heated case over-complies (with an improvement on the TER of around 13%). This is because the EPC database evidence suggests that ASHP-heated homes are over-complying in practice, in particular due to the following differences compared to the 2015 electric notional building in the majority of homes: omission of secondary heating, use of the heat pump for water heating as well as space heating and lower air permeability rates. Whilst waste water heat recovery was also omitted in the majority of homes (but is included in the notional building), this did not outweigh the other improvements. Analysis of the database did not suggest that other specification areas (e.g. U-values or air tightness) were relaxed for ASHP-heated homes. In practice ASHP-heated homes may over-comply even further if heat pump efficiencies are commonly better than the low value in the 2015 electric notional building, but this data was not available in the EPC database. Alternative specifications were discussed with Scottish Government Building Standards Division, but they took the view that the modelling should be based on the EPC database evidence and on the default heat pump efficiencies in SAP.

71. Key results from the modelling are set out in Table 1.5j. The columns show the TER and DER as calculated in SAP 9.92, using SAP 9.92 carbon emission factors; the DER calculated using the SAP 9.92 methodology but with SAP 10.1 carbon emission factors; and the Dwelling Primary Energy Rate (DPER) calculated using SAP 10.1 primary energy factors. Showing both SAP 9.92 and SAP 10.1 DERs allows a comparison of the impact of changes to the carbon emission factors separately from other changes to the methodology, as is discussed in section 1.5.10.

Table 1.5j: SAP 9.92 key modelling results by building sub-type – 2015 compliant cases – carbon emissions and primary energy

Building sub-type	**TER** - SAP 9.92 Factors	**DER** - SAP 9.92 Factors	**DER** - SAP 10.1 Factors	**DPER** - SAP 10.1 Factors
Detached house, gas	11.1	11.1	12.7	69.2
Semi-detached house, gas	13.5	13.5	14.5	79.8
Mid-terrace house, gas	12.3	12.3	13.3	73.4
Average flat, gas	12.6	12.6	13.8	75.9
Semi-detached house, ASHP	25.9	22.5	5.4	65.5

Source AECOM modelling using Stroma's FSAP 2012.
Results recorded and calculated in AECOM, '200122 Scotland Building Standards 2021 - SAP9.92 Results – v2.xls'

72. Further results from the modelling are set out in Table 1.5k. The columns show energy consumption by end-use, and energy generation from onsite PV (where applicable) as calculated using the SAP 9.92 methodology.

Table 1.5k: SAP 9.92 key modelling results by building sub-type – 2015 compliant cases – annual energy consumption by end-use, and annual onsite energy generation (kWh/yr)

Building sub-type	Space heating	Water heating	Pumps and fans	Lighting	PV generation
Detached house, gas	6,376	2,691	75	491	1,326
Semi-detached house, gas	3,618	2,458	75	369	782
Mid-terrace house, gas	3,113	2,466	75	379	782
Average flat, gas	2,514	2,306	75	314	700
Semi-detached house, ASHP	1,953	1,301	30	369	0

Source AECOM modelling using Stroma's FSAP 2012.
Results recorded in AECOM, '200122 Scotland Building Standards 2021 - SAP9.92 Results – v2.xls'

1.5.9 Modelling using SAP 10.1

73. The seven building sub-types and 2015 compliant specifications set out in Table 1.5a to Table 1.5i were subsequently modelled using the latest available version of SAP, SAP 10.1 (BRE, 2019). This is the proposed version to be used for checking compliance with Building Standards 2021 in Scotland (and Part L 2020 in England and Wales). Modelling was undertaken using an offline program provided by the BRE, which implements the SAP 10.1 methodology (SAP.exe Build 7, 20/01/20).

74. Key results from the modelling are set out in Table 1.5l. The columns show the DER and DPER calculated using the SAP 10.1 methodology (including SAP 10.1 carbon emission factors and primary energy factors).

Table 1.5l: SAP 10.1 key modelling results by building sub-type – 2015 compliant cases – carbon emissions and primary energy

Building sub-type	DER - SAP 10.1	DPER - SAP 10.1
Detached house, gas	13.0	69.0
Semi-detached house, gas	15.0	80.2
Mid-terrace house, gas	13.7	73.2
Average flat, gas	14.5	77.6
Semi-detached house, ASHP	6.1	63.7

Source AECOM modelling using BRE's SAP 10.1 software SAP.exe, Build 7, 20/01/20.
Results recorded in AECOM, '210507 Scotland Building Standards 2021 - SAP10.1 Results – v10.xls'

75. Further results from the modelling are set out in Table 1.5m. The columns show energy consumption by end-use, and energy generation from onsite PV (where applicable) as calculated using the SAP 10.1 methodology.

Table 1.5m: SAP 10.1 key modelling results by building sub-type – 2015 compliant cases – annual energy consumption by end-use, and annual onsite energy generation (kWh/yr)

Building sub-type	Space heating	Water heating	Pumps and fans	Lighting	PV generation
Detached house, gas	6,036	3,257	86	264	1,326
Semi-detached house, gas	3,315	3,007	86	198	782
Mid-terrace house, gas	2,774	3,018	86	204	782
Average flat, gas	2,259	2,849	86	169	700
Semi-detached house, ASHP	1,748	1,524	0	198	0

Source AECOM modelling using BRE's SAP 10.1 software SAP.exe, Build 7, 20/01/20. Results recorded in AECOM, '210507 Scotland Building Standards 2021 - SAP10.1 Results – v10.xls'

1.5.10 Impact of the calculation methodology

76. A secondary purpose of the SAP 9.92 modelling was to help understand the impact of changes to the calculation methodology between SAP 9.92 and SAP 10.1. The mains gas semi-detached case has been used as an example to assess impacts on energy demands, based on the specification assumptions set out above. Results are shown in Table 1.5n and discussed in Table 1.5o.

Table 1.5n: Comparison of SAP 9.92 and SAP 10.1 energy modelling results for semi-detached 2015 compliant example (kWk/yr)

Semi-detached house, gas	Space heating	Water heating	Pumps and fans	Lighting	Total Gas	Total Elec	PV generation
SAP 9.92 Results	3,618	2,458	75	369	**6,076**	**444**	782
SAP 10.1 Results	3,315	3,007	86	198	**6,322**	**284**	782

Source AECOM modelling, see Table 1.5k and Table 1.5m above.

Table 1.5o: Commentary on SAP 10.1 and 9.92 differences in energy modelling results, based on example case

Finding – SAP 10.1 compared to 9.92	Commentary
Space heating: energy consumed <u>decreases</u> by 8%.	Relates to assumed heating pattern changing in SAP 10.1 to a consistent pattern across the whole week, instead of a different pattern at the weekend (BRE, 2016a). Also relates to some increased gains from water heating (where consumption is increased), and increased gains from lighting in the consultation version of SAP 10.1 used in the modelling (as implemented by BRE) compared to SAP 9.92. Balancing the above somewhat, the heating efficiency adjustment due to weather compensation is lower in the SAP 10.1 modelling (+0.7% vs +3.0% gross points), tending to increase energy demands. In SAP 10.1 heating efficiency adjustments due to various types of controls have been differentiated by design/flow return temperatures and a new design flow/return temperature category has been added (80/60 or 70/60) which is assumed in the modelling.
Water heating: energy consumed <u>increases</u> by 22%.	The calculation of hot water consumption has been adjusted to account for different shower types and flow rates. In our example semi-detached model, the average hot water usage has increased (from around 100 litres/day in SAP 9.92 to around 120

	litres/day in SAP 10.1), affecting water heating demands. The heating efficiency adjustment due to controls is also lower in SAP 10.1, increasing overall consumption. The changes to SAP 10.1 to allow shower types and flow rates to be specified were intended to better reflect consumption, and are particularly important for estimating savings from solar hot water or waste water heat recovery (BRE, 2016b).
Pumps & fans: energy consumed increases by 15% (but this is a small absolute increase).	Assumption for annual electricity consumed by heating circulation pump (2013 or later) has increased by 11kWh/yr in SAP 10.1 Table 4f compared to SAP 9.92 Table 4f.
Lighting: energy consumed decreases by 46%.	The calculation of lighting energy has been updated in SAP 10.1 to allow recognition of different low energy lighting types. Individual lighting efficacies can now be specified, instead of simply the proportion of 'low-energy lighting' of any type. The efficacy assumed for the SAP 10.1 modelling has been based on an AECOM suggestion for an improved minimum standard reflecting good practice.
PV: total energy generated is unchanged.	No change, but it should be noted that SAP 2012 used a fixed assumption for the proportion of electrical energy generated by PV systems which is consumed within the dwelling (50%). This has been replaced by a calculation which also includes recognition of the presence of battery storage. It will impact on primary energy and carbon calculations (as emission and energy factors vary for energy used on site vs exported), as well as on SAP cost calculations.
Gas: total regulated energy consumed increases by 4%.	The changes in space heating and water heating consumption explained above to some extent balance each other out when looking at total regulated gas consumption.
Electricity: total regulated energy consumed decreases by 36%.	This is largely due to the lighting calculation changes explained above, and will impact on primary energy, carbon and cost calculations though total figures are relatively low compared to gas consumption for gas-heated cases.

Source AECOM modelling and analysis, with reference to SAP manuals (BRE, 2014) (BRE, 2019) and supporting technical papers.

77. The comparison example shows that space heating energy consumption decreases in SAP 10.1 compared to SAP 9.92 but overall the regulated energy consumption associated with heating increases slightly due to more significant increases in water heating energy consumption. One implication of this is that water heating demands become relatively more significant (a trend already seen over time with improvements to fabric standards which have reduced space heating demands). Measures which reduce water heating energy consumption will potentially have more of an impact in SAP 10.1, which may affect choices for 2021 standards.

78. The change to lighting energy consumption is also significant but is unlikely to have such an impact on measures considered for 2021 standards as this is in part due to the specification modelled for 2015, which AECOM views as appropriate for 2021 as well.

79. For PV, whilst generation figures are unchanged the new ability to recognise the impact of battery storage in SAP 10.1 may affect 2021 measures and target setting.

80. There are other changes to the SAP 10.1 methodology not covered above which will affect modelled energy consumption in some cases. These changes have been summarised by BRE elsewhere (BRE, 2018), but are considered less consequential to

the current main analysis. Where they have an impact on specific modelling areas or assumptions they are noted in other sections of the report.

81. A very significant change in SAP 10.1 is the update of the carbon emission factors (CEFs). A summary of the factors of particular relevance to the analysis is provided in Table 1.5p, where they are compared to the previous SAP 9.92 factors.

Table 1.5p: SAP 10.1 Carbon emission factor summary and comparison to SAP 9.92 ($kgCO_2e/kWh$)

Fuel type	SAP 10.1	SAP 9.92
Electricity – standard tariff	0.136	0.519
Electricity – displaced from grid, PV	0.136	0.519
Electricity – sold to grid, PV	0.136	0.519
Gas	0.210	0.216
LPG	0.241	0.241
Heating oil	0.298	0.298

Notes The figures provided here for electricity are annual averages, for ease of comparison, but SAP 10.1 applies monthly factors in practice. These monthly factors include small variations between some electricity tariffs (for example 7-hour and 10-hour, and PV electricity sold to grid).

Source SAP 10.1 Table 12 (BRE, 2019) and SAP 9.92 Table 12 (BRE, 2014).

82. The electricity CEFs are very significantly reduced in SAP 10.1, and the mains gas CEF is also slightly lower in SAP 10.1. Some of the impacts of this can be seen by comparing the DER results shown in Table 1.5j above, where energy consumption and generation figures are not varied so the impact of emission factor changes can be seen more easily. For the modelled mains gas cases the DERs are higher using SAP 10.1 CEFs, as although carbon emissions associated with energy consumption (in particular electricity consumption) are decreased, the reduction in the electricity CEF also leads to a significant decrease in carbon savings from PV electricity generation. For the electric-heated ASHP case, the DER is much lower using SAP 10.1 (it is around 25% of the SAP 9.92 DER), reflecting the reduction in the electricity CEF. The ASHP case does not include PV so reductions in PV carbon savings are not applicable in this case.

83. These changes have implications for future standard setting where carbon is used as a metric, with the change in electricity CEF making electric-heated options much more favourable from a carbon perspective than in SAP 9.92 modelling, and reducing the carbon-saving impact of PV as noted above. In SAP 9.92 the electricity CEF was much higher than that for gas (ratio of 2.4; compared to 0.65 in SAP 10.1). The primary energy factors (PEFs) in SAP 10.1 have also been updated, and factors of particular relevance to the analysis are shown in Table 1.5q. The PEFs are particularly significant as the Scottish Government intends to change to primary energy as the main target metric in 2021.

Table 1.5q: SAP 10.1 Primary energy factor summary

Fuel type	**PEF** (kWh/kWh)
Electricity – standard tariff	1.501
Electricity – displaced from grid	1.501
Electricity – sold to grid, PV	0.501
Gas	1.130
LPG (for main heating)	1.141
Heating oil	1.180
Renewable heat generated on-site[7]	0
Renewable heat generated off-site	1
Renewable electricity generated and used on-site[8]	0
Renewable electricity supplied from grid (as part of grid mix) or exported to grid from on-site generation	1

Notes The figures provided here for electricity are annual averages, for ease of comparison, but SAP 10.1 applies monthly factors in practice. These monthly factors include small variations between some electricity tariffs (for example 7-hour and 10-hour).

Source SAP 10.1 Table 12 (BRE, 2019), and MHCLG for renewable energy PEFs.

84. The change to primary energy as the main target metric will have significant implications for how different specification options perform in relation to each other, compared to when applying the carbon emission metric used in 2015. In particular, it can be seen that whilst the SAP 10.1 average annual CEF for electricity (standard tariff) is significantly lower than the CEF for gas (ratio of 0.65), the average annual PEF for electricity is higher than the PEF for gas (ratio of 1.33). This impacts on comparisons between gas and electric options and will mean that electric-heated options will tend to show larger relative reductions in carbon emissions than in primary energy.

85. A further new consideration has been introduced with the change to primary energy as the main target metric; the application of PEFs for renewable heat and electricity. MHCLG has chosen factors which it is understood that the Scottish Government will also adopt. These are shown Table 1.5q. The choice of these factors has a significant impact on the relative attractiveness of different renewable technologies in primary energy terms. The choice of the PEF for renewables is also used in calculating PEFs

[7] This is understood to include district heat networks supplied by renewable heat (PEF = 0 applied to renewable portion). It does not include biomass and biofuels which have a PEF = 1 applied plus adjustments for processing energy. BRE have confirmed that this is because such fuels are not considered to be on-site renewable fuels, as the energy is not created on site and it could have been used elsewhere in the economy. This will have implications for biomass-heated homes where currently targets are based on CEFs which are close to zero (though the use of a concurrent 2015 notional building differentiated by heating fuel and based on biomass in Scotland will mean that the change is less significant here than in other UK administrations, as biomass-heated homes already have to meet stricter targets).

[8] These renewable electricity factors inform others above.

for electricity supplied from the grid and therefore affects any technology using grid-supplied electricity (and in particular those which use electricity for heating as this accounts for a relatively high proportion of regulated energy demand). The difference between primary energy factors for on-site and off-site renewables also means that primary energy savings per kWh electricity generated from PV and exported are lower than savings where this electricity is used on site.

86. The implications of the change to primary energy as the main target metric will be illustrated and discussed more fully in section 0, including consideration of the need for a secondary carbon metric (see section 1.10).

Task 2: Develop Improved Notional Building Specifications

87. Task 2 of the analysis was to develop potential improved notional building specifications for new buildings in Scotland. The aim was to identify three proposed specification levels representing ‘low’, ‘medium’ and ‘high’ uplifts over Building Standards 2015. To achieve this involved the following steps:

1. Reviewing current notional buildings for design optimisation.
2. Identifying potential improved specifications based on a review of key existing data sources.
3. Analysing opportunities, constraints and risks.
4. Proposing specification options for review.

88. This section of the report sets out the evidence and rationale for the approach taken. It also summarises key findings and proposals.

1.6 Review of current notional buildings for design optimisation

89. A high-level review was undertaken looking at how the notional building could be defined at a strategic level to encourage design optimization – i.e. encouraging designs with lower energy consumption and carbon emissions.

90. One significant specification item which it has been suggested would benefit review in terms of impact on energy performance is the assumption that the size and shape of the notional building are the same as the actual building.[9] This will be considered in later analysis on potential modifications to performance targets for energy efficient design, focusing on built form (see section 1.18).

91. Another significant item is the differentiation of the notional building by fuel type. The Scottish Government wished to explore moving to a single notional building in 2021 instead. If the 2021 notional is based on gas, for example, this would allow heat pumps to receive a benefit in comparison, and the implications of this (in terms of potential relaxation of fabric specifications, for example) are considered at a later stage of analysis, in sections 1.10.6 and 0. It may also help to disincentivise higher carbon fossil fuels such as oil and LPG, though this may depend on whether carbon targets are set (as primary energy factors for these fuel types are similar to mains gas).

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[9] In cases where the notional is defined as being the same as the actual building, this can allow more flexibility in compliance and can help avoid situations where developments are penalised or rewarded for variables largely determined by factors which may not relate to energy performance alone and may be outside of their control – or which may have a more complicated relationship with energy performance meaning that they impact positively or negatively in different circumstances. However, this flexibility needs to be balanced with consideration of encouraging good energy performance.

92. Specification items in the current notional building relating to opening assumptions have also been considered, but it was not thought that changing these assumptions would have a significant impact on design optimisation.

93. It should be recognised that the notional specification should be viewed in the light of overall targets, and that there are other approaches to encouraging design optimisation for energy efficiency beyond adjusting the notional building definition. For example, additional targets relating to limits on maximum values (as in Section 6 Table 6.3 of the Technical Handbook (Scottish Government, 2019a)), or setting limits on space heating requirements can do this, particularly if they are defined in absolute terms (as in the current optional targets in Section 7).[10] The space heating targets in particular reward more energy efficient exposed surface to floor area ratios, glazing designs which make use of solar gains (with potential for increasing availability of natural light as a side-effect), and other measures to make use of passive heating.

1.7 Identification of potential improved specifications

94. Several key data sources were reviewed to inform proposals for potential improved notional building specification options for 2021 Building Standards. These included:

- The EPC database extract for new dwellings for years 2016-2018, processed as described in section 0 above.
- Responses to the Scottish Government's 2018 call for evidence on energy standards for new buildings.
- Proposals for Part L 2020 new dwelling notional buildings in England and Wales.
- Research informing the development of 2015 standards.
- The 2019 report on the assessment of cost-optimal energy performance requirements for the UK.

The findings from this review are summarised in the sub-sections below.

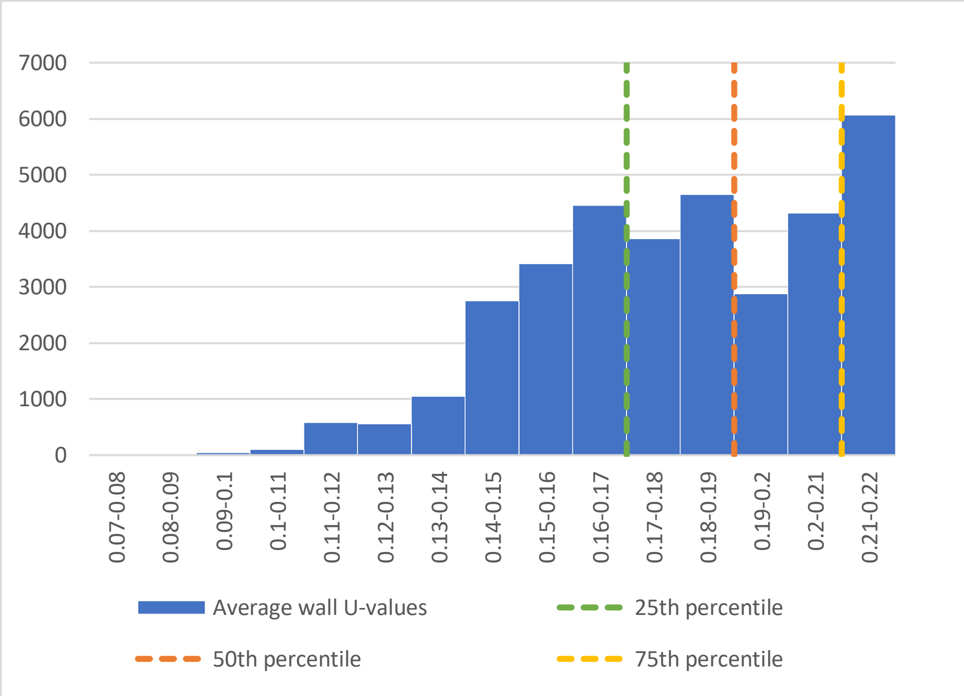
1.7.1 Review of EPC database extract

95. As the EPC database extract covered registrations over three years only, it was difficult to robustly identify trends in much of the data. In any case, fabric U-values and airtightness values did not appear to vary significantly by year. The distribution of average fabric U-values by main building element (external wall, floor and roof – no useful detailed data was available on windows) were more usefully analysed, with results shown in Figure 1.7a, Figure 1.7b and Figure 1.7c. Table 1.7a provides a summary of values at the 10th, 25th and 50th percentiles for the fabric elements, compared to the current 2015 notional building specifications. U-values over the maximum limits in Table 6.3 of the Technical Handbook (Scottish Government, 2019a) were excluded from this analysis. The findings suggest that a significant proportion of

[10] Note that the Section 7 targets may need reviewing/checking to align with improvements made to Section 6 standards, and to see how changes in the methodology in SAP 10.1 may affect the figures (see Table 1.5o for a summary of relevant changes). This is outside of the scope of the current study, but the space heating demands of modelled buildings will be reported upon.

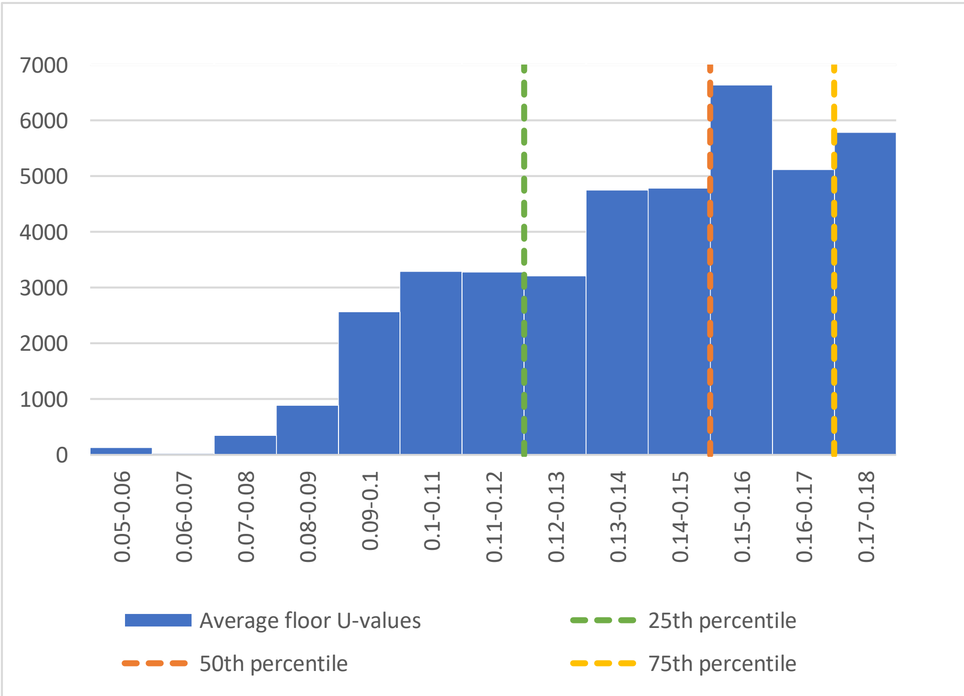
buildings improve upon the current notional building values and this has been used to inform U-value proposals in section 1.10.2.

Figure 1.7a: External wall U-value distribution in EPC database extract



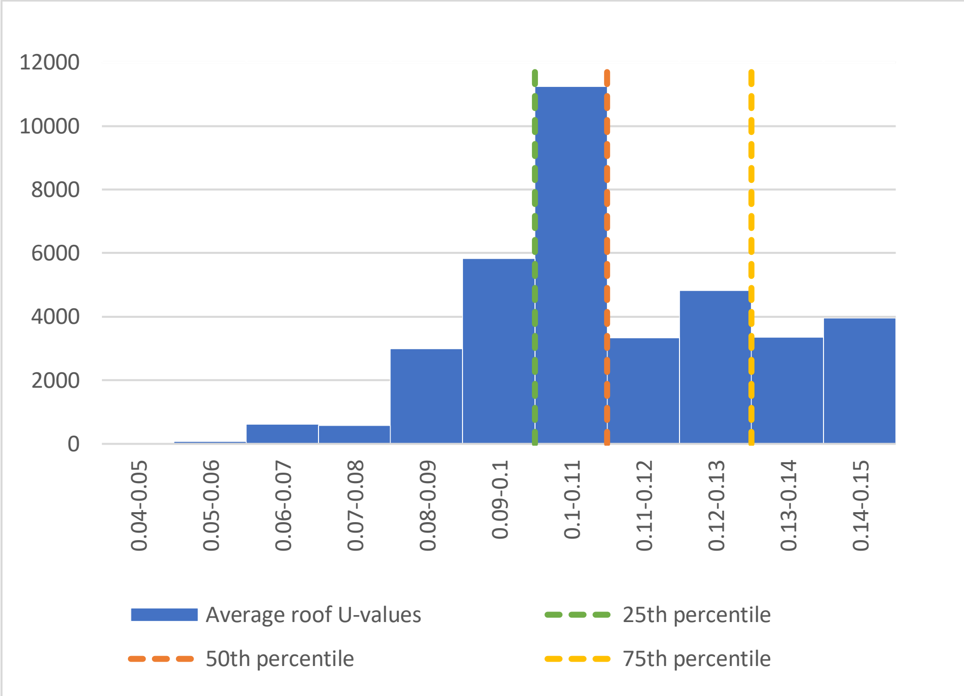
Source AECOM analysis of *EPC database extract 2016-18 SAP new build* (provided by Scottish Government, December 2019)

Figure 1.7b: Floor U-value distribution in EPC database extract



Source AECOM analysis of *EPC database extract 2016-18 SAP new build* (provided by Scottish Government, December 2019)

Figure 1.7c: Roof U-value distribution in EPC database extract



Source AECOM analysis of *EPC database extract 2016-18 SAP new build* (provided by Scottish Government, December 2019)

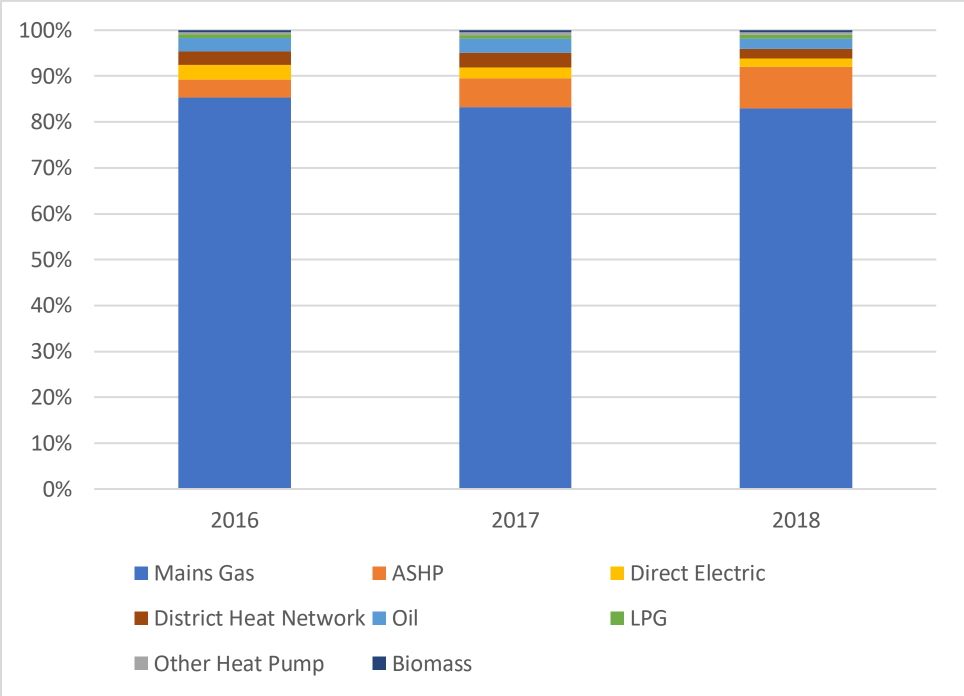
Table 1.7a: EPC database extract 10th, 25th and 50th percentile U-values for main fabric elements, compared to 2015 notional building specification

Element	2015 Notional	10th percentile	25th percentile	50th percentile
Wall (W/m^2K)	0.17	0.15	0.17	0.19
Floor (W/m^2K)	0.15	0.11	0.12	0.15
Roof (W/m^2K)	0.11	0.09	0.10	0.11

Source AECOM analysis of *EPC database extract 2016-18 SAP new build* (provided by Scottish Government, December 2019)

96. Heating trends show little variation by heating type by registration year; the exception being the proportion of dwellings with ASHP which increased from 4% of dwellings in 2016 to 9% in 2018 (this was offset by slight decreases in the proportions of mains gas-heated, direct electric-heated, oil-heated homes and homes connected to district heat networks). This is shown in Figure 1.7d.

Figure 1.7d: Heating type trends by registration year in EPC database extract

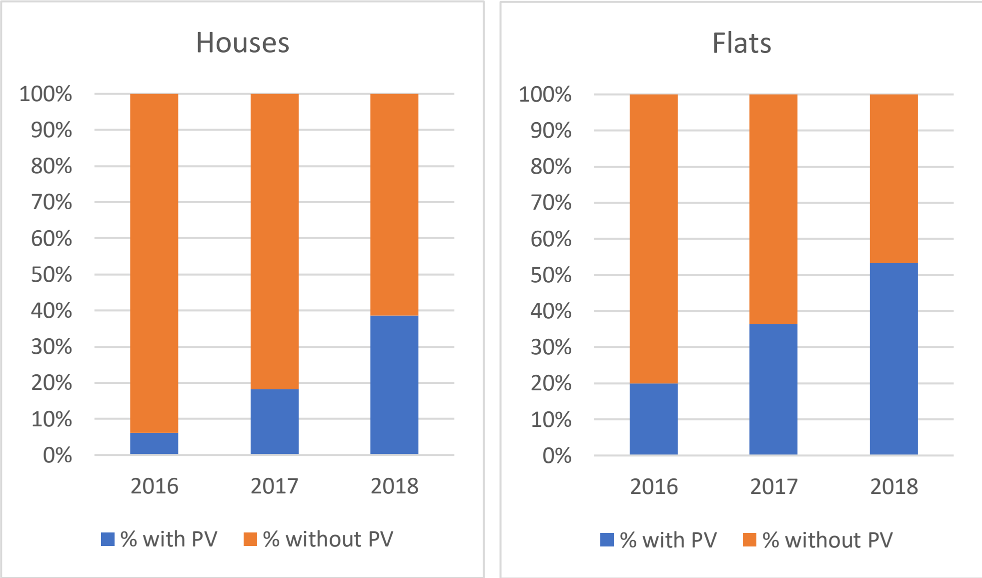


Source AECOM analysis of *EPC database extract 2016-18 SAP new build* (provided by Scottish Government, December 2019)

97. Trends in solar PV installations have already been discussed under section 1.5.6 and do suggest a clear change, likely linked to the increase in 2015 Building Standards-compliant dwellings over the period. As shown in Figure 1.7e, it was found that the proportions of dwellings with PV installed in each registration year increased significantly between 2016 and 2018 – from around 20% to 50% for flats, and from around 5% to 40% for houses.

98. In terms of array size, Table 1.5i showed the median and interquartile ranges for different dwelling types (not taking into account floor area variation). Typically the median values were close to those in the 2015 gas-heated notional building, with the median values for detached houses being higher and median values for flats being lower, though this is likely to relate to variation in the sizes of dwellings with PV installed within the dwelling type categories. It is not possible to draw strong conclusions from the data in terms of the feasibility or cost-effectiveness of larger array sizes, as sizes are likely to be significantly influenced (i.e. limited) by the targets set in the notional building.

Figure 1.7e: PV trends by registration year in EPC database extract



Source AECOM analysis of *EPC database extract 2016-18 SAP new build* (provided by Scottish Government, December 2019)

1.7.2 Review of consultation responses

99. In June 2018 the Scottish Government conducted a consultation calling for evidence on 2015 energy standards for new buildings, with the aim of informing future standards (Scottish Government, 2018). It should be noted that specific questions were not posed in the consultation, though some examples of possible topic areas were provided. There were 41 published responses to the consultation, and these have been reviewed for particularly relevant information which might inform improved specifications for 2021 Building Standards. As might be expected, responses tended to provide broad indications of support for – or commentary on the advantages and/or disadvantages of – different strategies (e.g. pushing fabric, installing renewables, approaches to target-setting), rather than detailed input on specific suggested performance values for different elements of future notional buildings. It should be noted that the review did not aim to provide an exhaustive summary of responses. Key points are summarised below, covering fabric, ventilation, low and zero carbon technologies, other heating technologies, and overall standard setting.

100. In terms of fabric specifications, several responses gave support for pushing fabric further than current. Advantages noted included their longevity compared to services and low and zero carbon technologies. Several other responses indicated support for fabric improvements but also raised potential issues or limitations including approaching cost-benefit thresholds; potential health impacts relating to indoor air quality, overheating and condensation/damp; the need to consider and provide guidance on the impact of reduced U-values on thermal bridging/construction details; and similarly to address their interrelation with airtightness standards. Other relevant comments included a suggestion that fabric standards should be comparable with those in Europe , though detail was not provided on what this might mean. One response provided an indication of where developers may most commonly be incurring costs from pushing specifications beyond current notional building standards: walls, roofs and floors, and triple glazing (and also MVHR on the ventilation side).

101. Comments relating to ventilation were less common, and mostly related to concerns with ventilation/compliance strategies or the details of how standards are implemented. These included concerns that: developers are currently sometimes using inappropriately low airtightness rates to avoid installing low and zero carbon technologies,[11] that airtightness tests should be required for all properties (i.e. the use of a SAP default should be removed) to avoid inappropriate ventilation strategies in practice, that airtightness rates/ventilation strategies are currently leading to damp/mould issues. One respondent commented on disadvantages of mechanical ventilation systems, raising issues of embodied carbon impact, increased electricity use, maintenance, and use in practice.

102. There were many comments on low and zero carbon technologies. These included particular support for their inclusion in future standards from several. Respondents sometimes indicated broad support for a range of technologies whereas others were especially supportive of particular ones. Advantages noted included the role of new building installations in developing the wider supply chain (with implications for improved quality and reduced costs), increasing occupant familiarity with technologies; and in the case of solar PV its cost-effectiveness, the potential to adjust the notional building to take advantage of the economies of scale of larger array sizes by maximising use of available roof space, and benefits to occupants in terms of energy bill savings[12].

103. Potential disadvantages of or issues with low and zero carbon technologies were also raised in many responses. Costs to the consumer were highlighted including capital costs (passed on to occupants), operational and maintenance costs with some noting particular concerns for maintenance costs of some technologies in rural locations. Many of the responses also raised concerns about constraints on the electricity grid; particularly in relation to PV but also in relation to heat pumps. Such concerns also apply to some other technologies, especially direct electric heating.

104. Specifics of these concerns included: particular constraints on the grid in rural and island locations, and affecting large areas overall – though one respondent noted that the impact was greatest on commercial projects, with some respondents suggesting that PV systems are regularly having to earth generated electricity to protect the grid. One respondent suggested that PV requirements should not be increased until the electricity network had been upgraded.

105. Several other respondents however proposed mitigating measures. The potential benefits of PV in electricity system balancing and stabilisation were also commented on, particularly where combined with battery storage and the increased uptake of

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[11] Note that in SAP 10.1 it is proposed that energy savings from increased airtightness in naturally ventilated buildings are now no longer assumed to accrue below air permeability rates of $3m^3/m^2/h$; this change formed part of the England Part F 2020 consultation.

[12] To help ensure these benefits to occupants are realised, a respondent suggested that “new build flats solar installations could be connected to individual flats to ensure that generation could be consumed locally instead of being exported back to the grid to benefit of the landlord.“

electric vehicles.[13] Support for electrical battery storage and better alignment of generation with use to reduce impacts on the grid was also expressed by other respondents. Suggestions included incentives or requirements for storage within SAP/Building Standards, and introducing the ability to reflect time of use of electricity within SAP. The need to improve alignment between Building Standards with Planning was suggested by one respondent. Another noted a need to build upon existing work with Distribution Network Operators to accurately identify and calculate grid constraints, review network upgrades and allow flexibility for embedded generation; and the potential to use export limiters where needed as a temporary measure until longer term solutions were found . For electric heating, one respondent suggested that minimum efficiencies should be specified (>100%) to mitigate impacts on the grid and avoid wasting electricity now that electricity carbon emission factors are so low, as is currently done in Norway.

106. Other concerns specifically about PV were raised by some respondents including lack of roofspace with optimum orientation – particularly for flats, inverter replacement frequency, and its embodied carbon impact. Other concerns specifically about heat pumps were raised by some respondents including the need for training, operational complexity, maintenance issues, performance in very cold weather, and longevity and performance particularly in island locations exposed to sea water.

107. Support for direct electric heating was specifically expressed by one of these respondents, who noted lower capital costs and complexity and increased longevity compared to heat pumps, and the low carbon emission factors for electricity in Scotland and particularly on some islands. Support for electric heating was given by another respondent too. Some respondents suggested that heat pumps were being/might be replaced at a later date with lower efficiency alternatives and it was noted that there is no provision to stop this happening. Other responses raised concerns with direct electric heating; including disbenefits for consumers in terms of energy costs/inefficiency and impacts on the grid.

108. Other comments relating to heating systems included concerns about biomass such as lack of skilled installers and maintenance teams, and costs of maintenance particularly in rural locations – noting that 2015 Building Standards encouraged biomass in such locations. One respondent also questioned the performance of waste water heat recovery systems (WWHR), stating that it needs very low flow rates to work. Another noted support for futureproofing if/where low carbon heating is not included in developments.

109. Overall standard setting was commented on in many of the responses. It should be noted that the introduction of primary energy as a target metric was not mentioned in the Scottish Government’s consultation document, and so was not mentioned in the responses. Additionally, whilst a range of information gathered from responses relating to standard setting has been included here, consideration of some of the approaches proposed (for example consideration of allowable solutions; potential targets other than primary energy, carbon emissions or performance target modifiers for energy efficient

[13] A respondent suggested that “As electricity demands increase [e.g. due to EVs], new homes must be capable of generating a minimum of 30% of their consumption if not as much energy as they use.”

design relating to built form; other changes outside of defining the Section 6 notional building) is outside of the scope of AECOM's current work and so would need to be considered separately by Scottish Government.

110. Several of the responses included support for setting targets based on energy consumption – with suggestions of basing this on net consumption recognizing the contribution of renewables or on energy efficiency.[14] Consideration of the impact of built form on energy efficiency within Section 6 was also recommended by a couple of respondents. Another specifically noted that targeting Section 7 Gold Aspect 2 instead of Silver Aspect 2 (maximum annual space heating demand for houses/flats of 30/20 kWh/m²/yr instead of 40/30 kWh/m²/yr) had been reported as being challenging based on current construction methodologies and requiring a change in mainstream techniques.

111. Some of the responses called for the use of Passive House standards, either introduced in part/in a staged approach (e.g. QA, airtightness requirements, space heating requirements) or as exemplar standards or alternative compliance routes – one respondent noted that extra-over costs of building to Passive House standards are estimated at between 0%-10% as a proportion of build costs.

112. In terms of the maximum values for different elements specified in Section 6 Table 6.3, limited comments were made. One respondent noted that the values were generally strong but suggested that reducing the U-value for cavity party walls to zero (instead of 0.20 W/m²K) would be an effective and low-cost change. Various responses also indicated that the airtightness value (of 15 m³/m².h@50Pa) was no longer appropriate.

113. Support for retaining carbon as a metric was expressed by several respondents, with some of these expressing support for a zero/net zero carbon target in the near term but with the need for clarity on timescales and careful implementation noted; and one suggesting that a target equivalent to Section 7 Gold Standard (i.e. a 27% improvement over 2015 standards[15]) should be considered. There was support for review and use of the Silver/Gold system from other respondents too – though this extends beyond carbon targets alone. Some respondents noted concerns with the changes to the carbon emission factor for electricity and its impact on certain technologies (reduced PV attractiveness, increased direct electric attractiveness), with the need for mitigating measures/supplementary targets suggested.

114. In relation to zero carbon targets, support for allowable solutions was specifically noted by one respondent, opposition noted by another, and qualified support from another (i.e. if their overall contribution was limited and depending on the use of funds).

115. Various comments were also made relating to the performance gap, including: the difficulty of checking/verifying SAP assessments, the need for encouragement for quality assurance, and for measuring and reporting real energy and carbon performance.

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[14] One respondent additionally noted that the 2015 notional building fabric standards are similar to the 'full FEES' scenario previously proposed by the Zero Carbon Hub.

[15] Note that currently this reduction is calculated based on SAP 2012 carbon emission factors.

116. In terms of more general comments on the development and implementation of standards, one respondent in particular noted concerns with increased costs of future standards (including differences from other UK administrations and impacts on smaller developers) and suggested that wider measures would be needed to help mitigate these (e.g. consideration of the other recommendations in the Sullivan Report; clarity on and alignment with related policies and strategies e.g. for heat decarbonisation, training, business support; changes to planning authorities' abilities to set targets beyond Building Standards). This respondent also called for clarity on the timing and definition of future standards – a point echoed by others. Other comments were made relating to the need for holistic review of standards (e.g. Section 7, consideration of thermal comfort, flood resilience etc.) and to the need to carefully assess deliverability.

1.7.3 Review of England and Wales Part L 2020 proposals

England and Wales have both recently held consultations on proposed changes to Part L1A (their equivalent of Section 6 standards for new dwellings) which are due to come into effect in 2020. Details of these will be considered when shortlisting potential specifications for 2021 standards in Scotland, if and where appropriate. The key specifications proposed for their notional buildings (preferred options) are summarised in Table 1.7b. Table 1.7bTable 1.7b: Part L 2020 consultation preferred options for notional building specification – England and Wales, compared to Scotland 2015 gas notional building

Element	Scotland 2015 notional building (gas)	England Part L 2020 consultation preferred option	Wales Part L 2020 consultation preferred option
External Wall U-value (W/m^{2}K)	0.17	0.18	0.13
Corridor Wall U-value (W/m^{2}K)	0.17	0.18	0.18
Party Wall U-value (W/m^{2}K)	0.0	0.0	0.0
Roof U-value (W/m^{2}K)	0.11	0.11	0.11
Floor U-value (W/m^{2}K)	0.15	0.13	0.11
Window U-value (W/m^{2}K)	1.4	1.2	1.3
Window g-value	0.63	0.63	0.63
Door U-value (W/m^{2}K)	1.4	1.0	1.0
y-value (W/m^{2}K)	0.08	Based on SAP 10.1 Appendix R (option 2 column; values unchanged from SAP 9.92)	Based on SAP 10.1 Appendix R (option 2 column; values unchanged from SAP 9.92)
Ventilation type	Intermittent extract fans with trickle vents	Intermittent extract fans with trickle vents	Intermittent extract fans with trickle vents
Air permeability rate (m^3/m^2.h @50Pa)	7	5	5
Space heating source	Condensing gas boiler	Condensing gas boiler	Condensing gas boiler
Domestic hot water source	As for space heating	As for space heating	As for space heating
Boiler efficiency	89.0% (SEDBUK)	89.5% (SEDBUK)	89.5% (SEDBUK)
Heat emitters	Standard radiators	Large (low temp) radiators	Large (low temp) radiators
Space heating controls	Time and temp control, weather compensation, interlock, delayed start	ErP Class V, time and temp control, interlock	ErP Class V, time and temp control, interlock
Hot Water Controls / insulation (where applicable)	Cylinder thermostat, separate timer, fully insulated primary pipework	Cylinder thermostat, separate timer, fully insulated primary pipework	Cylinder thermostat, separate timer, fully insulated primary pipework
Shower flow rate (l/min)	n/a	8	8

WWHR	Efficiency of 36% 2 showers if TFA>100m^2, otherwise 1 shower	Efficiency of 36% Utilisation of 0.98 Connected to all showers	Efficiency of 55% Utilisation of 0.98 Connected to all showers
Fixed lighting capacity (lm)	n/a	185 x TFA	185 x TFA
Lighting efficacy (lm/W)	n/a	80	80
PV installation	kWp equivalent to 1% of total floor area; 8.3 m²/kWp assumed for calculating roof area limit	Area equivalent to 40% of building foundation area; 6.5 m²/kWp assumed	Area equivalent to 40% of building foundation area; 6.5 m²/kWp assumed

Notes Further details are provided in SAP 10.1 Appendix R (BRE, 2019).
Low temperature radiators (and associated low boiler flow temperatures) can be seen as a future-proofing measure.
For PV, there are some minor differences in other assumptions compared to the Scotland 2015 notional building e.g. roof pitch.

Source MHCLG, The Future Homes Standard, 2019 Consultation on changes to Part L and Part F (MHCLG, 2019f)
BRE, SAP 10.1 Appendix R (BRE, 2019)
Welsh Government, Consultation Document, Building Regulations Part L and F Review (Annex A) (Welsh Government, 2019b)

117. It can be seen that in some areas the proposed specifications go beyond the equivalent notional building 2015 standards in Scotland to varying degrees – including external wall U-values (Wales only), floor U-values, window U-values, thermal bridging, air permeability rates, boiler efficiency, boiler flow temperatures, WWHR efficiency (Wales only), and PV array sizes.

118. Both consultations note that heat pumps would provide alternative compliance options in 2020, and that the next iterations of standards in 2025 would be expected to be based upon low carbon heating; which is anticipated to be typically delivered using heat pumps and/or heat networks (as well as possibly direct electric heating in some circumstances). They also note that 2025 standards would be expected to include higher fabric standards (in particular noting that triple glazing is likely to be part of specifications).

119. Whilst reviewing the backstop values is outside of AECOM's scope, it is recommended that that the Scottish Government carefully considers the minimum energy efficiency standards for the individual building fabric and building services elements. This is likely to be particularly important if the 2021 notional building is based on gas, as in this case where low carbon/primary energy heating is specified by developers, it can be that the design solution significantly improves upon the notional building target. This potentially allows significantly poorer fabric and service efficiencies to be adopted.

1.7.4 Review of research informing 2015 standards

120. Work was undertaken on behalf of the Scottish Government in 2011 and 2012 to inform proposals for 2015 domestic Building Standards. Whilst a summary of all of this research is not considered necessary, there are some points which may provide useful context for future standards. As the 2012 report built upon the 2011 research, only the 2012 report has been focused on here.

121. The 2012 report was based on modelling for 14 dwelling types, primarily testing both gas and electric (ASHP) heating specifications to meet 2010 standards and how these might change to meet potential future carbon targets (45% reduction over 2007 standards, or 60%). Overall in their central cost benefit scenario the improvements resulted in net costs (with only the improvements to electrically heated dwellings showing a significant net benefit).[16]

122. The report also considered the impact of including a 'useful energy for space heating' target of 40 kWh/m^2/yr for houses and 30kWh/m^2/yr for flats, finding that applying this would lead to increases in capital costs but to more efficient fabric, as would be expected. The report noted that it would serve a similar function to backstops but would also account for the energy efficiency of the built form (e.g. ratio of floor area to exposed surface area; window orientation). This target is included as an optional standard under Section 7 (Aspect Silver level 2) but was not taken forwards as part of 2015 consultation proposals.

123. The Scottish Government's consultation report on the 2015 proposed changes (Scottish Government, 2014) provides more useful context. It shows that there was support from a majority of the consultation respondents for the following key domestic proposals (percentages agreeing with shown, with a total of around 80 respondents per question): inclusion of low carbon equipment for electricity and biomass packages (58%); addition of PV for gas, LPG and oil packages (56%); introduction of waste water heat recovery for all packages (58%); improvement to U-values (69.7%). Whilst it should be recognised that these responses were provided prior to implementation of the standards, they provide some background for future changes.

1.7.5 Review of UK cost-optimal report

124. In 2019 a report by AECOM and Currie & Brown was published by MHCLG providing the second cost optimal assessment of energy performance requirements for the United Kingdom, based on analysis undertaken in 2016 (MHCLG, 2019c). The report compares to relative lifecycle-cost-effectiveness of packages of measures to reduce the primary energy in new domestic buildings, based on a semi-detached house and a block of flats – using similar dwelling typologies to those in the current analysis. Elemental values were not separately assessed for new buildings. Macroeconomic costs were assessed with central energy prices, at a 3.5% discount rate and over a 30-year period in the central analysis scenario. An example graph is shown in Figure 1.7f. The cost-optimal point was chosen as being at the base of the curve where lifecycle costs and primary energy were plotted. It can be seen however that there are solutions available with lower primary energy and relatively small increases in lifecycle costs.

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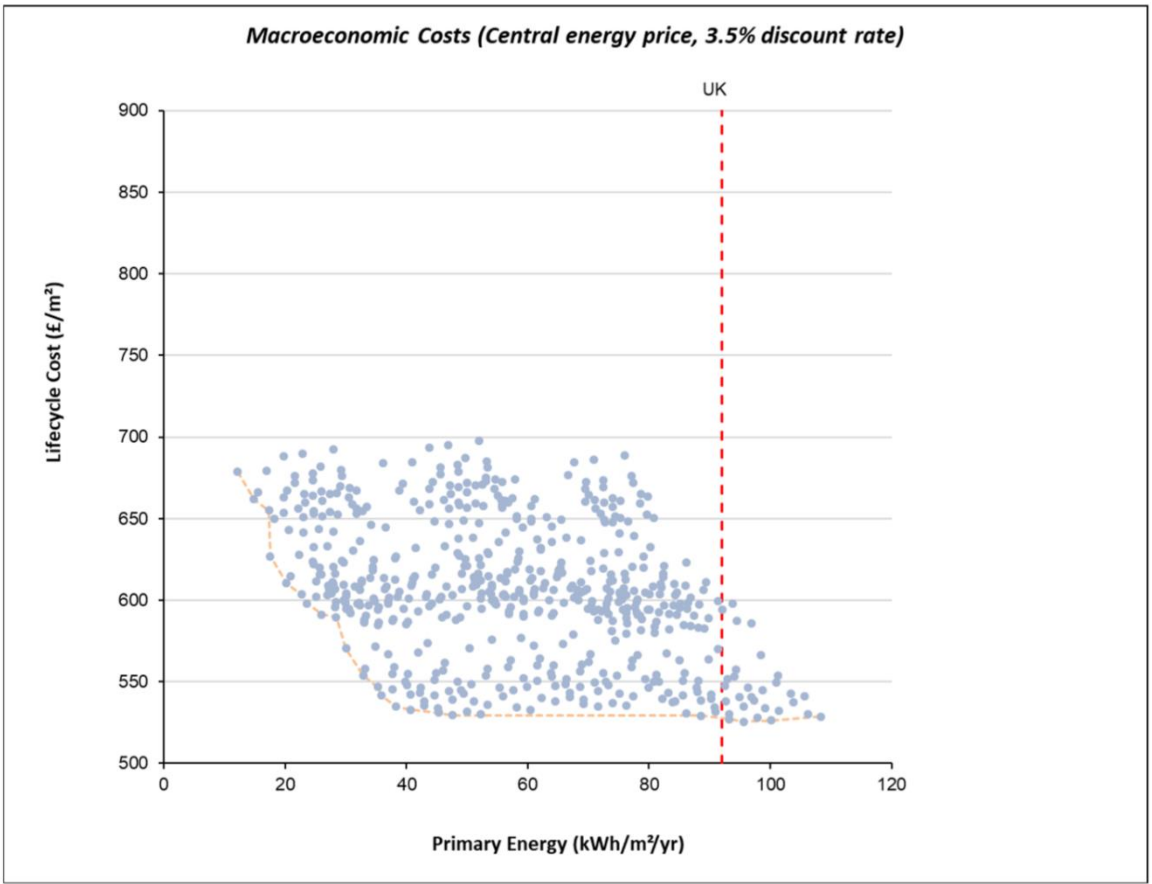
[16] It should be noted however that the specifications modelled for the 45% reduction scenario were significantly different from those in the 2015 notional building (and in the 2015 compliant buildings used for the current research); for example typically including MVHR, with solar thermal in some cases, and improved thermal bridging – PV was usually only added/substituted for solar thermal in the 60% reduction cases. It is unclear from the report why MVHR was specified in preference to PV, for example, though the report refers to providing "typical cost-effective example[s]" of improvement specifications; this perhaps relates to different ways of defining cost-effectiveness.

Figure 1.7f: UK cost-optimal analysis results for a semi-detached house



Source MHCLG, UK cost-optimal report, Figure 6.1a (MHCLG, 2019c).

125. The headline finding from the report was that dwelling in Scotland at 2015 standards (based on the notional building specification for gas-heated dwellings) were assessed as being beyond cost-optimal levels. Semi-detached houses were estimated to have primary energy levels of 74 kWh/m^2/yr, and flats 71 kWh/m^2/yr, compared to estimated cost-optimal levels of 96 kWh/m^2/yr for houses, 77 kWh/m^2/yr for flats.

126. The report included tables summarising various solutions which appeared along the bottom of the cost-optimal curves, i.e. had relatively low lifecycle costs for the level of primary energy modelled (see the example cost-optimal curve shown in Figure 1.7f). This included several solutions found to have a lower primary energy than 2015 standards – these have been shown in Figure 1.7g, for the semi-detached house.

Figure 1.7g: Results of the UK cost calculations for the most cost-optimal packages, semi-detached house

Package						PE (KWh/m²/yr)	Initial Investment Cost	Annual Costs		Cost of Emissions	Residual Value	Macro Cost
Fabric	Opening	TB	Vent	Heating	PV			Maintenance	Energy			
Wall 0.12	Triple	Advanced	MVHR	Gas + SHW	40%	12	699	56	3	3	-83	679
Wall 0.18	Triple	Advanced	MVHR	Gas + SHW	40%	17	667	56	6	4	-77	655
Wall 0.21	Double	Advanced	MVHR	Gas + WWHR	40%	28	587	56	8	5	-66	590
Wall 0.18	Triple	Advanced	NV	Gas + WWHR	40%	35	566	33	8	7	-67	547
Wall 0.21	Double	Advanced	NV	Gas + WWHR	40%	41	549	33	10	7	-66	533
Wall 0.21	Double	Advanced	NV	Gas	40%	48	541	33	13	8	-65	529
Wall 0.21	Double	Advanced	NV	Gas + WWHR	0%	89	512	33	42	9	-66	529
Wall 0.18	Double	Advanced	NV	Gas	0%	93	507	33	44	9	-66	527
Wall 0.21	Double	Advanced	NV	Gas	0%	96	504	33	45	9	-65	526
Wall 0.21	Double	Default	NV	Gas	0%	108	499	33	50	11	-65	529

Source MHCLG, UK cost-optimal report, Table 5.12a (MHCLG, 2019c).

Notes Costs are shown on a per square metre of floor area basis.

The green box shows cost-optimal solutions with primary energy below current standards, as modelled in the report.

The orange box shows the cost-optimal solution chosen as being at the lowest point of the curve.

127. Various comparisons can be made using the data in Figure 1.7g (and similar findings could be seen looking at the flat dwelling type). For example:

- Solutions which were modelled as having lower primary energy than current standards typically include fabric packages with wall U-values around current notional building levels.
- Going down to the 0.12 wall U-value package – which also includes a floor U-value of 0.10 compared to 0.15 in most other packages – involves a leap in lifecycle cost and capital cost (this can be seen by comparing the top two rows: the difference in macroeconomic cost per square metre is around £24; the difference in initial investment cost per square metre is around £32; the difference in primary energy is around 5kWh/m^2/yr).
- Triple glazing also appears to involve a leap in lifecycle cost and capital cost (this can be seen by comparing the fourth and fifth rows: the difference in macroeconomic cost per square metre is around £13; the difference in initial investment cost per square metre is around £14; the difference in primary energy is around 3kWh/m^2/yr. These cases also have a change in fabric package, but this can be seen elsewhere to have a limited impact – comparing the row highlighted in orange with the one above it – and these costs/primary energy savings have been subtracted off).
- WWHR is included in several solutions, and this involves a low increase in lifecycle cost and a relatively low increase in capital cost (this can be seen by comparing the row in the orange box with the row two above it; the difference in macroeconomic cost per square metre is around £3; the difference in initial investment cost per square metre is around £8; the difference in primary energy is around 7kWh/m^2/yr).
- MVHR is included at the lowest levels of primary energy; here there is a leap in lifecycle cost and capital cost (this can be seen by comparing the third and fifth rows; the difference in macroeconomic cost per square metre is around £57; the

difference in initial investment cost per square metre is around £38; the difference in primary energy is around 13kWh/m^2/yr).

- Solar thermal is included at the lowest levels of primary energy; this appears to involve a leap in lifecycle cost and capital cost for a relatively small saving in primary energy when compared to gas + waste water heat recovery (a direct comparison is not possible, but the increase can be approximated by comparing the second and fourth rows and subtracting out the difference for MVHR shown above; the resulting difference in macroeconomic cost per square metre is around £51; the difference in initial investment cost per square metre is around £63; the difference in primary energy is around 5kWh/m^2/yr).
- All solutions below current standards include PV at 40% of the building foundation area (PV areas are reduced where solar thermal is also installed), and this involves a low increase in lifecycle cost and a leap in capital cost for a significant reduction in primary energy (this can be seen by comparing the bottom row in the green box with the row in the orange box; the difference in macroeconomic cost per square metre is around £3; the difference in initial investment cost per square metre is around £37; the difference in primary energy is around 48kWh/m^2/yr but electricity factors have changed significantly since).
- Thermal bridging values are improved in all solutions shown above current standards.
- In the most improved case of all the solutions shown, the primary energy was reduced to 12kWh/m^2/yr. Higher figures were shown for the flat dwelling type, likely due to the relatively limited roof area available per flat.

128. It is however important to note that results would change with updated input assumptions. In particular, the primary energy factors for electricity in SAP 10.1 are significantly lower than those used in the cost-optimal analysis.[17] In addition, the costs of some measures may also have changed,[18] and the performance of some technologies may have improved. However the analysis provides some useful findings for potential future standards, particularly in terms of the cost impacts of different measures.

1.8 Review of risks relating to overheating and indoor air quality

129. A targeted review was undertaken to consider the potential increased risks associated with fabric improvements relating to poor indoor air quality/ventilation and summer overheating in new homes. AECOM recently undertook work on these topics to inform the consultation on Part L 2020 in England, and reports summarising this research were published as part of the consultation package (MHCLG, 2019g; MHCLG, 2019d; MHCLG, 2019e).

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[17] This will particularly affect heat pumps, and also solar PV. For PV savings in primary energy for the same packages would be reduced due to the lower factors, in particular depending on assumptions about grid export/use of generated energy on-site. For heat pumps, overall primary energy would significantly reduce due to the lower factors.

[18] This might particularly affect technologies which have historically been less commonly specified, though learning rates were applied in the analysis.

1.8.1 Indoor air quality risks

130. The 2019 report on ventilation and indoor air quality was based on various levels of inspection/monitoring of 80 new build homes in England with design airtightness values of under $7m^3/m^2$.h@50Pa, designed to England Part F 2010 and Part L 2010/2013 standards (25 with dMEV and 55 naturally ventilated).[19] The research found that only three of these homes met the minimum recommendations in England's Approved Document F relating to extract fan flow rates and trickle ventilator provision, despite testing and commissioning requirements. Poor indoor air quality was found in a number of the homes. In these cases the minimum ventilation provisions recommended in Approved Document F were not being met in practice, and it was suggested that this would explain some of the issues found. Concerns were also raised about whether the recommendations themselves provide sufficient fresh air in naturally ventilated bedrooms e.g. trickle ventilators being hidden when curtains were closed[20]. Some concerns were also raised in the report about noise impacting on the use of ventilation systems and subsequently reducing ventilation rates – including some residents reporting that they turned off extract fans due to their noise, and some that they closed trickle vents due to external noise.

131. The research has informed changes proposed to Approved Documents F and L in England in MHCLG's consultation (MHCLG, 2019f). In particular, in relation to Part L, the consultation proposes not accruing energy savings in SAP for improving the airtightness in naturally ventilated dwellings beyond $3m^3/m^2$.h (defined as 'highly airtight' homes) to reduce the risk of insufficient natural ventilation in airtight properties. It is also noted that MHCLG has not included mechanical ventilation in the consulted notional building options. In relation to Part F, in the case of natural ventilation the consultation proposes setting guidance for the size of background ventilators on a per room (rather than per house) basis, and only providing guidance for less airtight homes.[21] In the case of continuous mechanical extract ventilation, the proposals also include recommending background ventilators in more airtight dwellings. In terms of airtightness testing, it is proposed to report results in SAP to the nearest $0.5m^3/m^2$.h to account for uncertainty, to require all properties to be tested and to revise the testing methodology.

132. A study commissioned by Scottish Government in 2014 looked at the impact of occupant behaviour in naturally ventilated homes, based on a survey of 200 homes and monitoring of a sample of 40 of these homes, alongside analysis of other monitoring undertaken as part of the TSB's Building Performance Evaluation programme (Sharpe et al., 2014). This followed previous research which looked at the impact of increased airtightness on indoor air quality and concluded that the guidance in Scotland's Domestic Technical Handbook on Standard 3.14 relating to natural ventilation was fit for

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[19] Homes were selected for monitoring only where they most closely approached meeting Part F 2010 guidance.

[20] It was noted that this issue would be expected to increase as buildings become more airtight, reducing general infiltration and increasing reliance on trickle ventilation.

[21] This is intended to reflect that for more airtight homes the design, sizing and positioning of ventilators is more critical and that suitable expert advice should be obtained instead.

purpose at airtightness levels of 5m^3/m^2.h@50Pa or above; but based on the assumption that trickle ventilators (and internal doors) would all be open (BRE, 2011).

133. The 2014 study found that in practice trickle vents are infrequently adjusted by occupants with the majority being left closed, and suggested that the main driver was generally thermal comfort (i.e. avoiding heat loss, rather than providing fresh air and enabling control of moisture and pollutants). The impacts of closed trickle vents included low ventilation rates (evidenced here by monitored CO_2 levels), but issues were also found in dwellings were trickle vents were left open.

134. The 2014 study helped to inform changes to ventilation requirements within the Domestic Technical Handbook in 2015, which included the introduction of a requirement for carbon dioxide monitors to main bedrooms in new homes with an airtightness level below 15m^3/m^2.h@50Pa, and changes to the calculation of required trickle ventilation areas which increased their provision in practice.

135. A further recent report commissioned by Scottish Government considered the effectiveness of dMEV in providing whole-house ventilation in the context of increasing airtightness, based on a study of 223 new homes with airtightness levels between 3 and 5m^3/m^2.h@50Pa (Sharpe, et al., 2018). It found poor overnight ventilation in over 50% of homes (citing a variety of contributing factors), and that around 40-50% of installed systems were sub-optimal or non-compliant. It concluded that the evidence suggested that "whilst there are some situations where a dMEV system can assist with the ventilation provision of modern airtight homes, the ability to act as a whole house system is limited, particularly in larger more complex layouts, and where ventilation loads are high" (p.5).

136. Whilst the reports were written in the context of upcoming improvements to energy standards for dwellings, neither specifically looked in detail at potential future changes to fabric design and the potential impacts on indoor air quality. However as problems were found with homes built to iterations of energy standards below 2015 levels it is reasonable to expect many of these issues may become more problematic in the future unless addressed – the 2019 report in particular noted an expected increased reliance on background ventilators as general infiltration is reduced. The reports focused on improvements relating to ventilation guidance and testing rather than recommending any limits on fabric performance.[22] As such it is suggested that this information is considered under any separate review of ventilation requirements which may be undertaken.

137. Points most relevant to the current work include proposals on limiting energy savings airtightness in naturally ventilated homes in SAP; it is suggested that the Scottish Government consider these. Other proposals in the English consultation relevant to Part F could also be considered as these may help to mitigate unintended consequences of more airtight dwellings.

[22] This is somewhat similar to a recent report for Scottish Government which noted the risks of increased airtightness impacting adversely on indoor air quality, but referenced research suggesting that better and correctly used ventilation should mitigate these risks (Aether, 2017).

138. In terms of informing the notional building specification in 2021, the research suggests that there are potential risks associated with any ventilation system type, in terms of design, construction, installation, commissioning and operation. Wider work would be needed to address these. AECOM's proposals for the airtightness specification in the 2021 notional building will take into account the 'highly airtight' definition in the consultation version of England's Approved Document F (design air permeability rates lower than $5m^3/m^2$.h@50Pa; or as-built air permeability rates lower than $3m^3/m^2$.h@50Pa) (MHCLG, 2019a), with a value of $5m^3/m^2$.h@50Pa proposed if and where a natural ventilation strategy is assumed and a value of $3m^3/m^2$.h@50Pa if and where MVHR is assumed.

1.8.2 Summer overheating risks

139. The 2019 research on overheating in new homes included a phase 1 report focusing on better understanding the dwellings most at risk, based on dynamic modelling and different dwelling types and locations in England and on the CIBSE TM59 definition of overheating (MHCLG, 2019d; CIBSE, 2017).

140. The dwelling types assessed included different built forms (detached/semi-detached/terrace/flat), sizes (large/small flat, mid-rise/high-rise), aspects (dual/single for flats), ventilation strategies (natural ventilation/MEV – MVHR was not analysed), heating systems (individual gas boiler/communal) and construction types (masonry for houses, concrete-/steel-frame for mid-/high-rise flats – so not including timber frame, but with low thermal mass assumed), all compliant with England Part L 2013 (with fabric specifications generally similar to the England Part L 2013 notional building). The core analysis made various assumptions, including: all living rooms facing south, continuous occupancy, unrestricted window opening, and no external shading or internal blinds/curtains (the latter were looked at in phase 2 of the work).

141. The study found that all dwellings modelled failed to comply with the CIBSE TM59 criteria, with higher risks for flats, and greatest risks in London locations. Results were found to be sensitive to orientation (with West-facing living rooms performing worse), flat location in block (with ground-floor flats performing worse due to lower wind speeds and ventilation rates; in practice window-opening restrictions would also have an impact),[23] window opening behaviours (including restrictions on opening), and weather data – with the last two variables being particularly significant. Fabric infiltration rates were not found to affect the results significantly.

142. The phase 2 report assessed the costs and benefits of different overheating risk mitigation strategies for different building types and locations, including modifications to building design (but also occupant behaviour). Further dynamic modelling was undertaken to assess the most cost-effective package for each scenario, from five graded options which all prioritised passive measures, to reduce overheating risks to comply with CIBSE TM59. Costs included capital, replacement, and energy costs and the cost of carbon. Quantified benefits included reduced mortality and improved mortality.

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[23] On the other hand, other research has also highlighted mid- and top-floor flats as being particularly at risk where sufficient ventilation and protection from heating by the sun is lacking (Committee on Climate Change, 2017).

143. MHCLG has announced their intention to hold a consultation on overheating in new dwellings in early 2020, following which new overheating regulations and guidance will be produced and are expected to come into force in mid-late 2020 alongside revised Part L and Part F regulations (MHCLG, 2019f). It is noted that SAP is not set-up to assess compliance with the CIBSE TM59 criteria which requires dynamic thermal modelling.

144. Earlier research into low energy homes in Scotland (Morgan et al., 2015; Foster et al., 2016) has suggested that there is growing evidence of overheating already occurring in Scotland despite more severe climate projections being delayed compared to more southerly parts of the UK. The research focused on Building Performance Evaluation studies for 26 low energy new build homes in Scotland – including 5 Passive Houses – built under 2007 or 2010 standards, which already showed incidences of overheating. The homes were analysed based on Passive House criteria for overheating,[24] and under a third were found to overheat for less than 10% of the year, with over half of homes exceeding the threshold temperature for more than half the year. Findings suggested that design and occupancy factors had more of an impact than location or climate, but the authors noted the difficulty of identifying primary contributing factors or trends. However it was identified for example that none of the homes had external shading, that occupant understanding and control use was often poor, and a range of other factors such as uninsulated pipework were common. The prevalence and potential impact of lightweight timber construction was also noted; this has been associated with increased overheating risks in previous studies (Holmes & Hacker, 2007; Peacock, Jenkins, & Kane, 2010; Dengel & Swainson, 2012), and is particularly relevant for Scotland. The heat loss parameters (which relate to fabric and ventilation heat losses) were low (under 2.1W/m^{2}K) for all the dwellings but there was not a clear correlation with overheating – in fact the two homes with the highest heat loss parameters showed some of the worst levels of overheating.

145. There were not clear findings to suggest the Passive House homes performed worse or better compared to the others in terms of overheating, and the sample was quite small. It was observed however that there were issues with imbalanced MVHR systems and insufficient ventilation rates (affected by occupancy density) in most of the Passive House homes. The research cited an earlier study suggesting that installing external solar shading and adjusting glazing ratios could significantly contribute to mitigating future overheating risks in Passive Houses (McLeod et al., 2013), and noted that other simple passive design measures would also be helpful (e.g. provision of high level openings for purge ventilation, higher ceilings on upper floors).

146. This research into overheating in low energy buildings in Scotland was cited in a later report for Scottish Government looking at options for climate change mitigation in the built environment (Aether, 2017). This report concluded that further research is

[24] Mean internal temperature exceedance of 25°C for more than 10% of the year (based on annual rather than occupied hours), though a 4% limit is seen as preferable. It should be noted that findings on overheating using this check did not always correspond well with occupant feedback, which the authors suggest may relate to different occupant expectations relating to comfort.

necessary investigating the benefits of the Passive House approach and how to adapt it to Scotland's climate and culture.[25] A more recent report on climate change risks in UK housing by the Committee on Climate Change also noted that there are limited studies on overheating in Scotland more generally, implying that further research is needed (Committee on Climate Change, 2019b). It estimated that total heat-related deaths in Scotland may increase from around 40 per year to between 70 and 280 per year by the 2050s.[26]

147. In terms of implications for the notional building specification for 2021 in Scotland, whilst previous research has highlighted the increased overheating risks associated with higher levels of energy efficiency, it is unclear where thresholds are in terms of specific levels of fabric performance, nor whether these would have a significant impact if other factors were taken into account – for example if effective ventilation (especially at night-time) was possible. The MHCLG report also suggested that reduced fabric infiltration associated with more airtight homes would not necessarily have a significant impact on risk; ventilation from other sources is more significant. In addition, the level of risk found in the research, even in the north of England, should be different from equivalent modelling for dwellings in Scotland due to differences in climate.

148. The scope of the current research is focused on energy performance and is limited to SAP modelling, which only includes a relatively basic check on overheating risk. It is suggested that the Scottish Government may want to consider further the risks of overheating and how these may affect building specifications, and may wish to undertake more detailed modelling of proposed future standards to assess their overheating risk including in relation to current standards. The consultation on overheating in England should also be considered in terms of whether Scotland may wish to adopt similar changes.

1.9 Analysis of opportunities and constraints

149. A high-level analysis of the costs and savings of different improvement measures is provided in Table 1.9a. This analysis is based on SAP 10.1 modelling of the 2015 compliant specification for a semi-detached gas-heated home (as set out in section 0, adjusted for the various improvement measures) for primary energy and carbon emission savings, and on rough cost data and AECOM's experience for the capital cost analysis and commentary on energy cost savings, replacement and maintenance costs.[27]

150. Considerations of key opportunities and constraints drawn from this analysis and the review of evidence described in section 1.7 are summarised in Table 1.9b.

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[25] It also noted concerns with MHVR and cited research suggesting natural ventilation strategies may be preferable in terms of impact on both thermal comfort and indoor air quality.
[26] Cold-related winter deaths however are projected to continue to be more significant though on a downwards trend (Climate Exchange, 2016).
[27] It should be noted that savings would differ should an alternative baseline heating fuel/system be assumed. For example, if a more efficient heating system such as a heat pump was assumed, savings for energy efficiency measures would be relatively less – however such savings might be worth more in terms of energy costs per unit of energy saved (as electricity prices are higher than gas prices). There would also be a different profile in terms of primary energy/carbon emission savings due to different primary energy and carbon emission factors for different fuels. There are also interactions between some measures – for example fabric efficiency would impact on heat pump sizing and performance.

Table 1.9a: Costs and savings analysis table, comparisons to baseline 2015 compliant gas specification for semi-detached house

Specification element	Capex	PE saving	CO_2 saving	Energy consumption	Replacement and maintenance
Walls	Low – 0.15 Med – 0.13	Low	Low	Savings in space heating	-
Roof	Low – 0.09	Low	Low	Savings in space heating	-
Floor	Low – 0.13/0.11 Med – 0.09 (higher end)	Low	Low	Savings in space heating	-
Window	Med – 1.2 High – 0.8	Low – 1.2 Med – 0.8	Low – 1.2 Med – 0.8	Savings in space heating	Replacement costs (30yrs)
Door	Low – 1.0	Low	Low	Savings in space heating	Replacement costs (30yrs)
Thermal bridging	Low – 0.05	Low (but higher end)	Low (but higher end)	Savings in space heating	-
MVHR + improved airtightness	Med	High	High	Savings in space heating	Replacement costs (MVHR unit 20yrs) Maintenance costs (significant as annual)
PV	Med	High	High	Energy savings from generation – electricity	Replacement costs (15yrs inverters, 25yrs panels)
PV + battery	Very high (High if battery only)	High (Med if battery only)	High (None if battery only)	Battery allows greater onsite savings from generation – electricity	Replacement costs (as above plus 12yrs battery)
Low temp rads	Low	Low (but higher end)	Low (but higher end)	Savings in space heating	Replacement costs (20yrs)
WWHR	Low	Med	Med	Savings in water heating	Replacement costs (20yrs, but tray systems only)
Solar thermal	Very high	High	High	Savings in water heating	Replacement costs (panels 15yrs, separate cylinders 20yrs) Maintenance costs (significant as additional)
ASHP	High	Very high	Very high (higher percentage than PE)	Significant savings in space and water heating compared to direct electric. Also compared to baseline, but switch to higher cost electricity vs gas.	Replacement costs (ASHP 15yrs, separate cylinders 20yrs) Maintenance cost saving (as assumed lower than gas boiler)

Notes Capex is based on uplift from baseline gas compliant specification for a semi-detached house. Uplifts are classified as 'low' if less than around £500; 'medium' if around £500-£1500, 'high' if

around £1500-£2500, 'very high' if around £2500-£4000. Values included here for fabric elements show the U-values/y-values modelled.
PE and CO_2 savings are classified as 'low' if <5% compared to baseline of semi-detached house on gas, 'medium' if 5-10%, 'high' includes savings from 10-25%, 'very high' >50% (no options fall between these latter two categories).
Energy consumption – looking at the 'PE saving' column will give an idea of the scale of energy savings, though in cases of ASHP and PV this is also affected by different fuel type (with different primary energy factors and costs).
Savings calculated from PV (both with and without battery) currently include some savings from electricity exported to the grid. It has been suggested that these could potentially be excluded from calculations to incentivise battery storage, but the analysis here follows the SAP 10.1 approach.
Replacement and maintenance column provides notes on applicable costs (replacements over 60 year period; figures are blank if no replacement/maintenance costs expected during this time. Figures in brackets show estimated life expectancy for replacements – see capex column for an idea of the scale of costs).

Source AECOM analysis, with cost input from Currie & Brown.

Table 1.9b: Opportunities and constraints analysis table

Element	Opportunities	Constraints
Walls	• Fabric efficiency built into dwelling • No maintenance/replacement costs • Low-medium cost	• Costs appear to go up a bit more significantly below U-value of around 0.15 • Savings relatively low
Roof	• Fabric efficiency built into dwelling • No maintenance/replacement costs • Low cost	• Savings relatively low
Floor	• Fabric efficiency built into dwelling • No maintenance/replacement costs • Low cost options	• Costs appear to go up significantly below U-value of around 0.11 • Lower values harder to achieve for dwelling types with larger floor areas/perimeters • Savings relatively low
Window	• Fabric efficiency built into dwelling • No additional maintenance costs • Medium savings for triple glazing • Potential capital cost reductions in future	• Medium cost, high for triple glazing • Replacement costs • Savings relatively low for 1.2 U-value • Market readiness for move to triple glazing
Door	• Fabric efficiency built into dwelling • No additional maintenance costs • Low cost	• Savings relatively low
Thermal bridging	• Fabric efficiency built into dwelling • No maintenance/replacement costs • Low cost	• Common performance gap issue • Skills gaps
MVHR + improved airtightness	• High primary energy and carbon savings • Medium cost • Potential cost reductions in future	• Medium cost • Annual maintenance costs • Replacement costs • Common performance gap issue • Skills gaps • Possibly limits use of alternative ventilation systems if basis of notional
PV	• High primary energy and carbon savings • Medium cost • Significant energy (electricity) cost savings for occupants (where direct connections to dwelling)	• Medium cost • Constraints on electricity grid • Constraints on roofspace particularly for higher blocks of flats, constraints on orientation

Element	Opportunities	Constraints
	• Potential cost reductions in future • Current approach does not maximise use of roofspace / cost-effectiveness	• Modelled carbon and primary energy savings will reduce as grid decarbonises over time • Carbon and primary energy savings would also be reduced if proportion exported is excluded from calculations
PV + battery	• As above (except higher cost) • Alleviating impacts on electricity grid • Increased energy cost savings for occupants • Potential cost reductions in future	• As above (except higher cost) • High cost of batteries (initial and replacement) • Relatively low additional primary energy savings compared to cost • No additional carbon savings • Total cost savings not fully recognised (e.g. savings in terms of grid connection/reinforcement, potential for time of use tariffs etc.) • Market readiness would need consideration
Low temp rads	• Low cost • Future-proofing (for ASHP if gas-based notional)	• Change in common practice, potential skills gaps
WWHR	• Low cost • Medium primary energy and carbon savings • Potential cost reductions in future	• Apparently low uptake to date (based on EPC database) • Lower savings where tray systems used
Solar thermal	• High primary energy and carbon savings • Potential cost reductions in future	• High cost • Savings are in gas use so lower value for residents (compared to electricity) • Replacement costs • Additional maintenance costs • Limits on ability to connect flats particularly for higher blocks • Availability of roofspace – impacts on /relates to space for solar PV
ASHP	• Very high primary energy and carbon savings • Future-proofing as grid decarbonises further • Potential cost reductions in future	• High cost • Impacts on electricity grid • Availability of smaller heat pumps for very well-insulated dwellings • Market readiness for move to heat pumps • Skills gaps • Exposure issues for island locations • Limits on alternative compliance routes if basis of notional

Notes Comments in table are based on analysis in section 1.7 above.

1.10 Selection of 2021 notional buildings

1.10.1 2021 modelling specifications – introduction

151. The specifications used in the modelling of potential 2021 standards have been shown in sections 1.10.2 to 0, where fabric, ventilation, heating and PV are considered separately. The specifications take into account key findings in sections 1.7 to 1.9 above, considerations on heating options discussed in section 1.10.6, and feedback from Scottish Government on earlier draft proposals. Overall, the proposed specifications form four cases:

- Gas + improved fabric + natural ventilation + PV (‘Gas improved’)
- Gas + advanced fabric + MVHR + PV (‘Gas advanced’)
- ASHP + improved fabric + natural ventilation (‘ASHP improved’)
- ASHP + advanced fabric + MVHR (‘ASHP advanced’).

152. The intention was that these four modelled cases could be grouped into a smaller set of two or three options for the 2021 targets; either by defining notional buildings differentiated by fuel type or by selecting a single fuel notional building option which also allows compliance using other fuels – but without introducing overly onerous requirements or risking unintended consequences by allowing too much relaxation of specification elements such as fabric. This is discussed further in sections 1.10.6 and 1.11.1.

153. Where modelled 2021 specification details are not shown they are assumed to be as per 2015 compliant specifications (e.g. lighting specification, detailed assumptions for PV, additional window design assumptions).

154. It should be noted that some of the specification details may also differ if and when they are entered into a notional building specification (for example, items such as opening areas or boiler types/hot water cylinder sizes may be standardised across building types); the tables below show the modelled specifications used for the purposes of the current analysis.

155. When reviewing notional building specifications it is important to consider that they are not prescriptive; they are used to set standards but developers can deviate from them in practice as long as sufficient flexibility is allowed for – for example relaxing some elements of the specification and compensating elsewhere if required.

156. For some specification elements there would be an expectation that work would be required outside the Building Standards remit (e.g. to build supply chains, and upskill designers, installers and commissioners) to achieve them at scale in practice and to avoid performance gaps. It is recommended that the Scottish Government consider these points further.

1.10.2 2021 modelling specifications – fabric

157. The modelled fabric specifications are set out in Table 1.10a, where they are compared to the 2015 compliant base case.

Table 1.10a: Building Standards 2021 specification options – fabric improved/advanced cases

	2015 compliant case	2021 improved case	2021 advanced case	Source/Rationale
External Wall U-value	0.17	0.15	0.13	0.17 is 25th percentile in EPC database; 0.15 appears a reasonable improvement and is around 15th percentile. Whilst 0.13 appears a step up in cost and is below 10th percentile, there are policy drivers for improving fabric further. For information, 0.13 is included in the Wales 2020 proposed notional.
Corridor Wall U-value	0.17	0.15	0.13	Scottish Government do not wish to introduce differentiation by wall type here.
Party Wall U-value	0.0			As per 2015
Floor U-value	0.15	0.12	0.10	0.15 is 50th percentile in EPC database; 0.12 is 25th percentile and reasonable reduction; looking at lower values 0.10 is below 10th percentile but there are policy drivers for improving fabric further. Costs appear to increase significantly at 0.09 so this was seen as a limit.
Roof U-value	0.11	0.09	0.09	0.11 is 50th percentile in EPC database; 0.09 appears a reasonable step down and is around 10th percentile.
Window U-value	1.4	1.2	0.8	Client confirmed use of 1.2 U-value as a step down from 2015. 1.3/1.2 is Wales/ England 2020 proposed notional (1.2 possible limit for double glazing). 0.8 is triple glazing typical value, and pushes fabric further in line with policy drivers, though current high costs of triple glazing and limits on supply are noted.
Window g-value	0.63	0.63	0.57	Linked to glazing type
Door U-value	1.4	1.2	1.0	Low cost with 1.2 seen as a reasonable step down from 2015. Note 1.0 U-value included in England/Wales notional.
y-value	0.08	0.06	0.04	Similar to England/Wales notional with the improved value seen as a possible interim step. Low cost.
Thermal Mass Parameter	As actual			As per 2015

Notes Units for U-values and y-values are W/m^2K.

1.10.3 2021 modelling specifications – ventilation

158. The modelled ventilation specifications are set out in Table 1.10b, where they are compared to the 2015 compliant base case.

Table 1.10b: Building Standards 2021 specification options – ventilation improved/advanced cases

Element	2015 compliant case	2021 improved case	2021 advanced case	Source/Rationale
Ventilation type	Intermittent extract fans with trickle vents	Intermittent extract fans with trickle vents	MVHR	High savings for MVHR and reflective of a move towards a passive house approach, but note constraints. Improved case unchanged from 2015. MEV not proposed as gives relatively minor benefit.
Air permeability rate ($m^3/m^2.h@50Pa$)	5.0	5.0	3.0	Linked to ventilation system type

Notes The MVHR product used in the modelling is the Vent Axia Sentinel Kinetic Advance S (BRE SAP Product Characteristics Database reference 500477). The system is also assumed to be located exclusively in the heated envelope, with rigid insulated ductwork, and to be installed under an approved scheme, reflecting good practice.

1.10.4 2021 modelling specifications – heating

159. The modelled heating specifications are set out in Table 1.10c, where they are compared to the 2015 compliant gas base case.

160. The gas and ASHP cases reflect heating systems commonly/relatively commonly currently specified in new homes, with the ASHP case also reflecting future policy aims. Other heating options were considered but ruled out for the modelling following consideration of the evidence and discussion with Scottish Government. For example, a gas heating with solar thermal option was excluded given the constraints outlined in section 1.9; in particular as it would be required to be combined with solar PV to achieve more stretching targets, which would form a high capital cost approach compared to installing a larger PV array.

Table 1.10c: Building Standards 2021 specification options – heating gas/ASHP cases

Element	2015 compliant (gas) case	2021 gas cases (improved and advanced)	2021 ASHP cases (improved and advanced)	Source/Rationale
Space Heating Source	Condensing gas boiler	Condensing gas boiler	ASHP	ASHP high savings and reflects solution looking to 2024
Emitters	Radiators (standard size)	Radiators (large)	Radiators (large)	Future-proofing measure in gas case
Efficiencies	89.0% (SEDBUK)	89.5% (SEDBUK)	Around 250% (SPF as modelled in SAP)	Heat pump efficiency significant improvement on 2015 notional. Gas boiler and heat pump efficiency as per England/Wales Part L 2020 proposals/analysis
Flow temperatures	>55°C	55°C	45°C	Future-proofing measure

Element	2015 compliant (gas) case	2021 gas cases (improved and advanced)	2021 ASHP cases (improved and advanced)	Source/Rationale
Controls	Time and temperature zone control, interlock, ErP Class V controls, delayed start	Time and temperature zone control, interlock, ErP Class V controls, delayed start	Time and temperature zone control	As per 2015
Flue Gas Heat Recovery	None	None	n/a	As per 2015
Pump details	2013 or later, in heated space	2013 or later, in heated space	n/a	As per 2015
Flue type	Balanced, fan-assisted	Balanced, fan-assisted	n/a	As per 2015
Boiler type	Detached: 18kW system/regular Semi/Mid/Flat: 24kW combi	Regular for houses, combi for flats	n/a	Requested by Scottish Government to align with 2015 notional and reflect desire for storage for flexibility in the future – though combis currently considered more common in semi-detached/mid-terrace houses
Domestic Hot Water Source	As for space heating	As for space heating	As for space heating	As per 2015. BRE confirmed previously that SAP modelled heat pump efficiency would take into account top-up for water heating
Hot water cylinder size (where applicable)	200l for detached house only	200l for detached house 150l for semi-detached and mid-terrace houses	180l (integral)	Gas boiler hot water cylinder sizing based on Hot Water Association calculator. ASHP sizing taken from heat pump product modelled.
Hot water cylinder declared loss factor (where applicable)	1.89 kWh/day	1.65 kWh/day for detached 1.39kWh/day for semi-detached and mid-terrace houses	1.35 kWh/day	Tightened to match requirement in England/Wales for gas boiler. ASHP declared loss factor based on heat pump model used.
Primary circuit loss assumptions (where applicable)	Cylinder thermostat, separate timer, fully insulated primary pipework			As per 2015
Shower flow rate (l/min)	8			As per 2015
Waste Water Heat Recovery	None	Yes, efficiency 55%, utilisation factor 0.98, waste water factor 0.9, connected to all showers	None	Cost-effectiveness. Efficiency is improvement on 2015 notional, same level proposed for Wales Part L 2020, and allows for some flexibility in flats across blocks where shower trays could be used on ground floor.

Element	2015 compliant (gas) case	2021 gas cases (improved and advanced)	2021 ASHP cases (improved and advanced)	Source/Rationale
				Shower connection assumption as per England and Wales Part L 2020 proposals.
Secondary heating	None			As per 2015
Electricity tariff	Standard			As per 2015

Notes The ASHP product used in the modelling is the 5kW Panasonic Aquarea High Performance (BRE SAP Product Characteristics Database reference 103455, intended for highly energy efficient homes). The product was selected as it provided good heating efficiencies as modelled in SAP for the design heat losses of the 2021 dwelling types.
Further work may be needed to assess how the efficiency might be specified in the notional building and to consider the range of heat pumps which could achieve similar performance; this is a complicated task as heat pump efficiencies vary with plant size ratio as modelled in SAP (i.e. ratio of maximum output to dwelling design heat loss). It is recommended that this is discussed with BRE as the contractor responsible for SAP, the Product Characteristics Database, and SAP’s heat pump calculation engine.

1.10.5 2021 modelling specifications – PV

161. The modelled PV specifications are set out in Table 1.10d and compared to the 2015 compliant gas base case. The areas proposed for the gas 2021 cases are based on the findings from the existing evidence that it is more cost-effective to maximise the PV array size. An area equivalent to 40% of the building foundation area has been modelled. This has also been proposed in other UK administrations as representing a reasonable maximum to allow for some flexibility and to avoid significant roof redesign (e.g. a change to mono-pitch roofs).

162. The ASHP 2021 cases exclude PV to reflect the significant improvement in performance which will be achieved through installing ASHP alone and to provide closer parity with the gas cases. In addition, if a single notional building was set, including PV in the ASHP case would be expected to exclude fossil fuels from compliance which is contrary to the aims expressed by the Scottish Government for the 2021 standards revision.

163. Another key decision where PV is included was whether or not to include battery storage. Previous work has suggested that this adds significant capital and replacement costs which will not be outweighed by the benefits of increased use of generated electricity on site as captured in the current modelling and cost-benefit assessment. Battery storage has therefore not been included in the specifications. However it is understood that Scottish Government policy objectives are strongly supportive of storage, and that there are wider benefits which may not be captured in the current analysis, such as reduced impacts on the electricity grid, avoidance of the need for export limiters as a temporary measure, and (where and when this is possible) load-shifting with time of use tariffs. Indeed, the Scottish Government has suggested that benefit may be assigned to onsite generation only where it can be used onsite (immediately or via storage). It is suggested that the promotion of battery storage is primarily a policy decision for the Scottish Government, which could be informed in part by the information presented above.

Table 1.10d: Building Standards 2021 specification options – PV

	2015 compliant (gas only)	2021 gas cases (improved and advanced)	2021 ASHP cases (improved and advanced)	Source/Rationale
PV calculation	PV included, sizes shown in Table 1.10e.	40% building foundation area	None	See text above – most cost-effective to maximise roof area. ASHP case excludes PV to provide closer parity with gas case.
Battery storage	No	No	No	See text above – there are strategic and policy reasons for promoting battery storage but excluded due to high costs and limits on modelled benefits. Alternative mechanisms to incentivise may be required.

Notes The 2021 proposed calculations take into account significant recent improvements in standard panel performance (6.5 m²/kWp is assumed).
Further consideration may need to be given to high-rise flats, but basing the array size on building foundation area helps to take into account the number of storeys in blocks of flats across which roof-based arrays would need to be shared.

Table 1.10e: Building Standards 2021 specification options – PV array sizes as applied to building sub-types

PV array sizes (kWp)	2015 compliant case (gas only)	2021 cases (gas improved and advanced)	2021 cases (ASHP improved and advanced)
Detached house	1.61	4.33	n/a
Semi-detached house	0.95	2.60	
Mid-terrace house	0.95	2.60	
Flat	0.85	1.44	
Block of flats	10.20	17.25	

1.10.6 2021 specifications – consideration of low carbon heating and renewable technologies

164. The choice of low carbon heating and renewable technologies within the 2021 notional building will have the most significant impact on the overall target. Their selection should be considered within the context of Scottish Government policy commitments and objectives, and of the wider impacts such decisions will have (including outside of Building Standards which focus on the individual dwelling level) – section 0 provides a summary. The evidence review findings in sections 1.7.2 and 1.9 are also particularly relevant in highlighting various advantages and disadvantages of different technologies. Some of these were also discussed – alongside others – in a recent Scottish Government report on climate mitigation options for the built environment (Aether, 2017).

165. The Scottish Government has indicated that the 2021 solutions should be achievable with higher carbon fuels, likely with on-site renewable generation. As noted in section 1.6, they also wished to explore the option of moving to a single notional building in 2021 which would not vary by fuel type. Hence, the notional building could be based on one of the following:

- Option 1: a higher carbon heating system with on-site renewable generation,
- Option 2: a lower carbon heating system that can be complied with using a higher carbon fuel with on-site renewable generation,
- Option 3: a notional building with alternative options depending on whether, say, a lower or higher carbon heating system is used in the actual building.

166. Option 1 could be based on a gas heated solution plus PV. Previous work by AECOM has suggested that if such a target was adopted, a solution which specifies a heat pump in practice is likely to form a lower capital cost alternative for compliance, at least for individual houses. This could have the benefit of encouraging ASHP adoption, but could also potentially allow relaxation of other specification elements (e.g. fabric) where ASHP is used, which may not be desirable – though setting robust minimum fabric and services performance values could help to mitigate this risk. Particularly in the context of reduced carbon emission (and primary energy) factors for electricity, it could also be important to ensure that it does not form a backwards step for electric-heated homes for which the target is currently based on an ASHP-heated notional building.

167. As an alternative, Option 2 could be adopted through setting a target based on a heat pump specification. However, if the heat pump is assumed to have an improved efficiency compared to the Scotland 2015 ASHP/electric compliant case (to better reflect performance of heat pumps on the market), AECOM analysis suggested that such an option may preclude compliance using gas heating even where a significant amount of PV is installed (above the 40% building foundation area equivalent array size proposed in the modelling) and high levels of energy efficiency are specified (with carbon targets being particularly challenging if/where these are set).

168. Alternatively, Option 3 could be adopted where the notional building is differentiated by fuel type e.g. a gas heated solution plus PV for most options and an ASHP specification where the actual building has a heat pump (and potentially also where it has a different type of electric heating, i.e. as in the 2015 standards).

169. Further analysis in section 1.11 tests the gas and ASHP comparison in more detail and presents the results of the 2021 modelling (see section 1.11.1 in particular). Following consideration of the above options, and informed by initial modelling results from Task 3, Scottish Government decided that their preference is Option 3. This is similar to the approach adopted in 2015 standards and helps ensure that high standards are achieved for different fuel types. This is therefore reflected in the following analysis.

Task 3: Modelling Options for a New Notional Building Specification

1.11 Modelling of national profile to improved standards

1.11.1 SAP modelling results

170. The seven building sub-types set out in Table 1.11i were modelled using the latest available version of SAP, SAP 10.1 (BRE, 2019), and the two levels of specifications set out in section 1.10: ‘improved’ (gas / ASHP) and ‘advanced’ (gas / ASHP). A summary of the cases modelled for each dwelling type is set out below:

- Gas + improved fabric + natural ventilation + PV (‘Gas improved’)
- Gas + advanced fabric + MVHR + PV (‘Gas advanced’)
- ASHP + improved fabric + natural ventilation (‘ASHP improved’)
- ASHP + advanced fabric + MVHR (‘ASHP advanced’).

171. The results for the 2021 options were compared to baseline results for 2015 compliant cases obtained using the specifications set out in section 0 and the same version of SAP (as described in section 1.5.9).

172. Key results from the modelling at the individual dwelling level are set out in Table 1.11a to Table 1.11d. The columns show the DPER and DER calculated using the SAP 10.1 methodology (including SAP 10.1 carbon emission factors and primary energy factors). These are compared to the equivalent results for the gas 2015 compliant (‘BS2015’) base cases previously presented in section 1.5.9. DPER is shown first here as this is proposed to be the primary target metric.

Table 1.11a: SAP 10.1 key modelling results for detached dwelling type – carbon emissions and primary energy

	DPER	% reduction in DPER vs 2015 gas case	DER	% reduction in DER vs 2015 gas case
Gas BS2015 case	69.0	0%	13.0	0%
Gas improved case	45.0	35%	8.6	34%
Gas advanced case	28.0	60%	5.0	61%
ASHP improved case	34.3	50%	3.3	75%
ASHP advanced case	27.4	60%	2.6	80%

Source AECOM modelling using BRE’s SAP 10.1 software SAP.exe, Build 7, 20/01/20.
Results recorded in AECOM, ‘210507 Scotland Building Standards 2021 - SAP10.1 Results – v10.xls’

Table 1.11b: SAP 10.1 key modelling results for semi-detached dwelling type – carbon emissions and primary energy

Semi-detached house	DPER	% reduction in DPER vs 2015 gas case	DER	% reduction in DER vs 2015 gas case
Gas BS2015 case	80.2	0%	15.0	0%
Gas improved case	51.6	36%	9.9	34%
Gas advanced case	32.7	59%	6.1	60%
ASHP improved case	38.8	52%	3.7	75%
ASHP advanced case	31.4	61%	3.0	80%
ASHP BS2015 case	63.7	21%	6.1	59%

Notes The ASHP BS2015 case is included for information and forms part of the base case. Note that, as explained in section 1.5.8, this case over-complies with 2015 standards.

Source AECOM modelling using BRE's SAP 10.1 software SAP.exe, Build 7, 20/01/20. Results recorded in AECOM, '210507 Scotland Building Standards 2021 - SAP10.1 Results – v10.xls'

Table 1.11c: SAP 10.1 key modelling results for mid-terrace dwelling type – carbon emissions and primary energy

Mid-terrace house	DPER	% reduction in DPER vs 2015 gas case	DER	% reduction in DER vs 2015 gas case
Gas BS2015 case	73.2	0%	13.7	0%
Gas improved case	45.6	38%	8.8	36%
Gas advanced case	28.3	61%	5.2	62%
ASHP improved case	37.2	49%	3.6	74%
ASHP advanced case	28.6	61%	2.7	80%

Source AECOM modelling using BRE's SAP 10.1 software SAP.exe, Build 7, 20/01/20. Results recorded in AECOM, '210507 Scotland Building Standards 2021 - SAP10.1 Results – v10.xls'

Table 1.11d: SAP 10.1 key modelling results for flat dwelling type – carbon emissions and primary energy

Average flat / Block of flats	DPER	% reduction in DPER vs 2015 gas case	DER	% reduction in DER vs 2015 gas case
Gas BS2015 case	77.6	0%	14.5	0%
Gas improved case	58.0	25%	11.0	24%
Gas advanced case	40.5	48%	7.6	48%
ASHP improved case	39.6	49%	3.8	74%
ASHP advanced case	30.2	61%	2.9	80%

Source AECOM modelling using BRE's SAP 10.1 software SAP.exe, Build 7, 20/01/20. Results recorded in AECOM, '210507 Scotland Building Standards 2021 - SAP10.1 Results – v10.xls'

173. Further results from the modelling of potential 2021 standards are set out in Table 1.11e to Table 1.11h. The tables show energy consumption by end-use, and energy generation from onsite PV (where applicable) as calculated using the SAP 10.1

methodology. Again these results are compared to the equivalent results for the 2015 compliant base cases.

174. The energy generated by PV is assumed to be split into electricity used on site, and electricity exported to the grid, with the split based upon the SAP 10.1 methodology. The proportions used on site or exported vary by dwelling type and compliance case, but generally around 50-55% is assumed to be used on site in the 2015 gas compliant cases for all dwelling types, around 50% for the flat block gas improved/advanced cases, and around 35-40% in the gas houses improved/advanced cases (where the overall amount of electricity generated is significantly higher).

Table 1.11e: SAP 10.1 key modelling results for detached dwelling type – annual energy consumption by end-use, and annual onsite energy generation (kWh/yr)

Detached house	Space heating	Water heating	Pumps and fans	Lighting	PV generation
Gas BS2015 case	6,036	3,257	86	264	1,326
Gas improved case	5,062	2,642	86	264	3,565
Gas advanced case	2,378	2,688	469	268	3,565
ASHP improved case	1,937	903	0	264	0
ASHP advanced case	953	888	383	268	0

Source AECOM modelling using BRE's SAP 10.1 software SAP.exe, Build 7, 20/01/20.
Results recorded in AECOM, '210507 Scotland Building Standards 2021 - SAP10.1 Results – v10.xls'

Table 1.11f: SAP 10.1 key modelling results for semi-detached dwelling type – annual energy consumption by end-use, and annual onsite energy generation (kWh/yr)

Semi-detached house	Space heating	Water heating	Pumps and fans	Lighting	PV generation
Gas BS2015 case	3,315	3,007	86	198	782
Gas improved case	2,647	2,441	86	198	2,141
Gas advanced case	935	2,498	266	204	2,141
ASHP improved case	1,063	852	0	198	0
ASHP advanced case	435	904	180	204	0
ASHP BS2015 case	1,748	1,524	0	198	0

Source AECOM modelling using BRE's SAP 10.1 software SAP.exe, Build 7, 20/01/20.
Results recorded in AECOM, '210507 Scotland Building Standards 2021 - SAP10.1 Results – v10.xls'

Table 1.11g: SAP 10.1 key modelling results for mid-terrace dwelling type – annual energy consumption by end-use, and annual onsite energy generation (kWh/yr)

Mid-terrace house	Space heating	Water heating	Pumps and fans	Lighting	PV generation
Gas BS2015 case	2,774	3,018	86	204	782
Gas improved case	2,186	2,451	86	204	2,141
Gas advanced case	572	2,520	266	210	2,141
ASHP improved case	910	913	0	204	0
ASHP advanced case	294	885	180	210	0

Source AECOM modelling using BRE's SAP 10.1 software SAP.exe, Build 7, 20/01/20.

Results recorded in AECOM, '210507 Scotland Building Standards 2021 - SAP10.1 Results – v10.xls'

Table 1.11h: SAP 10.1 key modelling results for flat dwelling type – annual energy consumption by end-use, and annual onsite energy generation (kWh/yr)

Average flat	Space heating	Water heating	Pumps and fans	Lighting	PV generation
Gas BS2015 case	2,259	2,849	86	169	700
Gas improved case	1,867	2,370	86	169	1,186
Gas advanced case	564	2,426	204	172	1,186
ASHP improved case	766	858	0	169	0
ASHP advanced case	279	808	118	172	0

Source AECOM modelling using BRE's SAP 10.1 software SAP.exe, Build 7, 20/01/20.
Results recorded in AECOM, '210507 Scotland Building Standards 2021 - SAP10.1 Results – v10.xls'

175. The primary energy and carbon emission results by individual dwelling and fuel type (Table 1.11a to Table 1.11d) were compared to help assess the suitability of the three potential options for the notional building set out in section 1.10.6 (i.e. Option 1, a single fuel notional building based on gas; Option 2, a single fuel notional building based on ASHP; or Option 3, a notional building differentiated by fuel type).

176. In terms of primary energy, as was expected, percentage level of improvement differed across all dwelling types for the equivalent cases for gas / ASHP (i.e. improved / advanced, which respectively have the same fabric and ventilation specifications for gas / ASHP, but which both omit PV in the case of ASHP). For the improved cases, the ASHP results were significantly better than the equivalent gas model results for all dwelling types. However for the advanced cases, the ASHP results were close to the equivalent gas model results for the houses only. This latter observation can be explained by observing that improving fabric specifications and switching to MVHR have a greater impact where a lower efficiency space heating system is being used. The results are further apart for the flats where space heating demands are lower.

177. However it can be seen that the gas *advanced* case comes out similar to/better than the ASHP *improved* case in terms of primary energy across the dwelling types modelled. In terms of carbon emissions, both ASHP cases (improved / advanced) have much lower results than either of the gas cases.

178. Some of the implications of these findings for the notional building options set out in section 1.10.6 are as follows (with the main focus being on primary energy targets, as this is the main target metric):

- Option 1 – a single notional gas-heated building:
    - A single notional gas building could be set but this would give ASHP a significant benefit in many situations (particularly at the 'improved' specification level), allowing specification relaxation which may not be sufficiently limited by improved backstops.
    - In terms of carbon, having this as an additional metric should not impact on ASHP – benefits/impacts relating to some other fuel types e.g. oil/LPG are discussed in section 1.17.

- Option 2 – a single notional ASHP-heated building:
    - A single notional ASHP building could be set at the improved specification level, but this would make it challenging for gas to comply, e.g. requiring similar specification to the gas advanced case.
    - A single notional ASHP building set at the advanced specification level would be even more challenging and would make gas heating challenging for at least some dwelling types.
    - The notional building ASHP efficiency could be reduced to provide more parity between gas and ASHP cases; however this potentially gives a confusing message particularly in the context of increased use of heat pumps and concerns about energy bills, and could allow poor fabric efficiency where better performing ASHP is used in practice.
    - In terms of carbon, having this as an additional metric where a single notional was based on ASHP would mean that gas-heated dwellings would be expected to be unable to realistically comply (in either the improved or advanced case).
    - In terms of cost-benefit, for the advanced specification this would be affected by the advanced measures having a smaller impact on the ASHP models compared to gas.
- Option 3 – a notional differentiated by fuel type (gas/ASHP):
    - This could have the benefit of helping to prevent some of the issues identified above with Options 1 and 2, and also perhaps the benefit of providing more clarity for the consultation.
    - As a downside, it potentially gives less benefit to/incentive for ASHP vs gas in terms of capex, but there would be some savings from excluding PV (and a small saving from excluding WWHR).
    - In terms of carbon, having this as an additional metric would not then rule out gas.

179. It should be noted that comparisons between gas and ASHP cases may vary when looking at a wider range of building types. This would be expected to have particular relevance if setting a single-fuelled notional building. Comparisons would of course also be affected by changes to underlying assumptions – for example if they are reviewed at a later date when primary energy and carbon emission factors for electricity would be expected to have reduced.

180. The benefits/impacts of potential targets (including carbon targets) relating to other sensitivity fuel/heating types (oil, district heating) are considered separately under sections 1.16 and 1.17.

181. Other relevant key findings from the SAP modelling include that the advanced cases for all dwelling types show a high risk of overheating, based on a SAP Appendix P assessment. It had already been noted that the ground floor flat showed a high risk in all cases (including 2015 compliant). Overheating risks and mitigation measures would need to be considered separately as they are outside of the scope of the current work – and it is understood that separate work is taking place on this topic.

182. It should also be noted that the mid-terrace and flat dwelling types required an extension to be made in SAP to the plant size ratios modelled for heat pumps in the advanced cases, as the design heat losses in these dwellings are so low, even though the heat pump product modelled was chosen as being particularly suited to low energy dwellings. This also meant that space heating efficiencies in these cases were somewhat lower in the modelling than the 250% figure proposed in section 1.10.4. Depending in part on where the notional building target is set, this is likely to require further exploration with BRE as the SAP contractors, and with the heat pump industry to investigate the suitability of a range of heat pumps for providing heating in very low energy dwellings and the efficiencies which can be achieved in practice and as modelled in SAP.

183. Consideration of the above findings relating to the notional building options led Scottish Government to decide to proceed with Option 3 for the modelling – a notional building differentiated by fuel type (gas/ASHP). As noted previously, this is similar to the approach adopted in 2015 standards and helps ensure that high standards are achieved for different fuel types. Two levels of standards were therefore assessed at the national level in the following analysis:

- Scenario 1: ‘Improved’ standards in 2021:
    - Gas + improved fabric + natural ventilation + PV (‘Gas improved’), where dwelling sub-type is gas-heated, and
    - ASHP + improved fabric + natural ventilation (‘ASHP improved’), where dwelling sub-type is ASHP-heated.
- Scenario 2: ‘Advanced’ standards in 2021:
    - Gas + advanced fabric + MVHR + PV (‘Gas advanced’), where dwelling sub-type is gas-heated, and
    - ASHP + advanced fabric + MVHR (‘ASHP advanced’), where dwelling sub-type is ASHP-heated.

1.11.2 Fuel mix

184. The SAP modelling results were used to assess the benefits at a national level. The seven building sub-types and annual build numbers used for the baseline were assumed in the counterfactual scenarios, and these were assumed to be unchanged over the analysis period. These assumptions were defined and explained in section 1.4 (Table 1.4b). The assumptions made are replicated in Table 1.11i.

185. Two alternative fuel mix scenarios, agreed with the Scottish Government, were considered which are also presented in Table 1.11i. In both cases, these were modelled separately for both the improved and advanced standards, and a full transition to the new standards is assumed to be achieved by 2025, as explained in section 1.11.3 below. The fuel mix scenarios are:

- A core ‘with fossil fuels’ case which assumes the same fuel mix as the base case, across the entire analysis period.
- A ‘without fossil fuels’ case which assumes a move to 100% off-fossil fuels.

186. In each case the specification for the building sub-type modelled is the relevant (gas / ASHP) specification set out at the end of section 1.11.1 above (see section 1.10 for detailed specifications). Note that in the core 'with fossil fuels' case, ASHP is not assumed other than for some semi-detached houses.

Table 1.11i: Seven building sub-types modelled in analysis – fuel mix assumptions

Building Sub-types - baseline	Proportion of build mix	Annual build numbers	Fuel to assume in 'with fossil fuels' case	Fuel to assume in 'without fossil fuels' case
Detached house, gas	30.32%	5,521	Gas	Electricity (ASHP)
Semi-detached house, gas	22.84%	4,158	Gas	
Mid-terrace house, gas	8.06%	1,467	Gas	
Ground-floor flat, gas	9.37%	1,706	Gas	
Mid-floor flat, gas	9.37%	1,706	Gas	
Top-floor flat, gas	9.37%	1,706	Gas	
Semi-detached house, ASHP	10.67%	1,943	Electricity (ASHP)	
TOTAL	**100%**	**18,207**		

Notes Percentages do not add up to totals due to rounding.

Source AECOM analysis of *EPC database extract 2016-18 SAP new build* (provided by Scottish Government, December 2019)

Scottish Government, *Housing Statistics for Scotland – All sector new build (completions)*, September 2019 (data for calendar years 2016-2018 used to derive an average annual total build rate)

Fuel assumptions for 'with / without fossil fuels' cases agreed with Scottish Government.

1.11.3 Transitional period

187. The national profile modelling assumes a transitional period as new standards are introduced (i.e. not all buildings built in 2021 will be to 2021 standards). The assumptions made were agreed with Scottish Government and are set out in Table 1.11j.

Table 1.11j: Transitional period assumptions for 2021 standards

Proportions of new dwellings built to relevant standard in each year	2021	2022	2023	2024	2025 onwards
2015 standard	80%	60%	40%	20%	0%
2021 standard	20%	40%	60%	80%	100%

Source Agreed with Scottish Government.

1.12 National impacts (carbon benefits) with fossil fuels

188. To form an initial estimate of the carbon benefit of the different potential future standards, prior to undertaking a full CBA, the energy results summarised in Table 1.11eTable 1.5m to Table 1.11h were applied to the national build profile, taking into account the assumptions on build/fuel mix and build rates set out in section 1.11. Initially the core 'with fossil fuels' scenario was assessed.

189. A 25 year analysis period was used. The two counterfactual cases (‘improved’ and ‘advanced’) were compared to the 2015 compliant base case. The carbon emission factors applied are those published by BEIS to support the HM Treasury Green Book supplementary appraisal guidance on valuing energy use and greenhouse gas (GHG) emissions (BEIS, 2019). The factors for electricity are projected to decrease over time and are summarised in Table 1.12a. The factor for gas is 0.184kgCO_2e/kWh.

Table 1.12a: Carbon emission factors used in benefit analysis – electricity (kgCO_2e/kWh)

Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Consumption	0.283	0.269	0.255	0.240	0.224	0.207	0.189	0.171	0.151	0.130	0.116	0.103	0.092
Generation	0.258	0.246	0.233	0.219	0.205	0.189	0.173	0.156	0.138	0.118	0.105	0.094	0.084

Year	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045
Consumption	0.082	0.073	0.065	0.058	0.052	0.046	0.041	0.040	0.038	0.037	0.036	0.034
Generation	0.075	0.066	0.059	0.053	0.047	0.042	0.037	0.036	0.035	0.034	0.032	0.031

Notes Generation-based emission factors are used for electricity generated by PV and exported. PV generated electricity used on site is assumed to offset consumption and therefore the consumption-based emission factors are applied.

Source BEIS, Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal – data tables 1 (electricity – long-run marginal domestic consumption-based figures and generation-based figures) and 2a (natural gas) (BEIS, 2019).

190. It should be noted that the carbon emission factors are different from those used in SAP 10.1. They are lower for gas, and for electricity they are initially significantly higher but are projected to decrease over time becoming lower from 2030 onwards and continuing to decrease until 2050. A different calculation of carbon savings from the counterfactual cases across the build mix using SAP 10.1 carbon emission factors (for a single year) is given in section 1.14.

191. The results by year are presented in Table 1.12b. Total emissions increase over time as the number of homes included in the analysis increases, though emission factors for electricity decrease. The estimated total carbon savings for the counterfactual cases across the analysis period are summarised in Table 1.12c. This shows that the ‘improved’ case is estimated to achieve a 21% reduction in carbon emissions compared to the base case; and the ‘advanced’ case to achieve a 42% reduction.

Table 1.12b: Annual carbon emissions for base case and counterfactual cases – ‘with fossil fuels’ scenario (ktCO_2e/yr)

Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Base	20	40	60	80	100	120	140	161	182	202	223	244	265
Improved	18	34	48	61	73	86	100	115	131	148	165	183	200
Advanced	17	31	42	51	58	66	75	84	95	107	119	130	142

Year (cont.)	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	ALL
Base	285	306	327	348	369	390	410	431	452	472	493	514	**6,632**
Improved	218	236	254	272	290	308	327	343	360	376	393	410	**5,147**
Advanced	155	167	179	192	204	217	229	240	251	262	274	285	**3,673**

Source AECOM modelling using assumptions on build mix, fuel mix and emission factors as set out above, and using SAP 10.1 energy modelling results as set out above.
Results recorded in AECOM, '210507 Scotland Building Standards 2021 - SAP10.1 Results – v10.xls'

Table 1.12c: Total carbon emissions for improved and advanced cases – 'with fossil fuels' scenario

Scenario	Total carbon saving ($ktCO_2e/yr$)	% reduction compared to base case
Improved	1,485	22%
Advanced	2,959	45%

Source AECOM modelling using assumptions on build mix, fuel mix and emission factors as set out above, and using SAP 10.1 energy modelling results as set out above.
Results recorded in AECOM, '210507 Scotland Building Standards 2021 - SAP10.1 Results – v10.xls'

192. Sensitivity analysis was undertaken to estimate the impact of excluding the benefit of carbon emission savings associated with electricity generated by PV and exported to the grid. This indicated that carbon emission reductions compared to the base case would decrease to 18% for the 'improved' case and 39% for the 'advanced' case, where other assumptions remain unchanged from the core case. It should be noted that for consistency, in this analysis the carbon benefit of exported generation was removed for the base case as well as the improved case.

1.13 National impacts (carbon benefits) without fossil fuels

193. The 'without fossil fuels' scenario was also assessed, using the same process and assumptions as for the 'with fossil fuels' scenario, set out in sections 1.11 and 1.12. The results by year are presented in Table 1.13a. The estimated total carbon savings for the counterfactual cases across the analysis period are summarised in Table 1.13b.

194. This shows that under the 'without fossil fuels' scenario, the 'improved' case is estimated to achieve a 73% reduction in carbon emissions compared to the base case; and the 'advanced' case to achieve a 75% reduction. As would be expected, this is significantly higher than the estimated 22% / 45% reductions for the improved / advanced cases under the core 'with fossil fuels' scenario, where the majority of new dwellings are assumed to be gas-heated over the analysis period.

Table 1.13a: Annual carbon emissions for base case and counterfactual cases – 'without fossil fuels' scenario ($ktCO_2e/yr$)

Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
Base	20	40	60	80	100	120	140	161	182	202	223	244	265
Improved	18	35	49	60	68	75	80	83	85	84	84	84	83
Advanced	18	33	46	56	62	68	72	75	76	75	76	75	75

Year (cont.)	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	ALL
Base	285	306	327	348	369	390	410	431	452	472	493	514	**6,632**
Improved	82	81	79	78	76	74	72	73	73	74	74	74	**1,799**
Advanced	74	73	71	70	69	67	66	66	67	67	67	68	**1,631**

Source AECOM modelling using assumptions on build mix, fuel mix and emission factors as set out above, and using SAP 10.1 energy modelling results as set out above.
Results recorded in AECOM, '210507 Scotland Building Standards 2021 - SAP10.1 Results – v10.xls'

Table 1.13b: Total carbon emissions for improved and advanced cases – 'without fossil fuels' scenario

	Total carbon saving ($ktCO_2e$)	% reduction compared to base case
Improved	4,834	73%
Advanced	5,001	75%

Source AECOM modelling using assumptions on build mix, fuel mix and emission factors as set out above, and using SAP 10.1 energy modelling results as set out above.
Results recorded in AECOM, '210507 Scotland Building Standards 2021 - SAP10.1 Results – v10.xls'

1.14 National impacts (Costs)

195. The capital costs (in 2020 prices) of each home type for the 2015, improved and advanced cases, and for both gas heating and ASHP, are shown in Table 1.14a to Table 1.14e.

Table 1.14a: Capital costs by cost case and fuel type – detached house

Detached house	Fabric	Ventilation	Heating and hot water	Photovoltaics	Balance of construction cost	Total	Percentage uplift on 2015
Gas BS2015 case	£58,154	£600	£9,030	£2,388	£98,788	£168,960	0%
Gas improved case	£62,135	£600	£9,930	£4,564	£98,788	£176,017	4%
Gas advanced case	£65,205	£4,216	£7,284	£4,564	£98,788	£180,057	6%
ASHP improved case	£62,135	£600	£11,942	£0	£98,788	£173,465	3%
ASHP advanced case	£65,205	£4,216	£9,296	£0	£98,788	£177,505	5%

Table 1.14b: Capital costs by case and fuel type – semi-detached house

Semi-detached house	Fabric	Ventilation	Heating and hot water	Photovoltaics	Balance of construction cost	Total	Percentage uplift on 2015
Gas BS2015 case	£32,765	£600	£7,102	£1,860	£54,778	£97,106	0%
Gas improved case	£34,967	£600	£7,852	£3,180	£54,778	£101,378	4%
Gas advanced case	£36,565	£3,511	£6,220	£3,180	£54,778	£104,254	7%
ASHP improved case	£34,967	£600	£9,914	£0	£54,778	£100,260	3%
ASHP advanced case	£36,565	£3,511	£8,282	£0	£54,778	£103,136	6%

Table 1.14c: Capital costs by case and fuel type – mid-terraced house

Mid-terraced house	Fabric	Ventilation	Heating and hot water	Photovoltaics	Balance of construction cost	Total	Percentage uplift on 2015
Gas BS2015 case	£24,754	£600	£7,102	£1,860	£54,346	£88,662	0%
Gas improved case	£26,680	£600	£7,852	£3,180	£54,346	£92,658	4%
Gas advanced case	£27,986	£3,511	£6,220	£3,180	£54,346	£95,243	7%
ASHP improved case	£26,680	£600	£9,914	£0	£54,346	£91,540	3%
ASHP advanced case	£27,986	£3,511	£8,282	£0	£54,346	£94,125	6%

Table 1.14d: Capital costs by case and fuel type – average flat (in block of 12 over 3 floors)

Average flat in block of 12	Fabric	Ventilation	Heating and hot water	Photovoltaics	Balance of construction cost	Total	Percentage uplift on 2015
Gas BS2015 case	£19,885	£450	£6,086	£935	£56,758	£84,114	0%
Gas improved case	£21,388	£450	£6,296	£1,584	£56,758	£86,477	3%
Gas advanced case	£22,650	£3,012	£4,999	£1,584	£56,758	£89,004	5%
ASHP improved case	£21,388	£450	£9,243	£0	£56,758	£87,840	4%
ASHP advanced case	£22,650	£3,012	£7,946	£0	£56,758	£90,367	7%

Table 1.14e: Capital costs by case and fuel type – semi-detached house – ASHP

Semi-detached house (ASHP)	Fabric	Ventilation	Heating and hot water	Photovoltaics	Balance of construction cost	Total	Percentage uplift on 2015
ASHP BS2015 case	£32,765	£600	£7,794	£0	£54,778	£95,938	0%
ASHP improved case	£34,967	£600	£9,914	£0	£54,778	£100,260	4%
ASHP advanced case	£36,565	£3,511	£8,282	£0	£54,778	£103,136	7%

196. The total costs of building homes with the advanced case fabric standards are lower than might be expected because some of the additional cost is offset by a reduction in the cost of providing radiators and associated pipework. This is drawn from evidence developed for the Committee on Climate Change which shows that ultra-low energy homes can be kept warm with reduced numbers of heat emitters (Committee on Climate Change, 2019c). In this study a 50% reduction in the costs of radiators and distribution pipework was allowed for advanced practice fabric standards compared to a 75% cost reduction assumed in the CCC study for construction to Passivhaus standards. This recognises that the advanced case fabric standards are significantly higher in performance than a typical home compliant with Section 6 2015 but that they are not at a level consistent with the Passivhaus specification, largely as a result of the lower level of targeted airtightness. A 50% saving is applied to both the house and flat

types which is slightly different from the assumptions used by the CCC but reflects that the same fabric specifications are used in all dwelling types and that as a consequence the reduction in space heating demand is greater in flats than in houses[28].

197. These capital cost estimates are based on a 'central belt' price level. In other areas of Scotland prices may be different reflecting the availability and costs of materials and labour. Drawing on Currie & Brown's experience in delivering projects across Scotland[29] the following adjustments on the base (central belt) costs are considered reasonable to reflect the additional costs of working in more remote parts of the country. The impact on the build cost of the semi-detached house for the different cases is shown in

198. Table 1.14f for the highest cost location the Western Isles.

- Central Belt (Glasgow, Edinburgh etc) – 100
- Borders / Dumfries & Galloway - 103
- Grampian (Aberdeen) - 103
- Highland - 110
- Orkney & Shetland - 125
- Western Isles – 130

Table 1.14f: Potential variation in build costs for homes built in the Western Isles – semi-detached house

Semi-detached house	Central cost	Cost for projects in Western Isles	Variation in overall cost from 2015 base
Gas BS2015 case	£97,106	£126,238	£0
Gas improved case	£104,074	£131,791	£5,553
Gas advanced case	£103,719	£135,531	£9,293
ASHP improved case	£102,906	£130,338	£4,100
ASHP advanced case	£102,551	£134,077	£7,839

199. The capital, maintenance and renewal, energy (variable cost) and lifetime costs of each case and fuel type are shown in Table 1.14g. These costs are the net present value costs over a 60 year period for a home built in 2021(in 2021 prices). Information is presented for the detached, semi-detached, mid-terrace and average flat in a three-storey block against a gas heated 2015 compliant reference case and also for the semi-detached house against a 2015 reference building with an ASHP. Lifetime energy costs are derived from energy price projections published by BEIS, renewal and maintenance costs are derived on an elemental basis in line with the assumptions in Appendix A. Renewal and maintenance costs reflect only those elements that are linked to the variations in specification and exclude other common elements such as decoration and other services (e.g. lighting).

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[28] By contrast in the CCC's research the same space heating demand level was targeted for each dwelling type and the fabric specification varied for each type to reflect the relative efficiency of their form factor.

[29] Currie & Brown's cost management team are currently delivering a wide range of projects across the whole of Scotland including for both housing associations and private developers.

Table 1.14g: Lifetime costs by home, case and heating type (£ present value per home)

Lifetime cost category	Detached 1. Improved with Gas	Detached 2. Advanced with Gas	Detached 3. Improved with ASHP	Detached 4. Advanced with ASHP	Semi 1. Improved with Gas	Semi 2. Advanced with Gas
Reference heating system	Gas	Gas	Gas	Gas	Gas	Gas
Change in capital cost	£7,057	£11,097	£4,505	£8,545	£4,272	£7,148
Change in 60 year energy cost	-£5,185	-£5,667	£5,544	£3,710	-£3,401	-£3,874
Change in renewals cost	£1,467	£1,455	£3,268	£3,256	£873	£898
Change in maintenance cost	£0	£826	-£2,002	-£1,177	£0	£826
Change in lifetime cost	£3,339	£7,710	£11,316	£14,334	£1,744	£4,998

Lifetime cost category	Semi 3. Improved with ASHP	Semi 4. Advanced with ASHP	Mid-terrace 1. Improved with Gas	Mid-terrace 2. Advanced with Gas	Mid-terrace 3. Improved with ASHP	Mid-terrace 4. Advanced with ASHP
Reference heating system	Gas	Gas	Gas	Gas	Gas	Gas
Change in capital cost	£3,154	£6,030	£3,996	£6,581	£2,878	£5,463
Change in energy cost	£3,412	£2,236	-£3,352	-£3,755	£3,463	£2,089
Change in renewals cost	£3,203	£3,228	£860	£850	£3,190	£3,180
Change in maintenance cost	-£2,002	-£1,177	£0	£826	-£2,002	-£1,177
Change in lifetime cost	£7,767	£10,318	£1,504	£4,501	£7,529	£9,555

Lifetime cost category	Flat (average) 1. Improved with Gas	Flat (average) 2. Advanced with Gas	Flat (average) 3. Improved with ASHP	Flat (average) 4. Advanced with ASHP	Semi 1. Improved with ASHP	Semi 2. Advanced with ASHP
Reference heating system	Gas	Gas	Gas	Gas	ASHP	ASHP
Change in capital cost	£2,363	£4,890	£3,726	£6,253	£4,322	£7,198
Change in energy cost	-£1,521	-£1,932	£3,092	£1,842	-£4,076	-£5,252
Change in renewals cost	£561	£932	£3,655	£4,025	£2,577	£2,602
Change in maintenance cost	£190	£1,016	-£962	-£137	£0	£826
Change in lifetime cost	£1,593	£4,906	£9,510	£11,983	£2,823	£5,374

1.15 Comparison with Sullivan Report recommendations

200. Carbon emission savings were also estimated using a single analysis year and SAP 10.1 carbon emission factors, to provide a comparison with Sullivan Report recommendations. The same build rates and fuel mix were used as for the core ‘with fossil fuels’ analysis above (see Table 1.11i), and it was assumed that 100% of homes were built to 2021 standards in the year assessed. The SAP 10.1 carbon emission factors (as shown in Table 1.5p) were applied to the energy results summarised in Table 1.11e to Table 1.11h.

201. The two counterfactual cases (‘improved’ and ‘advanced’) were again compared to the 2015 compliant base case. The estimated total carbon emissions and savings for the year are summarised in Table 1.15a. The percentage reductions are higher than in the benefit analysis for the core scenario presented in section 1.12 above mainly due to differences in carbon emission factors. The figures show that the ‘improved’ case is estimated to achieve a reduction of around 32% in carbon emissions compared to the base case across the build mix; and the ‘advanced’ case to achieve a reduction of around 57%. This compares to a commitment in the Sullivan Report to achieve an aggregate emissions reduction of at least 27.5% on 2015 standards across the build mix; indicating that either case would exceed this target.

Table 1.15a: Total carbon emissions and savings for base, improved and advanced cases – Sullivan Report comparison (based on a single year and SAP 10.1 carbon emission factors)

Scenario	Total carbon emissions for the year ($ktCO_2e/yr$)	Total carbon saving for the year ($ktCO_2e/yr$)	% reduction compared to base case
Base	23	0	-
Improved	16	7	32%
Advanced	10	13	57%

Source AECOM modelling using assumptions on build and fuel mix as set out above, and using SAP 10.1 energy modelling results and carbon emission factors as set out above.
Results recorded in AECOM, ‘210507 Scotland Building Standards 2021 - SAP10.1 Results – v10.xls’

1.16 Sensitivity analysis

202. Analysis of the EPC database extract provided by Scottish Government showed that gas-heated and ASHP-heated dwellings account for the majority of recent new build homes within Scotland. However, sensitivity analysis was undertaken to investigate the ability of dwellings to comply with potential 2021 standards where fuel/heating types other than gas and ASHP were specified. The heating types chosen for assessment were in part based upon analysis of the EPC database extract, as well as upon investigating cases where in discussion with the client it was thought that particular questions might arise which require further consideration from a policy perspective.

203. The analysis of the EPC database extract showed that the most common other heating types were oil and district heating, with each respectively accounting for around 3% of homes in the database extract. These were followed by direct electric (around 2.5% of homes), then LPG (under 1%) and biomass (under 0.5%). The EPC database extract is

discussed in more detail in section 1.4, with key findings on heating type presented in Table 1.4a.

204. Based on this analysis, oil, direct electric, and district heating for gas, heat pumps, and energy from waste were evaluated. Sensitivity analysis was undertaken to assess the ability to comply with potential 2021 standards.

205. For oil, the ratio of the gas carbon emission factor to the oil carbon emission factor in SAP 10.1 is 1:1.42, whereas the ratio of the gas primary energy factor to the oil primary energy factor is around 1:1.04.[30] This means that a carbon target would be significantly more challenging than the primary energy target.

206. For direct electric storage heating, the ratio of gas carbon emission factor to electricity carbon emission factor in SAP 10.1 is 1:1.54, whereas the ratio of the gas primary energy factor to electricity primary energy factor is around 1:33. This means that a carbon target would be more challenging than the primary energy target.

207. A key benefit of gas CHP arises from offsetting grid electricity with that generated from the CHP engine. With electricity carbon emission and primary energy factors reducing over time, the benefits associated with gas CHP electricity generation are significantly reduced making gas CHP less attractive than previously and making it harder for gas CHP heat networks to comply. A carbon target would also be more challenging than the primary energy target due to reductions in carbon emission factors for electricity. Whilst the primary energy factors for electricity have reduced, there is a significantly greater percentage reduction for carbon emission factors. The ratio of the gas carbon emission factor to the electricity carbon emission factor in SAP 10.1 is 1:0.65, and the ratio of the gas primary energy factor to the electricity primary energy factor is 1:1.33. This compares to comparable ratios of 1:2.4 and 1:2.52 in SAP 9.92. In terms of both primary energy and carbon emissions, district heating also requires additional measures to comply compared to an individually-heated gas case because of the distribution losses associated with the heat network.

208. For heat pump fueled district heating, the ratio of carbon emissions and primary energy factors compared to gas are the same as for direct electric storage heating which would mean a carbon target would be more challenging than the primary energy target.

209. For a district heating scheme which uses waste combustion for heat, the ratio of gas carbon emission factor to waste combustion carbon emission factor in SAP 10.1 is 2.84:1, whereas the ratio of gas primary energy factor to waste combustion primary energy factor is 1:1.03. This means that a carbon target would be much easier to comply with than a primary energy target.

- While the primary energy ratio is nearly equal it does not mean that a waste combustion heat network would be similar to a gas based heat network in terms of compliance; as the waste fuel has a more varied calorific value than gas due

[30] Oil has higher primary energy and carbon emission factors than LPG, so if oil-heated homes complied with potential targets given a certain specification then it would be expected that LPG-heated homes would too, but with the potential for relaxation in the specification.

to the nature and variety of waste. This means that a waste fueled boiler or CHP engine would likely have a much lower heating efficiency, and therefore be required to burn much more waste to produce the same heat output.

- This situation is the same for waste heat from a power station which has a similar ratio of gas primary energy factor to waste heat from a power station primary energy factor.

210. The following sensitivity cases were modelled. In each case the same individual built forms were used as in the core modelling, and compliance was tested against the relevant 2021 'improved' case (gas/ASHP) in terms of primary energy. Carbon emissions were also compared to aid in the assessment of a potential secondary carbon metric. For all fuel/system types, the sensitivity cases included PV.

- Oil:
    - A detached house with an oil boiler was modelled as the majority of oil-heated dwellings in the database extract were detached houses.
    - The primary energy and carbon emission results were compared to those of the 2021 'gas improved' case.
- Gas CHP district heating:[31]
    - A mid-floor flat was modelled as the majority of dwellings on district/communal heating in the database extract were flats.
    - It was assumed that gas CHP provided 75% of the annual heat supplied, with gas boilers providing the remainder.
    - A distribution loss factor of 1.5 was assumed, which corresponds to the value assumed in SAP for heat networks complying with the Heat Network Code of Practice for the UK (CIBSE; ADE, 2015).
    - The primary energy and carbon emission results were compared to those of the 2021 'gas improved' case.
- Heat Pump (+ gas CHP) district heating:
    - A mid-floor flat was modelled as the majority of dwellings on district/communal heating in the database extract were flats.
    - It was assumed that the district heating network was supplied by electric heat pump for 40% of the annual heat supplied, with gas CHP providing 50% and gas boilers providing the remainder.
    - A distribution loss factor of 1.5 was assumed, which corresponds to the value assumed in SAP for heat networks complying with the Heat Network Code of Practice for the UK (CIBSE; ADE, 2015).

[31] The case can be seen as an example of an existing heat network which is being expanded for new homes to connect. It could be expected that there will be greater encouragement for future new heat networks to adopt lower carbon heat sources.

- The primary energy and carbon emission results were compared to those of the 2021 ‘gas improved’ case and the 2021 ‘ASHP improved’ case.

- Energy from waste district heating:
  - A mid-floor flat was modelled as the majority of dwellings on district/communal heating in the database extract were flats.
  - It was assumed that the district heating network was supplied by a waste combustion fueled CHP that is operational for 90% of the year. When operating it is assumed 100% of the heat consumption is met by the heat generated by the plant. When the plant is offline for maintenance it is assumed gas boilers provided 100% of the heat consumed.
    i. The CHP is assumed to be part of an Energy from Waste plant which is electrically led with a power efficiency of approximately 25%, and heating efficiency of approximately 14%.[32]
  - A distribution loss factor of 1.5 was assumed, which corresponds to the value assumed in SAP for heat networks complying with the Heat Network Code of Practice for the UK (CIBSE; ADE, 2015).
  - The primary energy and carbon emission results were compared to those of the 2021 ‘gas improved’ case.

- Direct electric:
  - A detached house and a mid-floor flat were modelled.
  - An electric storage heater system was modelled for both buildings, with secondary heating provided by room heaters. Water heating was provided by immersion heaters.
  - The primary energy and carbon emission results were compared to those of the 2021 ‘gas improved’ case and the 2021 ‘ASHP improved’ case.

211. For each sensitivity case, the 2021 ‘improved’ case specifications (including WWHR and PV) were initially modelled (with heating systems changed). This provided an initial comparison, but as expected the primary energy and carbon emissions were higher than in the ‘gas improved’ case (so the specifications would not achieve ‘compliance’ should these be the 2021 targets). The ‘advanced’ case specifications (including WWHR and PV) were then modelled to see whether these would comply. If not, or if they over-complied, then adjustments were made to see what would bring them closer to compliance.

212. In terms of adjustments made, lower capital cost measures were applied first where possible, with cost-effectiveness also being considered (fabric was generally prioritised before MVHR, and wall/floor improvements before windows). The modelling did not look beyond the ‘advanced’ case specifications in terms of fabric or ventilation, but did look at a higher efficiency PV panel where the advanced case did not achieve compliance alone. This assumed an efficiency of 4.5 m^2/kWp (as opposed to 6.5 m^2/kWp in the core

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[32] Performance data sourced from recent energy from waste CHP assessment for a power led plant providing 14.3MW_{th} average heat output and 66.1MW_e average power export.

cases). The analysis is indicative of the scale of additional measures necessary for compliance.

213. For the oil sensitivity case, the following findings were observed:

- to achieve compliance in terms of primary energy alone, the ‘improved case’ specification could be adopted but with wall, floor and thermal bridging values adjusted to the ‘advanced case’ specification (i.e. wall U-value 0.13, floor U-value 0.10, and y-value 0.04).
- to achieve compliance in terms of carbon emissions, if a carbon metric were to be set, a specification close to the ‘advanced case’ specification would be expected to be required (the advanced case itself would slightly over-comply with a difference in dwelling emission rate of around 0.3kgCO_2e/m^2/yr).

214. For the gas CHP district heat network sensitivity case, the following findings were observed:

- to achieve compliance in terms of primary energy alone, the ‘advanced case’ specification would not be sufficient. If a higher efficiency PV panel was also to be adopted, this would comply and there could be some relaxation elsewhere of the advanced specification (e.g. if the window specification was relaxed to double glazing, this would still be very close to compliance).
- in terms of carbon emissions, even if the ‘advanced case’ specification were adopted and a higher efficiency PV panel to be specified, the case would still be far off compliance if a carbon metric was to be set (with a dwelling emission rate over 30% higher than that for the comparison individually-heated gas ‘improved’ specification case).
- It should be noted that the mid-floor flat would be expected to form the most challenging example in terms of compliance of all the core dwelling types modelled. Block averaging across flats may also help to some degree in this case.

215. For the heat pump (+ gas CHP) district heat network sensitivity case, the following findings were observed:

- to achieve compliance in terms of primary energy alone the ‘advanced case’ specification would not be sufficient when compared to the 2021 ‘ASHP improved’ case. If a higher efficiency PV panel was also to be adopted, this would comply and there could be some relaxation elsewhere of the advanced specification (e.g. relaxing the window specification to double glazing). When compared to the 2021 ‘gas improved’ case the ‘advanced case’ specification would be sufficient to comply. The ‘improved case’ specification would not be sufficient to comply in either case.
- in terms of carbon emissions, the ‘advanced case’ specification would be sufficient to comply against the 2021 ‘gas improved’ case but not against the 2021 ‘ASHP improved’ case. Even if the ‘advanced case’ specification were adopted and a higher efficiency PV panel to be specified, the carbon emissions would still be approximately two and a half times higher than the ‘ASHP

improved' target. The 'improved case' specification fails to comply against both the 2021 'gas improved' case and the 2021 'ASHP improved' case.

- It should be noted that the mid-floor flat would be expected to form the most challenging example in terms of compliance of all the core dwelling types modelled. Block averaging across flats may also help to some degree in this case.

216. For the energy from waste district heat network sensitivity case, the following findings were observed:

- to achieve compliance in terms of primary energy alone, neither the 'improved case' or 'advanced case' specification achieved compliance against the 2021 'gas improved' case. The primary energy for the 'advanced case' specification was approximately five times that of the 'gas improved' case target. The cause of this difference is the low efficiency of a waste to energy plant (14% heat and 25% power) compared to a gas boiler (approximately 90%) which is not matched by a comparable reduction in the primary energy factor of waste as a fuel. The combustion process of waste is inherently less efficient than a fuel such as gas due to the mixed composition and high moisture content. The fact that the waste would otherwise go to landfill is not accounted for in the primary energy factor given to waste in SAP leading to high primary energy consumption associate with waste combustion, even as a CHP process
- in terms of carbon emissions, neither the 'improved case' or 'advanced case' specification achieved compliance against the 2021 'gas improved' case. The 'advanced case' specification failed to comply by approximately 25%.
- It should be noted that the mid-floor flat would be expected to form the most challenging example in terms of compliance of all the core dwelling types modelled. Block averaging across flats may also help to some degree in this case.

217. For the direct electric sensitivity case, the following findings were observed:

- to achieve compliance in terms of primary energy alone, the 'advanced case' specification would be sufficient for both the detached house and mid-floor flat for both the 2021 'gas improved' case and the 2021 'ASHP improved' case (achieving around 30% improvement on the 2021 'gas improved' case and a 5% improvement on the 2021 'ASHP improved' case). The 'improved case' specification would not be sufficient for compliance against either the 2021 'gas improved' case or the 2021 'ASHP improved' case.
- in terms of carbon emissions, the 'advanced case' specification would be sufficient for both the detached house and mid-floor flat for both the 2021 'gas improved' case and the 2021 'ASHP improved' case (achieving around 80% improvement on the 2021 'gas improved' case and a 40-50% improvement on the 2021 'ASHP improved' case). The 'improved case' specification would not be sufficient for compliance against the 2021 'ASHP improved' case but would comply with the 2021 'gas improved' case (producing around 50% of the carbon emissions compared to the 2021 'gas improved' case for both the detached house and mid-floor flat).

There is a policy decision as to whether a gas or ASHP notional building should be used for direct electric heating. The analysis shows that a direct electric compliant solution is possible with a specification between ‘improved’ and ‘advanced’ for both heating system types with an ASHP notional building resulting in a more stringent target. Direct electric heating is a well-established technology that has lower carbon emissions compared to fossil fuels. However, direct electric heating is much less efficient than a heat pump and as a result fuel bills are more expensive than gas heating and, if deployed at scale, will have greater impact on the national grid.

1.17 Review of the need for a carbon target

218. The Scottish Government has indicated the intention to retain the carbon dioxide equivalent emissions target as an additional secondary metric. The Scottish Government is looking to drive down greenhouse gas emissions and will need to continue to record progress against national carbon targets. There was also support for a carbon target from several respondents to the Scottish Government’s 2018 call for evidence on energy standards, as discussed in section 1.7.2 above.

219. Primary energy and carbon dioxide emissions targets can have different impacts depending on the fuel type and on how the notional dwelling is set. As a result of grid decarbonisation, carbon emission factors for electricity are now significantly lower than gas whilst primary energy factors for electricity remain higher than gas. This would make carbon targets more challenging for gas-heated homes than primary energy targets if these were set based on a single electric-heated notional. However, given that the proposed preferred approach is to set a notional building differentiated by fuel type (gas / ASHP), the addition of a carbon metric would not be expected to have the impact of making it more difficult for gas-heated dwellings to comply.

220. Adopting a secondary carbon target would not be expected to impact on the compliance specification for direct electric-heated dwellings (whether based on a gas-heated or ASHP-heated notional), as in these cases the primary energy target is more challenging. Similarly, a carbon target would not be expected to impact on biomass-heated homes as the primary energy target would be much more onerous than a carbon target (as carbon emission factors for biomass are very low). The impact of a secondary carbon target would be on some of the other less commonly used (but higher carbon) fuel types / heating systems.

221. A potential benefit of setting a carbon target would be to introduce more differentiation between gas and higher carbon fossil fuels such as oil and LPG. Under the 2015 standards, the notional is differentiated into five cases – gas, LPG, oil, electricity (ASHP-based), and biomass. The same specifications are applied for gas, LPG and oil except for fuel/boiler type and assumptions on secondary heating. This means that there is no disincentive for higher carbon fossil fuels than gas. As shown in the sensitivity analysis described in section 1.16, comparing all higher carbon fuel types to a 2021 gas notional building with a primary energy target will make it more challenging for higher carbon fuels to comply compared to gas, albeit the impact is limited, particularly for LPG, as the primary energy factors are similar to gas. If an additional carbon target is adopted, it is much more onerous for higher carbon fuels to comply as their carbon emission factors are significantly higher than that of gas. Given the policy intention of phasing out fossil fuels in 2024, it could make sense to introduce a greater disincentive for higher carbon fossil fuels in 2021 which reflects their carbon impact.

222. Similarly, a secondary carbon target would introduce more differentiation between individually gas-heated homes and homes on a gas CHP-based heat network. However, as shown in section 1.16, it would be very challenging for such homes to comply with a carbon target. This may make sense in terms of reflecting carbon impact, but there may also be other strategic reasons for wanting to allow new homes to continue to connect to existing gas CHP-based heat networks. Proposals for Part L 2020 in England and Wales have reflected this through the proposed introduction of technology factors for heat networks but there could be other approaches taken. These may not necessarily be primarily within the remit of Building Standards and the notional building targets – though one possible option could be to explore a district heating based notional building sub-type (or sub-types). Differentiation between new and existing heat networks may also be useful - new heat networks could potentially be treated differently as they may be encouraged to adopt lower carbon fuels, whereas gas CHP-based networks could be more likely to be existing networks being expanded for new homes to connect. The approach for non-domestic buildings should be considered at the same time, as similar findings would be expected there, and it may be appropriate to have a common approach.

223. Whilst the implications of a secondary carbon metric have not been considered in detail for all possible fuel types or heating systems, the ones considered particularly relevant for new homes in Scotland have been discussed above. Further sensitivity analysis covering a wider range of fuel/dwelling types or specifications could also be undertaken, and other views could be sought.

224. The analysis suggests that there would be benefits of applying a secondary metric based on carbon, in terms of encouraging a move away from higher carbon fossil fuels and heating systems, and provides an indication of what specifications might be needed should developers still continue to specify such systems.

225. It also finds that a carbon metric would raise significant challenges for gas CHP district heating. It may be that separate policy changes or mechanisms are needed to address this challenge if the Scottish Government takes the view that it wishes to continue to encourage gas CHP district heating.

1.18 Accounting for energy efficient design in target setting

226. As touched upon in section 1.6, there are aspects of the notional building target setting methodology which may not always reward all aspects of energy efficient design. One of the issues which has been raised previously within industry is the lack of incentive for design changes which improve thermal efficiency through adjustments to built form and shape. Because the notional building dimensions used for target setting are defined as being the same as the actual building dimensions, this means that built forms which have lower external wall areas (such as semi-detached compared to detached houses) and designs which adopt more simple rectangular shapes in terms of layouts are not directly rewarded for reduced heat loss area since the target emission/primary energy rate changes as well as the design emission/primary energy rate when they are altered. This issue was the subject of a report by NHBCF in 2016 (NHBC Foundation, 2016) and was also raised by some respondents to the Scottish Government’s 2018 call for evidence on energy standards – as discussed in section 1.7.2 above.

227. The NHBCF report presented the idea of a ‘form factor’, which can be used to compare the relative efficiency of different built forms and shapes. In the report, it was calculated as follows:

- Form Factor = Total heat loss area of exposed walls[33], roofs, floors and openings (m^2)/ Total Floor Area (m^2)

228. Some limited analysis was undertaken as part of the current project to compare form factors and key results for the core dwelling types which reflect different built forms. The aim was to assess whether differences in form factor could potentially be used to modify the performance targets set by the notional building (i.e. primary energy, or carbon if used as a secondary target metric).

229. It should be noted that the basis for the calculations undertaken was different from that used in the NHBCF report which compared five dwelling types with the same total floor area but different forms (i.e. flat, mid-terrace, semi-detached, detached and bungalow, all with simple rectangular layouts). The comparison within the current project did not compare like-for-like total floor areas but was undertaken to give an idea of trends within form factor and energy results for the different core dwelling types, to inform a discussion of how energy efficient design could potentially be rewarded within Building Standards. Similar to the NHBCF dwelling types, the core dwelling types in the current analysis all have simple layouts – so comparison focuses on built form rather than built shape.

230. The analysis compared form factors and primary energy results across the dwelling types modelled. It found that there was not a simple relationship between form factor and primary energy. Comparisons of primary energy results across dwelling types would also be impacted by assumed heating type which could be problematic depending on how any modification was implemented. Similar observations would be expected where carbon emissions were being compared. Previous analysis for Part L in England showed similar findings – even where different dwelling forms and shapes with the same total floor area and fabric specification were compared – and also showed that there were a number of variables relating to the differences in built form which impacted on primary energy results (for example, relative U-values and areas of different exposed elements; thermal bridging lengths and resultant y-values). The NHBCF report noted other variables impacting on results when looking at built shape as well.

231. The analysis also compared form factors and space heating demands. These are less affected by heating system design (though water heating gains have some impact). The relationship here appears somewhat clearer – with dwellings with higher form factors

[33] The NHBCF calculations excluded party walls from the calculation (and possibly also semi-exposed walls, though this is not clear from the report). If form factor was to be assessed in order to inform modifications to notional building targets, there might be a question of whether party walls should be included given that there can be heat loss associated with these walls. However, this would not be expected to substantially change the findings observed in the current report. In the current analysis, semi-exposed walls were included in the form factor calculations.

having higher space heating demands, as would be expected and as also shown in the NHBCF report.[34] However particularly given the small sample of dwelling types modelled there is not enough evidence to define this relationship more precisely or to base a potential policy change upon.

232. Further work would be needed to establish if there was a means of using form factors to inform the adjustment of notional building targets which would reflect differences in space heating demands in a robust and fair way, avoiding loopholes and unintended consequences. This would need to consider a wider range of dwelling types. Challenges would include determining on what basis a good practice comparison form factor case would be set, and how this would be applied – for example within SAP or without. As an example, a notional building within SAP could be used where a standardised built form was considered, but this would potentially be very complex to define, and reflecting good practice in terms of shape would be potentially still more challenging. Alternatively, form factors could perhaps be used to implement a change outside of the notional building by applying an adjustment factor or penalty to the main proposed target metric of primary energy, or to a secondary carbon target metric, but the above analysis suggests that this would also be challenging to implement well.

233. These observations arguably reflect those implied in the NHBCF report, which noted in its conclusions section that “it is not possible to quote a single ‘best practice’ value of Form Factor at which designers might aim” (p.21), and focused on the idea of promoting greater understanding of form factor – suggesting that efficient building shape should be included as a key design consideration for new homes (as is stated in the Passive House standard).

234. As already discussed in section 1.6, there are various alternative approaches to encouraging design optimisation for energy efficiency beyond adjusting the notional building definition or targets. For example, setting limits directly onto space heating requirements can do this, particularly if they are defined in absolute terms (as in the current optional targets in Section 7 of the Domestic Technical Handbook). Given the findings of the above analysis this might be a more pragmatic approach to consider further, and it has the benefit of being a metric which already has currency within industry given its use in Section 7 and in the Passive House standard for example. As already noted in section 1.6 of the current report, the Section 7 targets would potentially need reviewing/checking to align with improvements made to Section 6 standards, to identify how changes in the methodology in SAP 10.1 may affect the figures, and perhaps also to generally review their evidence base including consideration of a range of dwelling types.

[34] Unless consistent floor areas were being compared across dwelling types, the relationship would also be different if space heating demands were looked at in terms of per square metre of floor area as opposed to total annual demands.

Task 4: Full Cost Benefit Analysis

1.19 Cost benefit analysis

235. Based on the build/fuel mix, capital and lifetime costs, benefits and transition period defined in Section 5, the national costs and benefits for the improved and advanced 'with fossil fuel' cases compared with continuation of the existing 2015 standards are shown in Table 1.19a. The analysis is based on the HM Treasury Green Book standards and the accompanying supplementary guidance on the valuation of energy use[35]. Relevant assumptions include:

- Energy savings are valued at the variable rate in accordance with the supplementary Green Book guidance. This is appropriate for social analysis and assumes that the retail energy savings enjoyed by the consumer occupying an energy efficient building does not fully reflect the social benefit.

- The appraisal time period for estimating the impact of the policy is 10 years with a consistent build rate and mix in each year equivalent to that forecast for 2021. We assume a 60 building life from the year of construction resulting in a total model period of 70 years.

- A discount rate of 3.5 per cent has been used for the first 30 years of building life and 3 per cent for subsequent years.

- Construction costs are in 2020 prices energy and carbon prices and costs are in 2019 prices all results are presented in line with a 2021 policy implementation year.

- Similar to the approach taken in MHCLG's recent consultation Impact Assessment (MHCLG, 2019h), this analysis does not include any comfort taking for new dwellings.

[35] Valuation of energy use and greenhouse gas emissions for appraisal (April 2019)

Table 1.19a: Summary of results from cost benefit analysis: total over the appraisal period

Element	Section 6 2021 Improved fabric, no change in heating fuel	Section 6 2021 Advanced fabric, no change in heating fuel
Energy savings (£M)	417	483
Incremental costs (£M)	(609)	(1,171)
Total financial benefit/(cost) (£M)	**(192)**	**(688)**
Carbon savings - non-traded (£M)	153	346
Carbon savings - traded (£M)	36	31
Total carbon savings (£M)	189	377
Air quality savings (£M)	50	61
Net benefit/(cost) (£M)	**46**	**(250)**

Amount of gas saved (GWh)	9,647	24,122
Amount of electricity saved (GWh)	12,087	10,621
Amount of CO_2 saved, non-traded ($MtCO_{2(e)}$)	2	5
Amount of CO_2 saved, traded ($MtCO_{2(e)}$)	1	0
Cost effectiveness, non-traded (£/tCO_2)	50	125
Cost effectiveness, traded (£/tCO_2)	(19)	594

236. The results show that Option 1 results in a net benefit of £46m once the benefits of carbon savings are considered, while Option 2 results in a net cost of £250m. This difference is principally driven by the incremental capital, renewal and maintenance costs associated with Option 2 being nearly double those for Option 1. While Option 2 delivers a larger saving in energy use compared to Option 1, the difference in energy costs is relatively small at just over 15%. The smaller difference in energy costs between Options 1 and 2 is in part due to the increased electricity consumption for Option 2 as a result of the use of MVHR in homes built to these specifications. While this additional electrical consumption has little impact on carbon emissions it does increase running costs.

Conclusions

237. The aim of this project was to assess and identify potential improvements in energy and emissions performance for new domestic and non-domestic buildings constructed in Scotland set via Standard 6.1 (carbon dioxide emissions). This was to inform the setting of targets within the next set of energy standards, programmed for implementation in 2021. This report focuses on the project findings for new domestic buildings.

238. Improvements to the current notional (reference) building were identified based on an analysis of where construction in Scotland is already going beyond the current notional building specifications, and relevant literature including Part L consultation options in England and in Wales. These improved measures were assessed based on various criteria including their relative cost-effectiveness, feasibility and associated risks (e.g. poor indoor air quality and summer overheating). Based on this, two new alternative standards (“Option 1” and “Option 2”) were proposed and their benefits and costs were assessed at an individual building and national level.

239. Option 1 comprises improvements to the fabric efficiency of the notional building and the inclusion of WWHR. Option 2 includes further improvements, including (but not limited to) triple glazing and the adoption of MHVR with improved air tightness. Developers can build to alternative specifications as long as they meet, or improve upon, the performance of the notional building.

240. The intention was, if practical, to base the notional building on a single fuel/heating system type. This would simplify the current approach where the fuel in the notional building depends on that included in the actual building. It could also help encourage the transition to lower carbon fuels. For both options, it is proposed that the notional building is based on gas heating + PV, with typically an increase in the array size compared to the current notional building. An exception is proposed if a heat pump is used in the actual building, where an air source heat pump (ASHP) is included and the PV element removed in the notional building. This is to help address the concern that using a heat pump in practice could significantly over-comply if compared to a gas-heated notional building with potentially an opportunity for a significant relaxation in fabric energy efficiency even with an improvement in the backstop values.

241. It is noted that the Scottish Government has indicated that for the next (2024) revision of Building Standards, the intention is to move to renewable or low carbon heating systems in new homes. One method to delivering this would be to build from the proposed approach for notional buildings to be based on an ‘ASHP only’ specification whatever the fuel in the actual building; this would result in a demanding target that would make it difficult for fossil fuel based heating to comply.

242. Options 1 and 2 are estimated to reduce carbon emissions by 32% and 57% respectively across the build mix. This was evaluated using the SAP 10.1 methodology, including SAP 10.1 carbon emission factors, across 7 buildings selected to represent common building and fuel types in Scotland. This compares to a recommendation in the 2007 Sullivan Report to achieve aggregate emission reductions equating to at least 27.5% on 2015 standards. Hence both options would meet this commitment.

243. It is estimated that Options 1 and 2 for a semi-detached home, as an example, will increase the capital costs by 4% and 7% respectively if gas heating + PV is used. This cost is reduced if ASHP is used, increasing the capital cost by 3% and 6% respectively, providing encouragement to lower carbon fuels. In general, it is estimated that the capital cost is lower for an ASHP for individual homes but higher for apartment buildings. A key reason for this difference for apartment buildings is that the amount of PV required is based on the foundation area of the building which reduces the cost of PV per apartment unit (and makes the gas heating + PV option more attractive) as the number of storeys increases.

244. The national cost benefit analysis shows that Option 1 results in a net benefit of £46m whilst Option 2 results in a net cost of £250m. This difference is driven by the incremental capital, renewal and maintenance costs for Option 2 being nearly double those for Option 1 and this negates the greater savings in energy use from Option 1.

245. In response to a 2018 amendment of the Energy Performance of Buildings Directive. the Scottish Government proposes that primary energy becomes the main target metric for building regulations compliance. Sensitivity analysis based on oil and gas CHP district heating, both higher carbon options than individual gas boilers, suggests that if the carbon emission target is retained as a secondary metric it will help encourage lower carbon fuels.

- A detached house with an oil boiler was modelled and the primary energy and carbon emission results were compared to the Option 1 ‘gas’ notional building. To comply with both the primary energy and carbon targets, the ‘advanced’ fabric efficiency specifications would be required. The carbon target was the most stringent of the two targets and dictated the compliant solution.
- A mid-floor flat with a gas CHP was modelled and the primary energy and carbon emission results were compared to the Option 1 ‘gas’ notional building. In this case it was not possible to comply with both the primary energy and carbon targets with the ‘advanced case’ specification and a higher efficiency PV panel. This was particularly dictated by the more stringent carbon target.

The Scottish Government does need to consider this within its broader strategic goal to encourage district heating. It also needs to consider that energy from waste district heating performs very poorly against the Option 1 ‘gas’ notional building primary energy target which does not account for the fact that waste would otherwise go to landfill.

246. There is a policy decision as to whether direct electric heating should be compared to the ‘gas’ or ‘ASHP’ notional building. Sensitivity analysis showed that a direct electric solution could comply both with the Option 1 ‘gas’ notional building and the Option 1 ‘ASHP’ notional building using a specification somewhere between ‘improved’ and ‘advanced’ – the Option 1 ‘ASHP’ notional building being more demanding. Direct electric heating is a well establishing technology and lower carbon compared to gas heating but less efficient than a heat pump resulting in higher fuel bills than gas heating and, if adopted at scale, a greater impact on the national grid.

247. The analysis also considered where the notional building target setting methodology may not reward energy efficient design. In particular the analysis focussed on the lack of incentive for improved efficiency through adjustments to built form and shape as the

notional building dimensions used for target setting are defined as being the same as the actual building dimensions. One approach identified is to use a ‘form factor’ in the target setting methodology based on the total heat loss area per unit floor area. Analysis suggests a correlation between the form factor of the building and space heating demand. Further work would be needed to establish if there is a means of incorporating form factors in the target setting methodology which would reflect differences in space heating demands in a robust and fair way across a wide range of dwelling types and avoiding unintended consequences or loop-holes.

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Appendix A: Cost Breakdown

248. The developed costs are based on the expert view of Currie & Brown's cost specialists, drawing on evidence from their internal cost datasets, recent published cost data and information provided by suppliers.

249. The cost analysis is intended to reflect typical national costs from Q1 2020 that might be incurred by a small/medium sized housebuilder using timber framed construction methods and with a reasonably efficient supply chain, design development and construction processes. However, costs incurred by individual organisations will vary according to their procurement strategies, the location of their activity (e.g. costs will be higher in more remote locations such as the Western Isles than in the Central Belt) and the detail of their housing product. These variations design, location and delivery method could result in a cost range of +/- c.30% or more (see Section 5). Notwithstanding these variations, the proportional uplifts associated with moving from one specification to another are likely to be relatively similar across different market segments[36].

250. To provide context to the cost variations assessed in the study an indicative overall build cost (£ per m^2) for each building archetype was estimated using Currie & Brown internal data. This figure is indicative of the level of cost that might be expected for a home built in accordance with the requirements of Section 6 2015. The build cost should be taken as indicative only as it is sensitive to a wide range of design and specification variables in addition to the economies of scale and regional variations discussed previously.

251. Base costs for future years are those for the 2020 price year, and subject to adjustments for learning for technologies that have not yet reached a mature market position. It should be noted that construction costs can vary considerably and rapidly with market conditions, particularly where activity levels result in a change in the availability of skills and materials. In these situations, it is not unusual to see quite large (several percentage points) change in overall costs over a period of months.

252. Table A.1 includes details of the cost information used for each specification option, including any variations between building type, costs are only shown for those specifications that vary between the considered specification options.

[36] Costs increases may be outside the described range for highly bespoke designs, however these homes are typically more expensive to build and so the relative impact on build costs may be similar or potentially smaller than for more typical homes built in higher volumes.

Table A.1 Cost data for fabric elements that vary between the selected specifications

Element	Specification	Unit	New cost (£ per unit)	Annual maintenance costs (£ per unit)*	Average life expectancy
External Wall – insulated plasterboard (30-60mm insulation), timber frame (120mm PIR insulation between studs), cavity and brick cladding	0.17 W/m².K	m²	£187	£0	60
	0.15 W/m².K	m²	£192	£0	60
	0.13 W/m².K	m²	£196	£0	60
Ground / Exposed Floor (concrete slab, rigid insulation and screed)	0.15 W/m².K	m²	£91	£0	60
	0.12 W/m².K	m²	£100	£0	60
	0.10 W/m².K	m²	£100	£0	60
Roof – mineral wool insulation between and above joists	0.11 W/m².K	m²	£216	£0	60
	0.09 W/m².K	m²	£208	£0	60
Windows uPVC	1.4 W/m².K	m²	£395	£0	30
	1.2	m²	£335	£0	30
	0.8	m²	£285	£0	30
Doors composite	1.4 W/m².K	Nr	£700	£0	30
	1.2	Nr	£800	£0	30
	0.8	Nr	£950	£0	30
Gas boiler (incl flue, pump and controls)	System boiler	Nr	£700	£100	15
	Combi boiler	Nr	£800	£100	15
ASHP	Standard (no cylinder)	Nr	£3,500	£75	15
	Higher efficiency (integrated cylinder)	Nr	£6,500	£75	15
Hot water cylinder	150l standard	Nr	£750	£0	20
	200l standard	Nr	£800	£0	20
	150l for heat pump	Nr	£880	£0	20
Waste-Water Heat Recovery	Vertical pipe system (houses and upper floor flats)	Nr	£400	£0	60
	Tray system (ground floor flats)	Nr	£1200	£0	20
Radiators (excluding heating pipework and valves)	Standard	Nr	£60	£0	20
	Sized for lower temperature heating	Nr	£90	£0	20

Element	Specification	Unit	New cost (£ per unit)	Annual maintenance costs (£ per unit)*	Average life expectancy
Extract fans	3 in large flats, 4 in semi /mid terraced and detached homes	Nr	£450-600	£0	20
MVHR unit	No ductwork	Nr	£1400	£30	20
MVHR ducting	Rigid ductwork	m^2 GIFA	£15-20	£0	60
Roof mounted - photovoltaic panels	Fixed costs for systems <4kWp	Per installation	£1,100	£48	25
	Variable costs for systems <4kWp	Per kWp installed	£800	Incl in fixed	25
	Variable costs for systems >4kWp	Per kWp installed	£1,100	£12	25

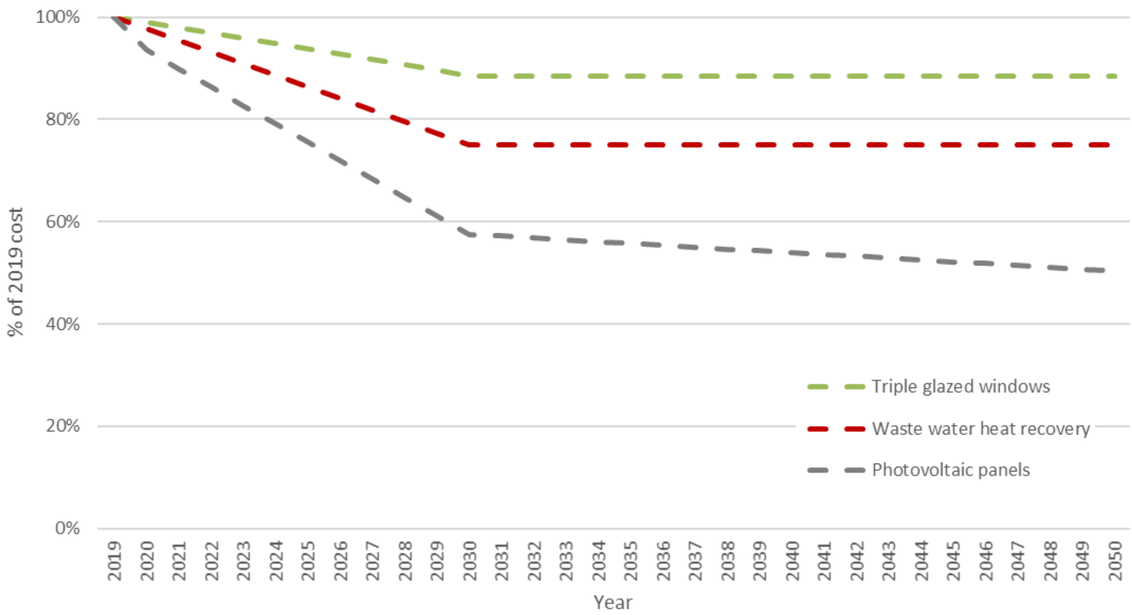
Cost projections

253. Cost projections were assigned to each specification option to capture any expected change in the current cost over time. For many building elements no adjustment was applied to the current costs because the technology is deemed mature and unlikely to experience a significant reduction in cost per unit of performance. This does not mean that cost in the future will be unchanged, only that it is not projected to change in a manner that is disproportionate to the wider construction cost base.

254. For more immature specifications, the potential for future reductions in cost through learning was assessed based on existing published cost projections or by applying appropriate learning rates to global market projections.

255. Figure A.1 shows the future cost projections of technologies relevant to this consultation. These cost projections are relative to 2019 costs and do not account for other economic and market factors that will impact costs over this period (e.g. market conditions, interest and exchange rates, skills availability and commodity prices).

Figure A.1 Projected variation in base costs as a result of learning



256. The analysis does not include any medium to long term cost savings associated with productivity gains of the sort envisaged by the Construction Sector Deal and the Construction Strategy 2025. Should these savings be realised, then this would have the effect of reducing build costs and the additional costs of more energy efficient and lower-carbon buildings, making the achievement of tighter standards more cost-effective. Further analysis of the relationship between build standards and construction productivity is ongoing.

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