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

## Non-Domestic Buildings

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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 non-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, three new alternative standards ("Low", "Medium" and "High") were proposed. Their benefits and costs were assessed at an individual building and national level.

3. The fabric standard of the "Low" option is aligned to the better of the two fabric standards used under the current Section 6 2015 standard. Further fabric improvements are included in the "Medium" and "High" options. All three options include improvements in the efficiency of most elements of building services over the 2015 standards.

4. For all three options, it is proposed that the notional building is based on gas heating plus PV with 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 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 whilst relaxing other elements of specification such as fabric.

5. The "Low", "Medium" and "High" options are estimated to reduce carbon emissions by 8%, 16% and 25% respectively across the build mix. This was evaluated using SBEM v5.6a and the proposed new carbon emission factors, across 12 building archetypes. This compares to a recommendation in the 2007 Sullivan Report to achieve aggregate emission reductions of at least 37% on 2015 standards. Hence none of these options would meet this recommendation without a move away from the use of mains gas.

6. It is estimated that the capital cost of compliant solutions comprising gas heating + PV are typically 1 – 3% higher than the current standard across the different building types and the three alternative standards. ASHP solutions are estimated to always be more expensive; in some cases this difference is very small.

7. The national cost benefit analysis shows that the "Low", "Medium" and "High" options result in a net cost of £6m, £23m and £107m respectively.

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 non-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.
- 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. As the electricity grid is decarbonising, increasingly, most emissions in 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 to 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 buildings.

### 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 several 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 31st December 2020, all new buildings should be nearly zero-energy buildings; and after 31st 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. 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. 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.

# Task 1: Establish Current Baseline

25. Task 1 is to establish the baseline from which to evaluate change. To achieve this, it is first necessary to establish the national build profile for Scotland for the analysis. This requires the derivation of a suitable number of representative building types and sub-types. Building types refer to the function of the building (office, school etc.) which sub-types represent distinct combinations of building type, heating fuel and HVAC strategy. The selected sub-types should be representative of the buildings added to the Scottish building stock over the last few years.

### 1.4 Establish the National Annual Build Profile for New Buildings

26. To derive the building sub-types an analysis has been undertaken of the EPC database for new non-domestic building over the period from January 2013 to March 2019. This analysis and the resulting sub-types are described below.

27. The EPC database contains information on each of the circa 1,800 EPCs lodged during this period. This includes several parameters such as building type, floor area, EPC rating and some information about the building fabric and services.

28. The client requested that for the purposes of this project, the building types/models should be selected from those used to support changes to building regulations for England and Wales as shown below. These models are readily available and it allows a comparison between national improvements.

| England | Wales |
|---|---|
| Office – deep plan, air conditioned | Primary School |
| Office – shallow plan, naturally ventilated | Office; naturally ventilated |
| Hotel | Office, air conditioned |
| Hospital | Hotel |
| Secondary School (includes sports facilities) | Small Warehouse/ Industrial |
| Retail Warehouse | Medium Warehouse/ Industrial |
| Distribution Warehouse | Large Warehouse/ Industrial |
| | Integrated Health Care Centre |
| | Multi-Residential |
| | A1 Retail (small food) |

29. The EPC database does not map directly to these building types but rather uses the building types embedded within SBEM which are based on the UK planning classification system. It was therefore necessary to map these planning classification categories to the building model types available; this mapping is shown in Table 1 and is based on building uses/profiles. In a small number of cases the mapping is a compromise (e.g. universities/colleges have been mapped to primary school). In some cases no logical mapping has been possible, however these cases account for less than 2% of the total floor area. Floor areas stated in Table 1 are the total floor area between January 2013 to March 2019. Given that for the first year the build-rate is significantly underestimated on the database as the requirement for the EPCs had just

commenced, it was agreed with the Building Standards Division that the floor area in this table represent a total over 5 years.

**Table 1: Mapping of EPC database building types to model types showing total database floor area**

| EPC Database Building Types | Sub-type for offices | Floor area (m²) | Floor area (%) | Available Model Types |
|---|---|---|---|---|
| Universities/college | | 519,230 | 15.0% | Primary School |
| General Assembly/Leisure | | 148,034 | 4.3% | Retail |
| Office/Workshop | Office/Workshop; Mixed-mode with Natural Ventilation; Shallow | 745 | 0.0% | Shallow Office NV |
| | Office/Workshop; Heating and Natural Ventilation; Shallow | 132,990 | 3.8% | Shallow Office NV |
| | Office/Workshop; Heating and Natural Ventilation; Deep | 62,553 | 1.8% | Shallow Office NV |
| | Office/Workshop; Air Conditioning; Deep | 441,408 | 12.8% | Deep Office AC |
| | Office/Workshop; Air Conditioning; Shallow | 25,987 | 0.8% | Deep Office AC |
| | Office/Workshop; Heating and Mechanical Ventilation; Shallow | 38,696 | 1.1% | Shallow Office NV |
| | Office/Workshop; Mixed-mode with Natural Ventilation; Deep | 2,182 | 0.1% | Shallow Office NV |
| | Office/Workshop; Mixed-mode with Mechanical Ventilation; Deep | 3,386 | 0.1% | Shallow Office NV |
| | Office/Workshop; Heating and Mechanical Ventilation; Deep | 5,005 | 0.1% | Shallow Office NV |
| Storage/Distribution | | 127,043 | 3.7% | Warehouse Distribution |
| Retail/Financial | | 296,221 | 8.6% | Retail |
| Education | | 841,403 | 24.3% | Primary School |
| Residential space | | 33,135 | 1.0% | Hotel |
| Residential school | | 59,731 | 1.7% | Hotel |
| Restaurant/Cafes/takeaway | | 33,418 | 1.0% | Retail |
| General Industrial | | 90,428 | 2.6% | Warehouse Distribution |
| Hospitals/Care Home | | 256,331 | 7.4% | Hospital |
| Stand alone utility block | | 687 | 0.0% | |
| Library/Museum/Gallery | | 34,458 | 1.0% | |
| Hotel | | 166,298 | 4.8% | Hotel |
| Emergency service | | 536 | 0.0% | |
| Community/Day Centre | | 47,610 | 1.4% | |
| Primary Healthcare Building | | 75,773 | 2.2% | Deep Office AC |
| Secure Residential Institution | | 577 | 0.0% | Hospital |
| Misc. 24 hr activity | | 61 | 0.0% | |
| Miscellaneous 24 hr activity | | 9,731 | 0.3% | |
| Passenger terminal | | 3,722 | 0.1% | |

30. Table 1 also shows how the office building type has been split into sub-types which reflect the two building forms available in the English and Welsh models (deep-plan and shallow-plan). The EPC database does not directly make this deep/shallow-plan distinction, so a definition of deep and shallow plan has been based on the ratio of building floor area to building surface area which is available in the database.

31. On this basis it was found that the EPC database contains 102 sub-type combinations of mapped building type, heating fuel and HVAC strategy. However, for this analysis, 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 if necessary on less common, but important, sub-types.

32. Selection of the most prevalent sub-types was undertaken through focussing on the most dominant heating fuels and HVAC strategies. For this purpose, it was necessary to achieve at least 5% of the total floor area represented in the EPC database. Where less than 5% was achieved, the most similar dominant strategy was identified for the analysis (an alternative would be to pro-rata across all heating fuels/HVAC strategies). This mapping is shown in Table 2 and Table 3:

**Table 2: Mapping of dominant heating fuel types.**

| Heating Fuel | Floor Area (%) | Mapped Heating Fuel |
|---|---:|---|
| Natural Gas | 62.4% | Natural Gas |
| Grid Supplied Electricity | 23.0% | Grid Supplied Electricity |
| Biomass | 8.0% | Biomass |
| District Heating | 3.3% | Natural Gas |
| LPG | 1.8% | Natural Gas |
| Oil | 1.2% | Natural Gas |
| Other | 0.1% | Natural Gas |
| Waste Heat | 0.3% | Natural Gas |
| Biogas | 0.0% | Natural Gas |
| Dual Fuel Appliances (Mineral + Wood) | 0.0% | Natural Gas |

**Table 3: Mapping of dominant HVAC strategies.**

| HVAC Strategy | Floor area (%) | Mapped HVAC Strategy |
|---|---:|---|
| Heating and Natural Ventilation | 46.3% | Heating and Natural Ventilation |
| Air Conditioning | 31.2% | Air Conditioning |
| Heating and Mechanical Ventilation | 21.9% | Heating and Mechanical Ventilation |
| Mixed-mode with Mechanical Ventilation | 0.2% | Heating and Mechanical Ventilation |
| Mixed-mode with Natural Ventilation | 0.2% | Heating and Natural Ventilation |
| Unconditioned | 0.1% | omit |

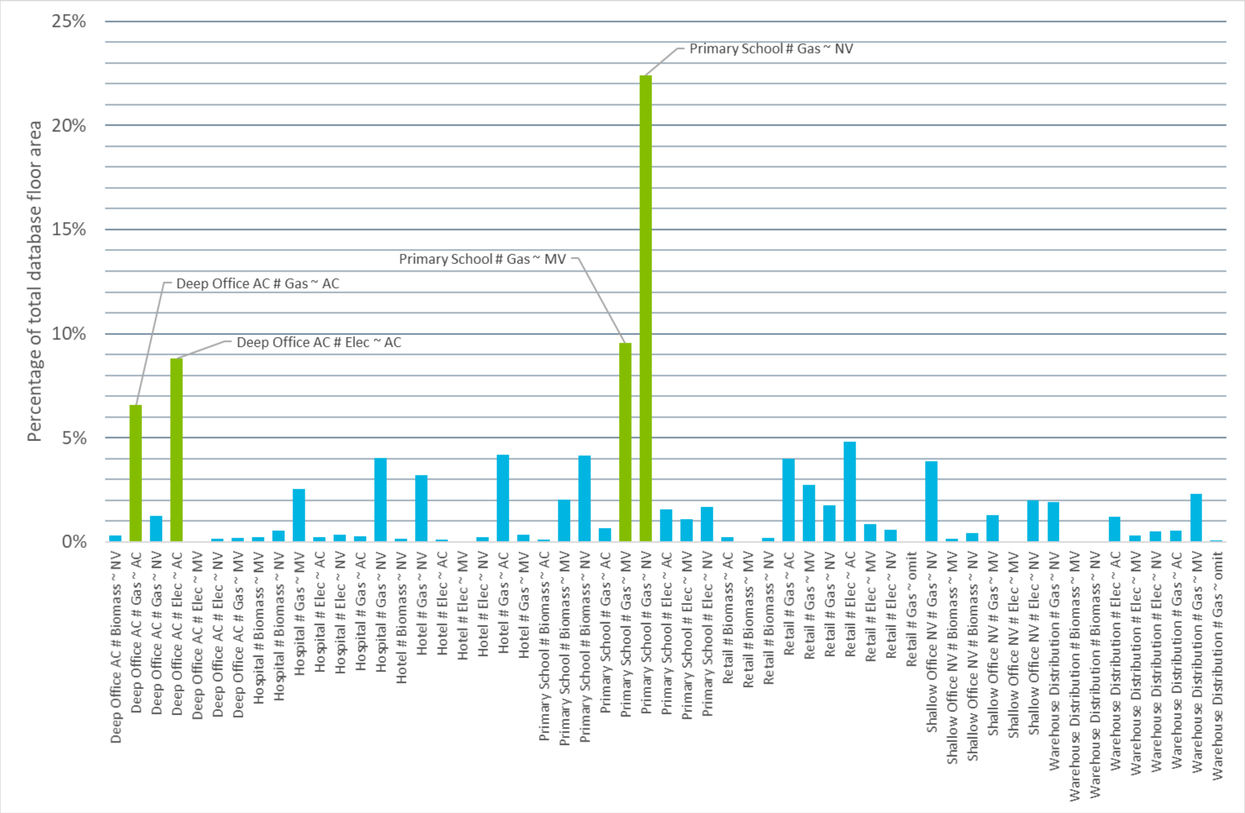

**Figure 1: Floor area percentage represented by 51 building sub-types.**

33. this basis the number of building sub-types is reduced to 44, these are shown in Figure 1. This shows that only four building sub-types account for more than 5% of the total EPC database floor area; these are highlighted in green in Figure 1. A final round of selective mapping was then undertaken to group the remaining sub-types together into groups accounting for more than 5% of the total floor area. This process mapped non-dominant sub-types together into groups accounting for more than 5% of floor area or, in some cases, mapped these to sub-types that already accounted for more than 5% individually. This process results in the twelve sub-types shown in Table 4; these include seven building types, three heating fuels and three HVAC strategies. These twelve sub-types are assumed to comprise the national build mix for this analysis. Table 5 provides a summary of the key dimensions of the seven building types used in this analysis.

**Table 4: Twelve building sub-types selected for analysis.**

| Building Sub-types | Floor Area (m²) | Floor Area (%) |
|---|---|---|
| Deep Office AC; Gas; AC | 261,444 | 8% |
| Deep Office AC; Elec; AC | 281,724 | 8% |
| Hospital; Gas; NV | 256,908 | 8% |
| Hotel; Gas; NV | 112,741 | 3% |
| Hotel; Gas; AC | 146,423 | 4% |
| Primary School; Biomass; NV | 198,659 | 6% |
| Primary School; Gas; MV | 404,090 | 12% |
| Primary School; Gas; NV | 757,884 | 23% |
| Retail; Gas; AC | 280,346 | 8% |
| Retail; Elec; AC | 197,327 | 6% |
| Shallow Office NV; Gas; NV | 245,557 | 7% |
| Warehouse Distribution; Gas; NV | 217,471 | 6% |

**Table 5: Sample building type summary of key dimensions**

| Building Type | Floor area (m²) | Number of Storeys | External Wall Area (m²) | External Glazed Area (m²) |
|---|---|---|---|---|
| Deep-plan Office | 12,100 | 5 | 4,000 | 1,500 |
| Hospital | 13,387 | 5 | 6,212 | 1,092 |
| Hotel | 1,087 | 3 | 903 | 319 |
| Primary School | 2,353 | 2 | 1,443 | 346 |
| Retail | 1,250 | 1 | 600 | 60 |
| Shallow-plan Office | 2,160 | 3 | 1,218 | 487 |
| Distribution Warehouse | 5,262 | Warehouse=1 storey<br>Integral office=2 stories | 2,463 | 684 |

34. In general, the building models will be those used for similar building regulations analysis in England. The one exception is the retail category where there was further investigation as to whether it is best represented by the small retail unit used for analysis in Wales or the larger retail warehouse used for the English analysis. The Welsh retail unit is a small detached retail building with a small office and storage and has a floor area of 1,250m² and the English retail warehouse is a detached building including a large retail floor and back-of-house office and other staff facilities including changing rooms and kitchen with a total floor area of 5,262m². Figure 2 shows the floor area distribution of the retail building category in the EPC database. This shows that there is a small number of retail units with large floor areas (typically one or two units of each size over around 3,000m²) but most retail floor area is in units with floor areas between 1,000m² and 3,000m². On this basis it is recommended that the smaller Welsh retail unit is used for this analysis as its floor area falls within this range.

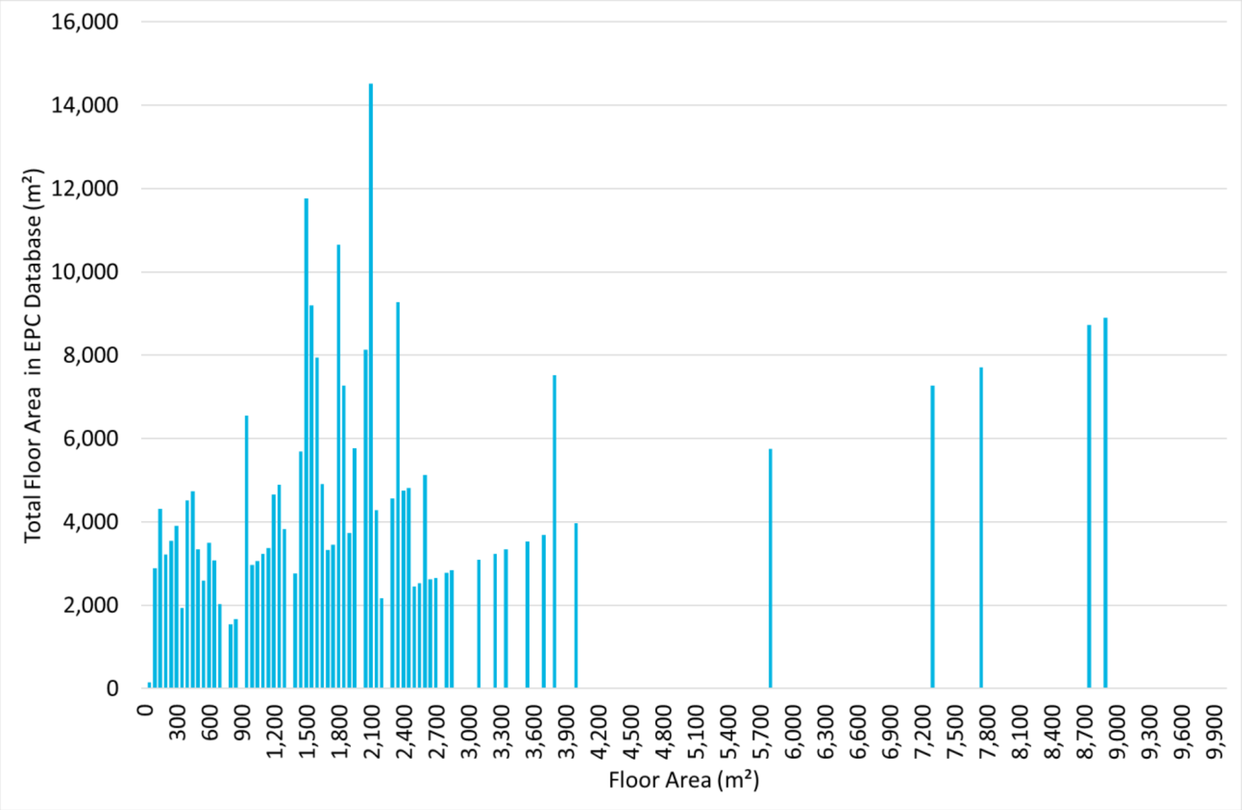

**Figure 2: Floor area distribution of retail buildings in EPC database.**

## 1.5 Model Building Sub-types

### 1.5.1 Baseline specs

35. To derive a baseline 2015 compliant specification for the sample buildings identified in the national profile above, as a default the specifications are based on the Section 6 2015 notional building values for the relevant fuel type. These values have been modified to reflect common practice where it is found to differ from the Section 6 2015 notional building values/approach. For example, there have been significant changes in lighting technology, with the significant adoption of LED lighting, over the last five years.

36. The modifications have been informed by a review of the following data source:

- EPC data made available by Scottish Government. There is significant variation in the design specifications used in projects – hence many projects do not simply adopt the values in the notional building. To identify tendencies for a significant difference between actual build and the values used in the notional building a data analysis has been undertaken to identify potential differences. The notional building values have been changed if they are in the lower quartile of energy performance (0-25%) or upper quartile of energy performance (75-100%) of the EPC database distribution i.e. do not tend to be common practice. In such cases, a value around the median has been adopted.

37. We also reviewed information from the consultation responses provided to the Scottish Government's 2018 Scottish Building Regulations: Review of Energy Standards: 'Call

for Evidence’. This provides evidence on approaches to meeting 2015 standards.[1] We identified no relevant evidence that differed or added to learning from the EPC database analysis.

38. Any amendments proposed to the baseline specifications from that given in the notional 2015 building(s) have been agreed with Scottish Government and modelled DERs/BERs are kept within 1% of the TER, see Section 1.5.5.

39. The non-domestic EPC database does not contain the same level of detailed information as is present in the domestic EPC database and so fewer conclusions can be drawn from it.

40. Several anomalies were identified in the database, and these cases have been excluded from the analysis described below to derive a robust sample of EPCs from which conclusions can be drawn. The following steps were taken to remove anomalies prior to analysis:

- All EPCs lodged prior to the end of 2016 were removed. The current version of Section 6 came into effect from October 2015. EPCs lodged prior to this will have been for buildings designed to be compliant with an earlier version of Section 6. Given the transitional arrangements and the length of typical design and construction programmes EPCs lodged for several months after this date are also likely to have been compliant with earlier versions of the regulation.
- EPC records which appear to fail to comply with Section 6 (i.e. TER<BER) were removed. Although the database provided was apparently for new-build projects only, it is possible that a significant number of EPCs are lodged incorrectly as being for new-build when they are for previously existing buildings and/or buildings built under previous versions of Section 6 were still being lodged through the sample period.
- Several EPC records were identified which showed the Notional Building average U-value to be zero. The reason for this is not apparent, however these cases have been removed from the analysis.
- Unconditioned buildings have been removed from the analysis.

41. Naturally ventilated buildings have been analysed separately from mechanically ventilated/ cooled buildings to assess the effect of the differences in energy demand balances.

### 1.5.2 Building Fabric

42. The EPC database does not contain information on individual building elements (walls, windows etc.), rather the database contains the following metrics:

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[1] https://consult.gov.scot/local-government-and-communities/building-standards-energy/consultation/published_select_respondent

- Air tightness;
- Average (area-weighted) building U-value;
- Average building thermal bridging (alpha-value).

#### 1.5.2.1 Air Tightness

43. Figure 3 and Figure 4 show the distribution of air tightness values for naturally ventilated and mechanically ventilated/cooled buildings respectively. These two distributions are fairly similar showing that the most common air tightness in both cases is between 4 and 5m³/m²/hr @50Pa. This trend is more pronounced for naturally ventilated buildings whilst mechanically ventilated/cooled show a similar but weaker trend.

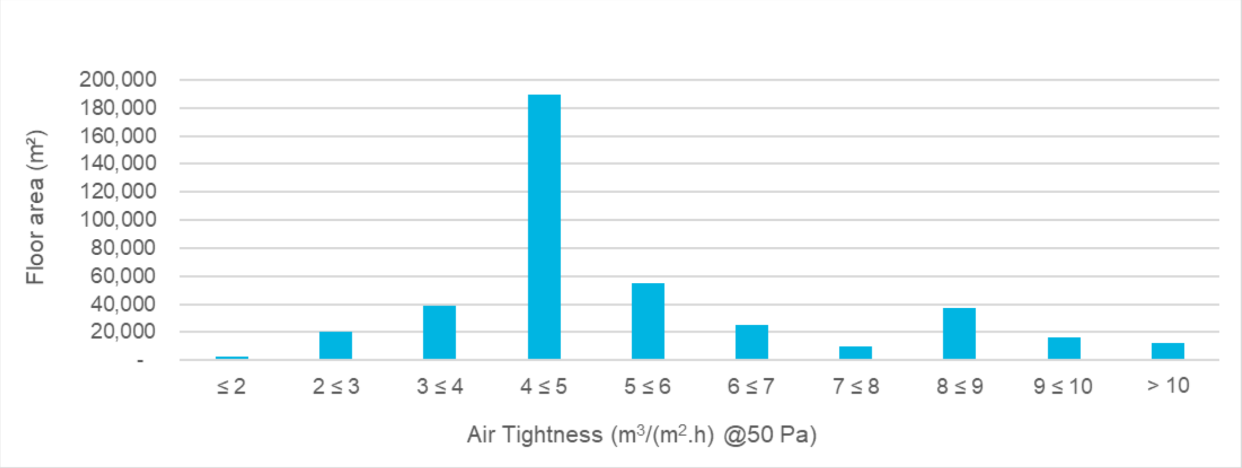

**Figure 3: Air tightness distribution for naturally ventilated buildings.**

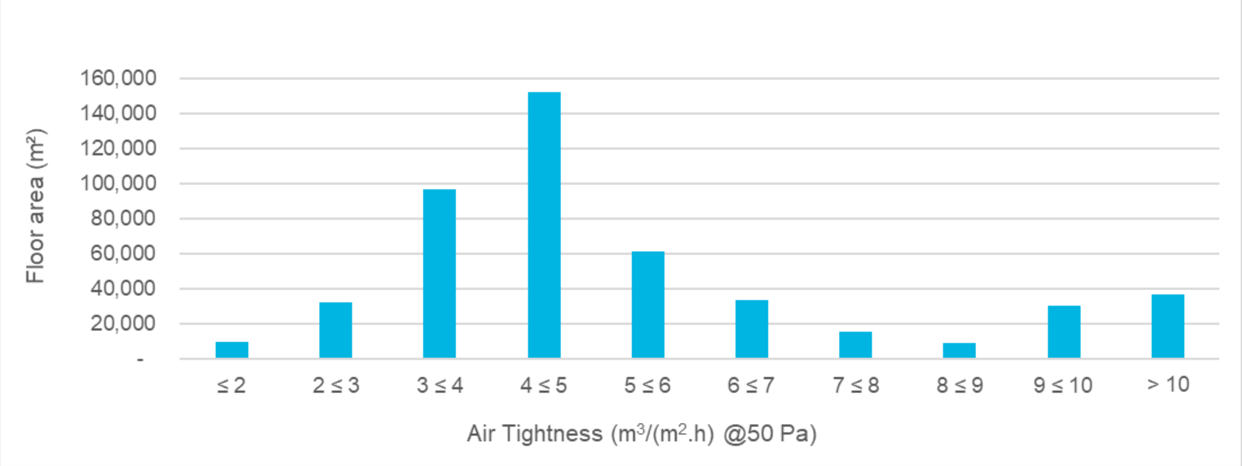

**Figure 4: Air tightness distribution for mechanically ventilated/cooled buildings.**

44. On this basis the air tightness for the compliant solutions is set to 5m³/m²/hr @ 50Pa to match the current notional building.

### 1.5.2.2 U-values

45. The building average U-value gives only a limited insight into the individual U-values being used for the different fabric elements. Buildings with large amounts of glazing will tend to have higher average U-values than those with less glazing. Similarly those with different built forms will have a different average U-value if a certain envelope element (e.g. wall) takes up a greater or less proportion of the total surface area.

46. Some overall insight is provided by comparing the average U-value of the Actual and Notional buildings. Figure 5 and Figure 6 compare the Actual and Notional average U-values for naturally ventilated and mechanically ventilated/cooled buildings respectively. Both graphs show that there is a tendency for the U-values of the Actual buildings to be less (i.e. better) than those of the Notional buildings, however this tendency appears to be limited.

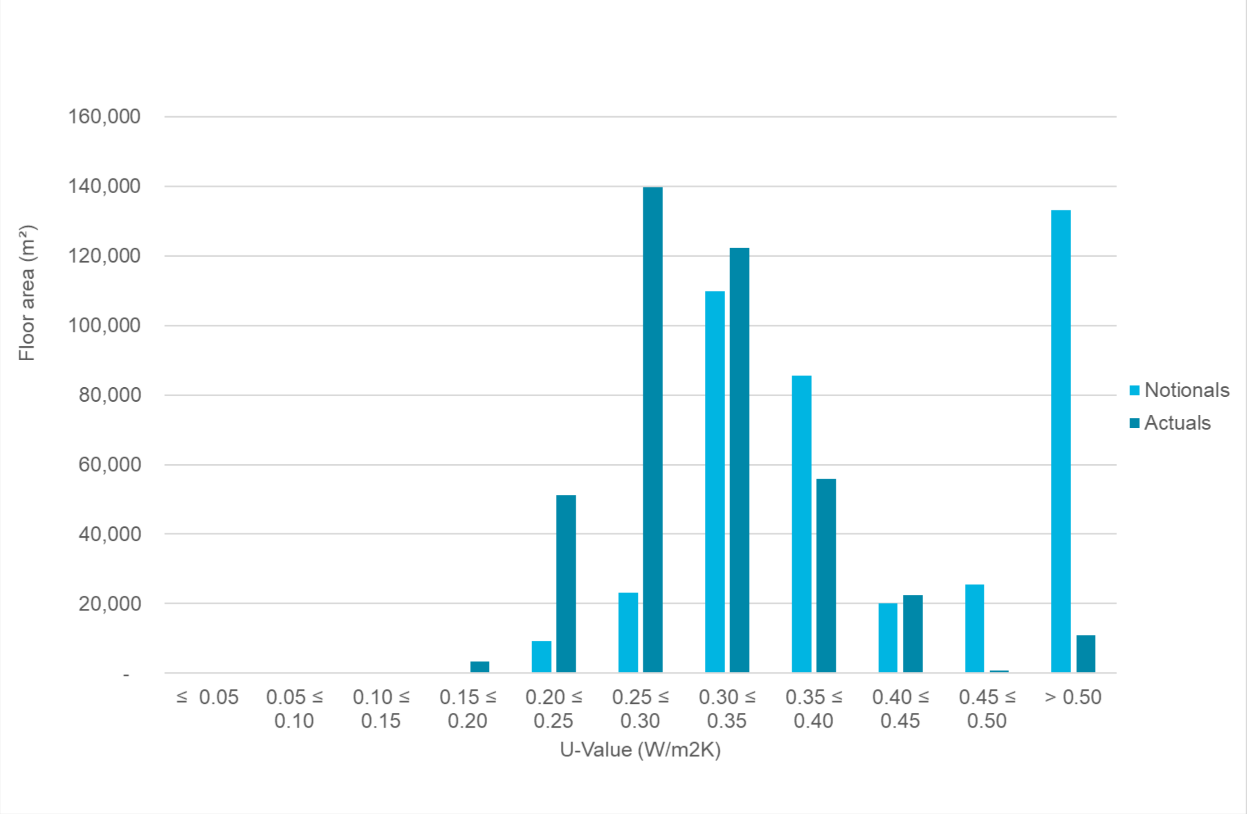

**Figure 5: Comparison of Actual and Notional average building U-values for naturally ventilated buildings.**

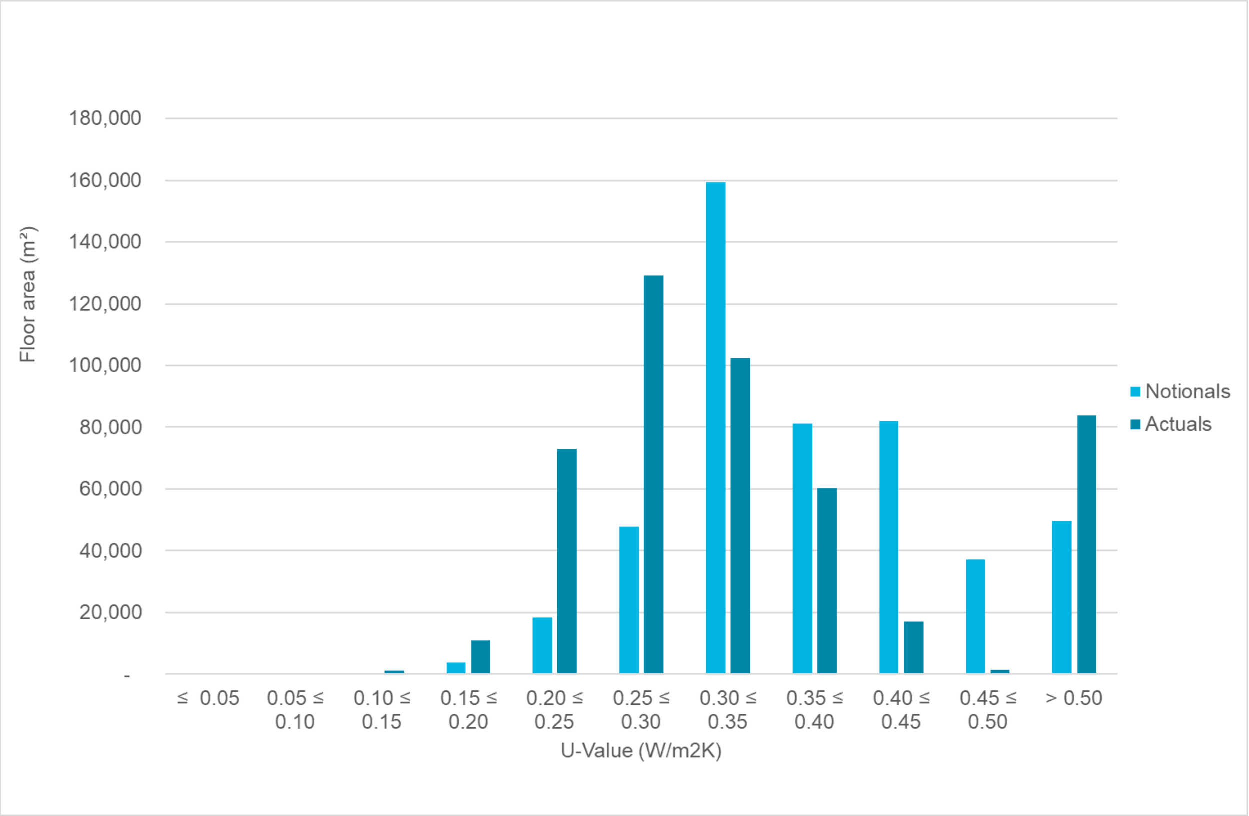

**Figure 6: Comparison of Actual and Notional average building U-values for mechanically ventilated/cooled buildings.**

47. On this basis the U-values for the compliant solutions are set to replicate the current notional building specification.

### 1.5.2.3 Thermal Bridging

48. The EPC database contains records for EPCs generated through both SBEM and DSM software. SBEM requires that the user inputs thermal bridging values on an individual basis (or uses default values). However in DSM software, the thermal bridges are generally input as a simple percentage adjustment to U-values, the default value being 10%. The EPC records show that the vast majority of DSM EPCs simply use the 10% default value, so the analysis here focusses on SBEM records only.

49. Figure 7 and Figure 8 compare the Actual and Notional thermal bridging values for naturally ventilated and mechanically ventilated/cooled buildings respectively. No clear trend is evident in these two graphs. However, it appears that thermal bridging in Actual buildings tends to be a little worse than Notional buildings. The median values for the Actual and Notional buildings with natural ventilation are 20.3 and 18.5 respectively. For buildings with mechanical ventilation/cooling these values are 20.3 and 18.4. This also suggests that there is not much variation in thermal bridging in relation the building servicing strategy.

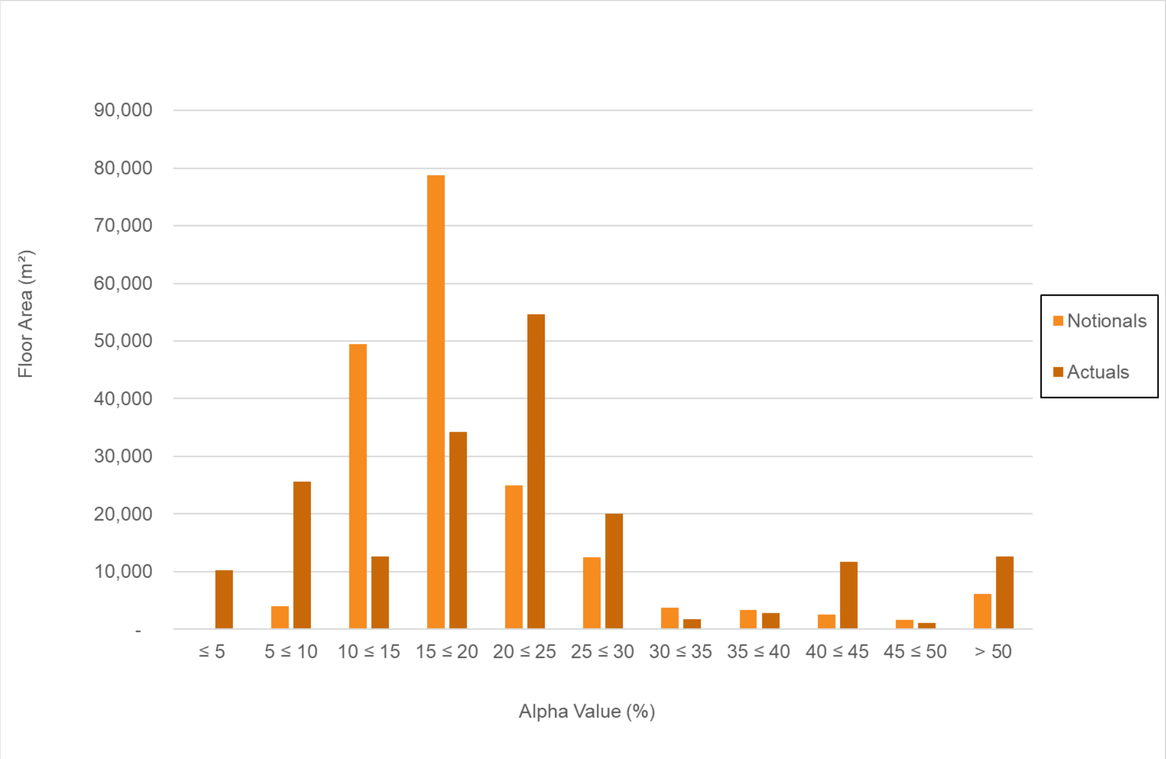

Figure 7: Comparison of Actual and Notional thermal bridging values for naturally ventilated buildings.

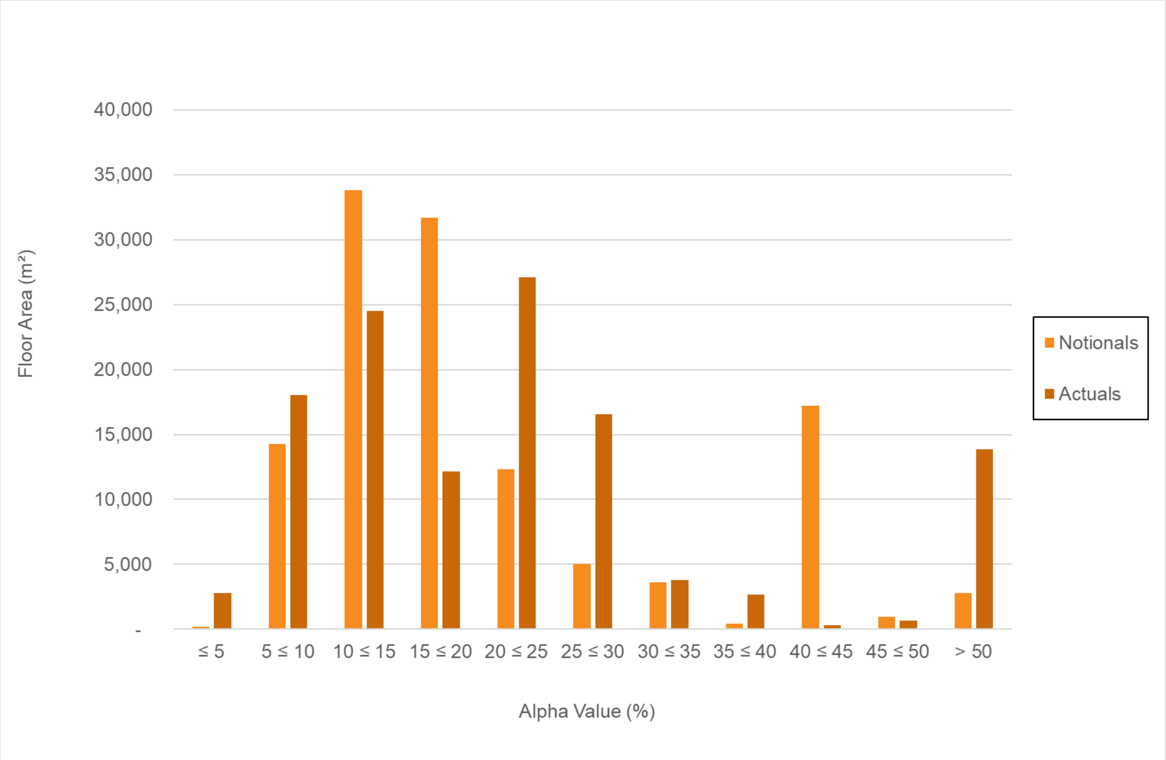

Figure 8: Comparison of Actual and Notional thermal bridging values for mechanically ventilated/cooled buildings.

50. As the difference between the actual and notional buildings appears relatively small, the thermal bridging for the compliant solutions are set to replicate the current notional building specification.

### 1.5.3 Building Services

51. The EPC database contains some limited information on individual building service efficiencies. Heating and cooling efficiencies are included in the database, however no other building service parameters can be viewed directly. The EPC database does include data on the modelled energy demand of each end use (heating, cooling, hot water, lighting and fans and pumps), and some conclusions may be drawn from this data.

52. The range of realistic efficiencies for building services is strongly influenced by the type of system installed. Analysis of the different HVAC system types recorded in the EPC database is shown in Figure 9. This shows that three system types dominate:

- Underfloor heating with natural ventilation;
- Radiators with natural ventilation;
- Split or multi-split heating and cooling.

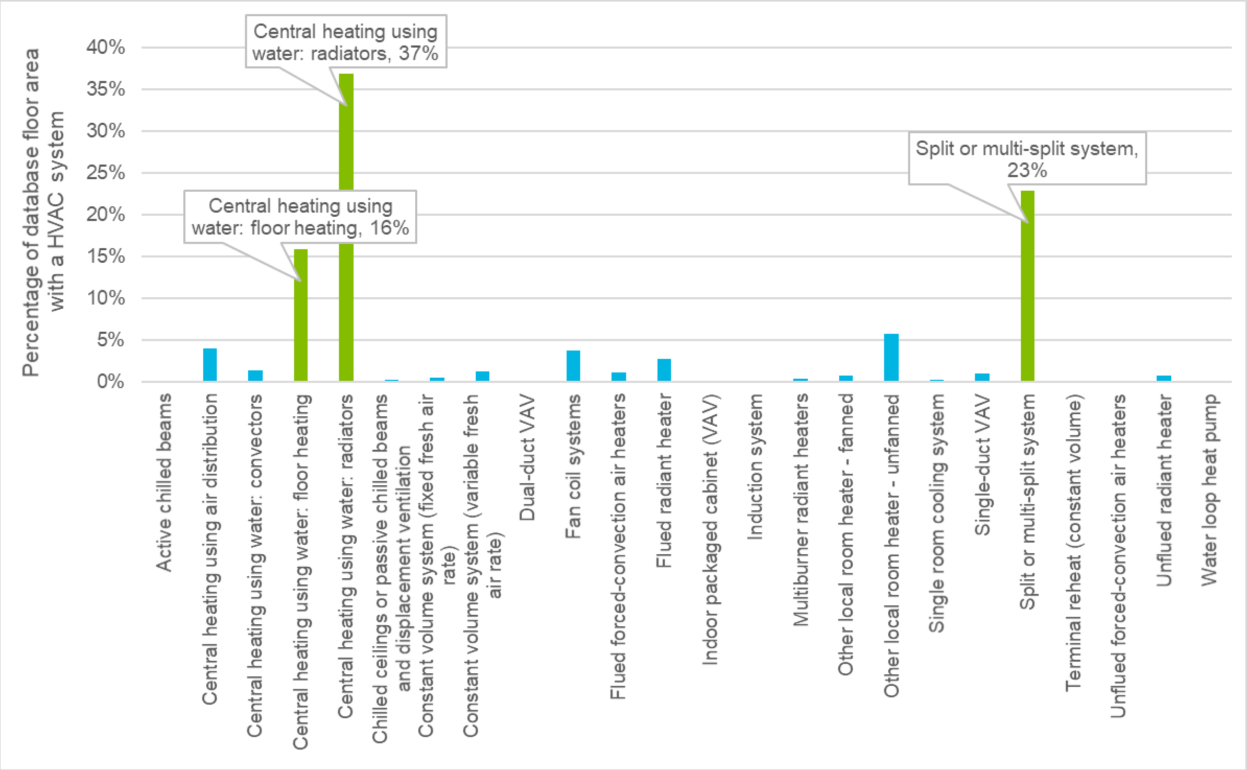

**Figure 9: Percentage of EPC database floor area with each NCM HVAC system type.**

#### 1.5.3.1 Heating

53. The efficiency of a heating system is strongly influenced by the type of heat generator in use. For example, the typical efficiency of a gas boiler is between 85% and 95%, whereas for a heat pump the typical efficiency is much higher (3-6, i.e. 300% to 600%).

Figure 10 shows the percentage floor area in the EPC database which is heated by each heat generator type.

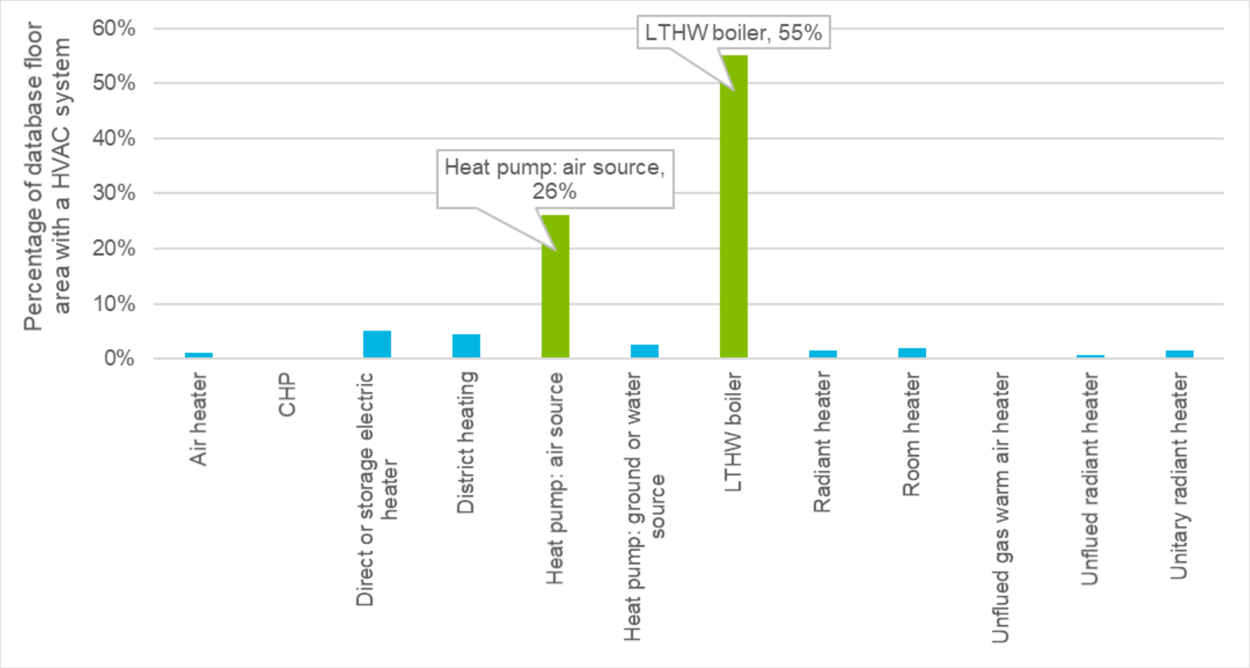

**Figure 10: Percentage of EPC database floor area served by each heat generator type.**

54. On this basis the compliant solutions will use either LTHW boilers or ASHPs for heating and hot water, see Table 4. The subsequent graphs analyse the ranges of efficiencies recorded for these two heat generator types.

#### 1.5.3.1.1 LTHW Boiler

The seasonal efficiency of the heat generator in the notional building is dependent on the generator and fuel type. For gas-fired heating, the notional seasonal efficiency is 91%[2] for side-lit spaces, and for biomass boilers the notional seasonal efficiency is 70% for both side-lit and top-lit spaces. Figure 11 and Figure 12 and Table 6 and Table 7 show that in both cases these notional seasonal boiler efficiencies fall below the 25th percentile recorded in the EPC database, however Section 1.5.4 shows that the Notional and Actual heating demands are often similar and so the compliant solutions described in Section 1.5.5 have adopted the notional boiler efficiencies.

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[2] Except for radiant heating in top-lit spaces.

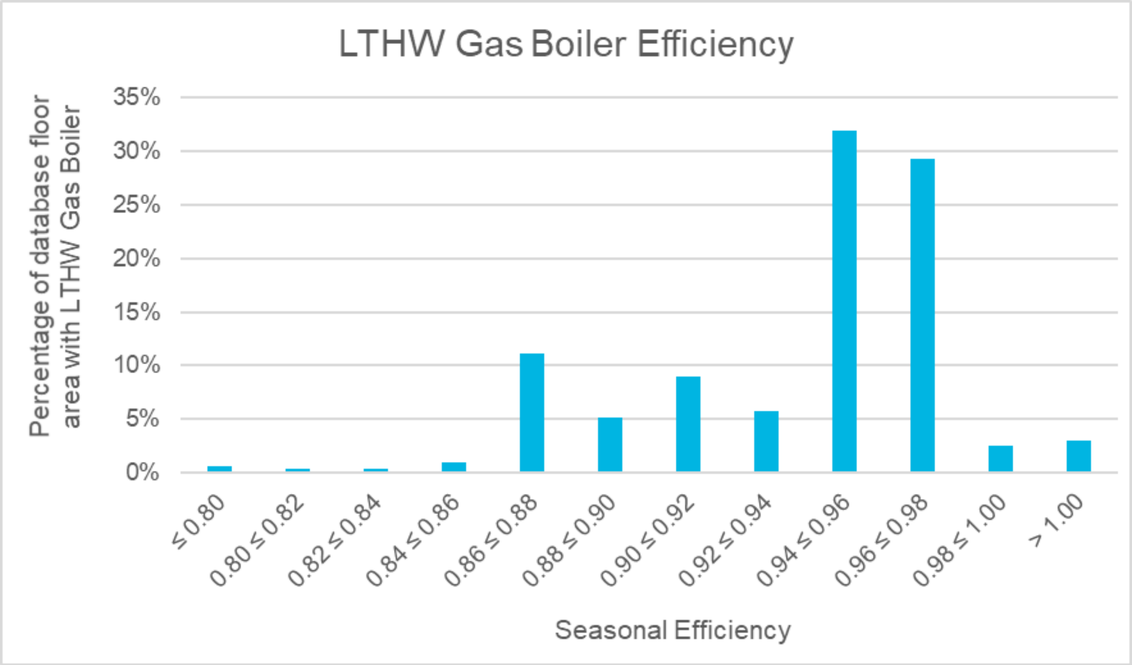


**Figure 11: Percentage of EPC database floor area served by different efficiencies of LTHW gas boilers.**

**Table 6: LTHW gas boiler percentiles.**

| Percentile | Seasonal Efficiency |
|---|---|
| 75th | 0.97 |
| 50th | 0.96 |
| 25th | 0.92 |

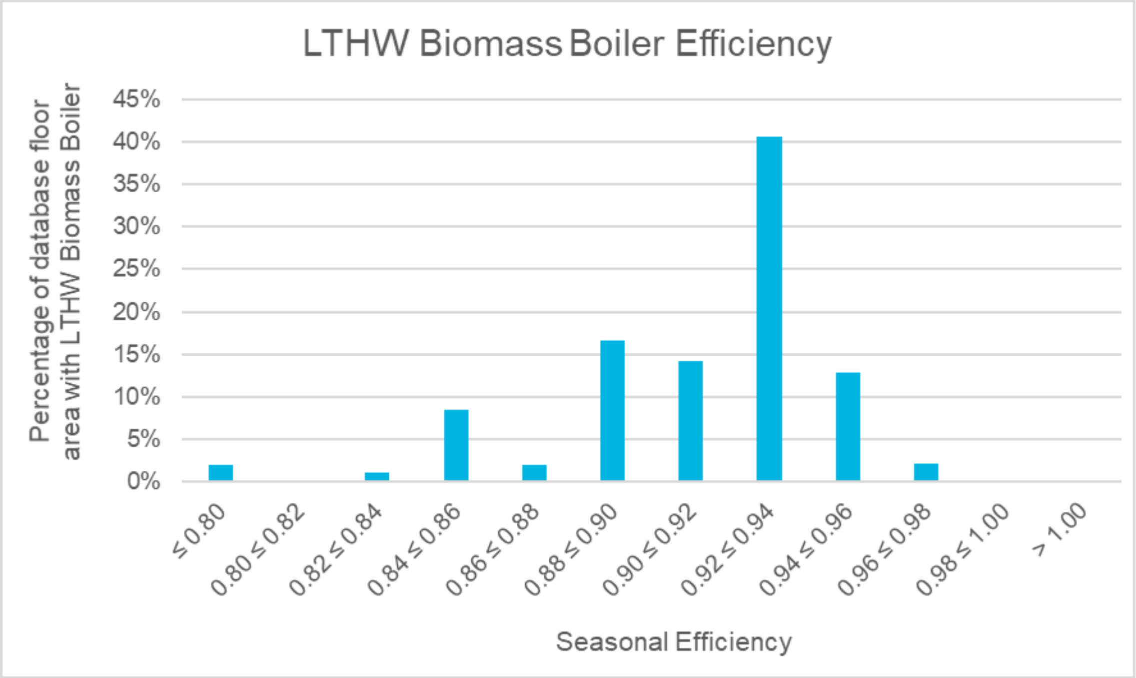


**Figure 12: Percentage of EPC database floor area served by different efficiencies of LTHW biomass boilers.**

**Table 7: LTHW biomass boiler percentiles.**

| Percentile | Seasonal Efficiency |
|---|---|
| 75th | 0.93 |
| 50th | 0.92 |
| 25th | 0.90 |

#### 1.5.3.1.2 Air Source Heat Pump (ASHP)

55. The data recorded in the EPC database does not explicitly differentiate between ASHP systems drawing heat from outside air to serve water-based systems and those that can move heat within buildings (Variable Refrigerant Flow – VRF) or those that deliver warm air rather than using water as the working fluid (split systems). However, this differentiation can be inferred from the NCM system type. Whilst VRF and split systems are often more efficient, ASHPs serving wet systems are more widely suitable to the new non-domestic building stock than VRF and split systems. For example, VRF and split systems are generally deemed inappropriate for clinical applications due to difficulty in cleaning. They are also more limited by the maximum pipe length they can accommodate (although this is increasing as technology develops). Hence, if ASHPs are to be included in the new notional buildings, it appears sensible to specify them based on characteristics of those ASHPs serving wet systems.

56. Figure 13 and Table 8 show the percentage distribution of ASHP efficiencies for wet heating systems only. When VRF and split systems are included, the recorded efficiencies tend to be higher.

57. The current notional building seasonal efficiency for ASHPs is 1.75. Figure 13 and Table 8 show that this falls well below the 25th percentile recorded in the EPC database and is therefore not deemed representative of current build.

58. Whilst VRF and split systems are not universally suitable, they are widely used and so it is reasonable to assume that for the two building sub-types in the national profile where ASHP is the heat source (office and retail), these system types might be used. Therefore, the currently compliant solutions for these two building sub-types described in Section 1.5.5 assume a SCoP of 4.0, which is the median value for all ASHP systems in the EPC database (not shown here) and the 75th percentile for ASHPs serving wet heating systems.

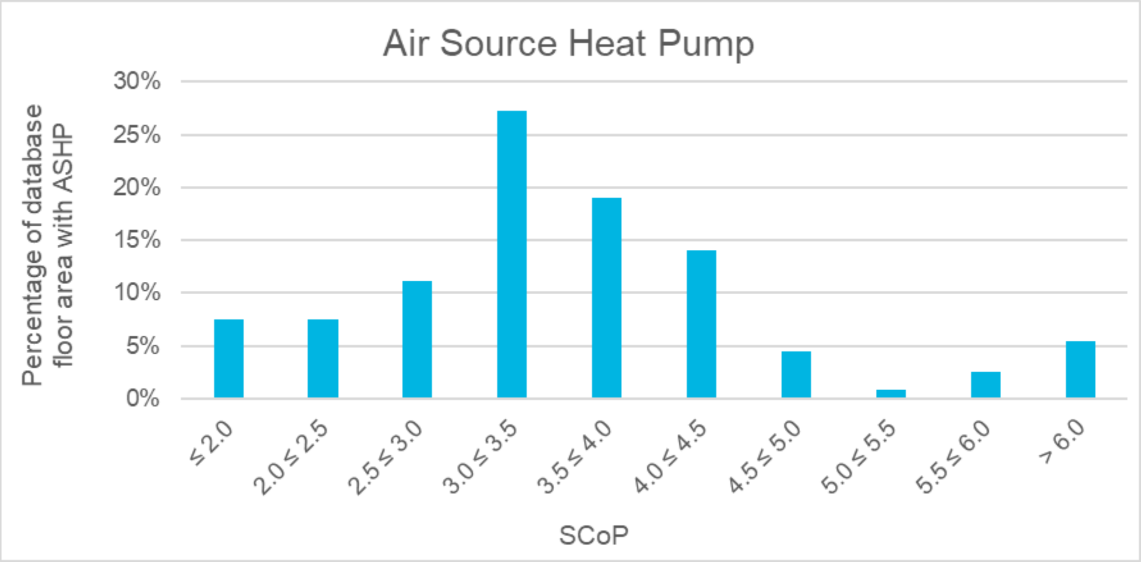


**Figure 13: Percentage of EPC database floor area served by different efficiencies of ASHP.**

**Table 8: ASHP percentiles.**

| Percentile | Seasonal Efficiency |
|---|---|
| 75th | 4.0 |
| 50th | 3.4 |
| 25th | 3.2 |

The EPC database does not contain information on the heating system flow temperatures assumed, and for most heat sources this variable has a minor impact, however ASHP efficiency is strongly influenced by the temperature which it is supplying; this matter is discussed in detail in Section 1.8.

#### 1.5.3.1.3 Radiant Heaters (for top-lit spaces)

59. Although Figure 10 shows that radiant heaters are only used in a small percentage of total floor area recorded in the EPC database, this type of heating is the dominant type for naturally ventilated top-lit spaces such as distribution warehouses. The notional building seasonal efficiency for radiant heaters is 86%. Figure 14 and Table 9 show that this falls slightly below the 25th percentile recorded in the EPC database. Top-lit naturally-ventilated buildings generally have relatively few parameters which can be improved upon to achieve compliance as there is no cooling, mechanical ventilation and DHW demand is generally low. Therefore, compliance is generally achieved through improvements to heating plant, lighting and fabric. On this basis the compliant solutions described in Section 1.5.5 have used the 75th percentile (92%) for the naturally ventilated distribution warehouse (i.e. the only sample building in which there is a top-lit space).

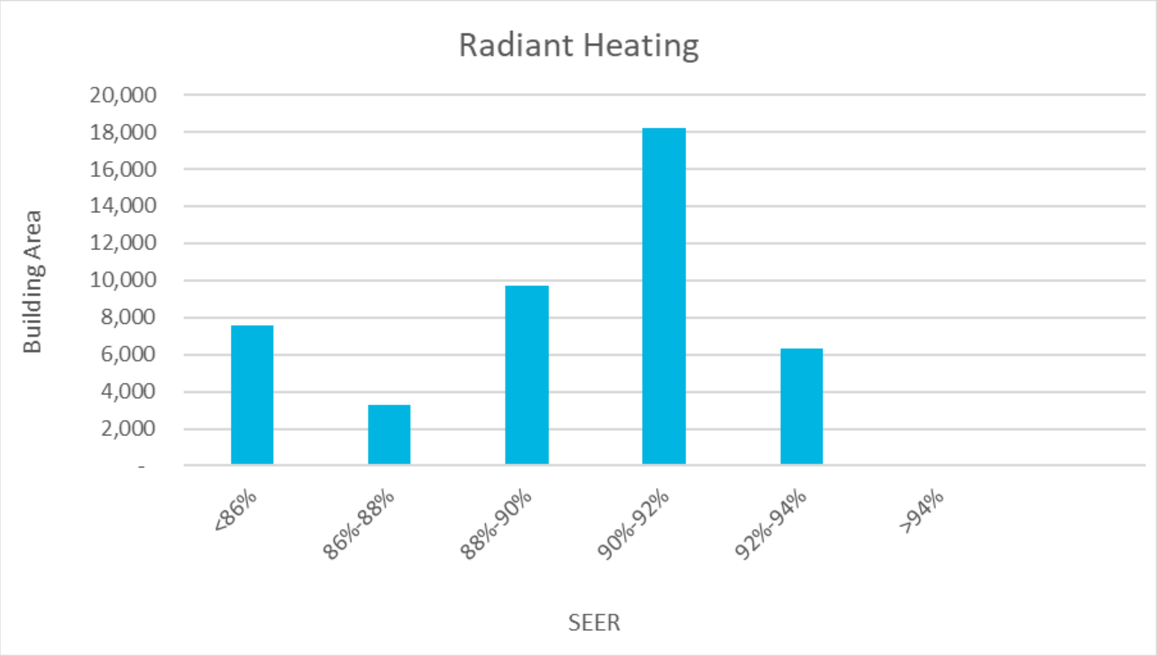


**Figure 14: Percentage of EPC database floor area served by different efficiencies of radiant heaters.**

**Table 9: Radiant heaters percentiles.**

| Percentile | Seasonal Efficiency |
|---|---|
| 75th | 92% |
| 50th | 90% |
| 25th | 87% |

### 1.5.3.2 Cooling

60. The notional SEER for cooling systems is 4.5. Figure 15 and Table 10 show that this falls between the 25th percentile and 50th percentile recorded in the EPC database, however Section 1.5.4 shows that the Actual cooling demands are generally much less than the Notional and so the compliant solutions described in Section 1.5.5 have adopted higher cooling efficiencies in cases where cooling is used.

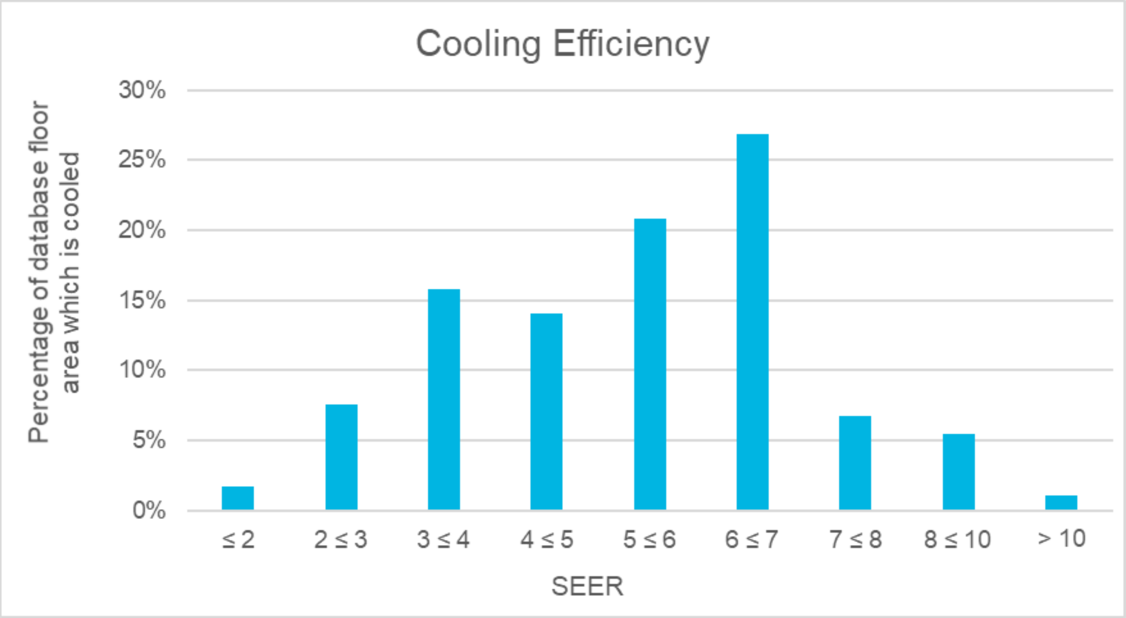


**Figure 15: Percentage of EPC database floor area served by different efficiencies of cooling plant.**

**Table 10: Cooling percentiles.**

| Percentile | Seasonal Efficiency |
|---|---|
| 75th | 6.4 |
| 50th | 5.6 |
| 25th | 4.0 |

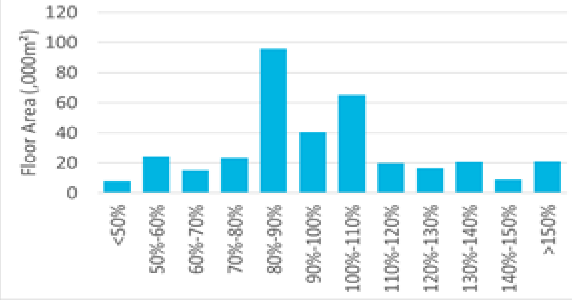
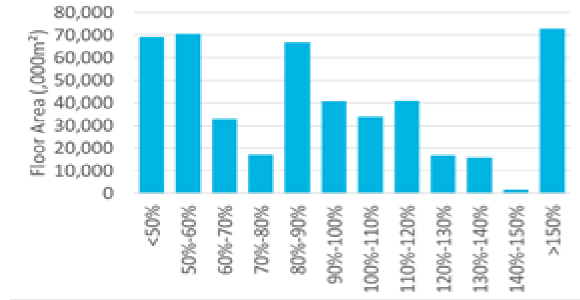
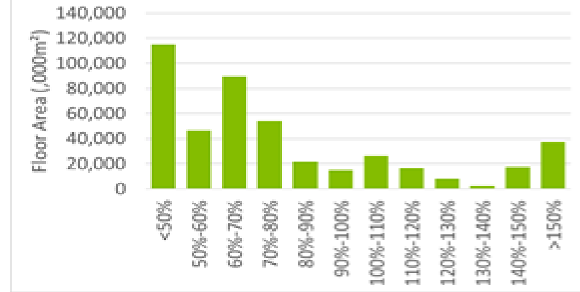
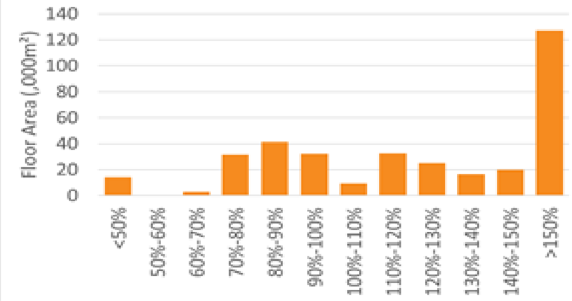
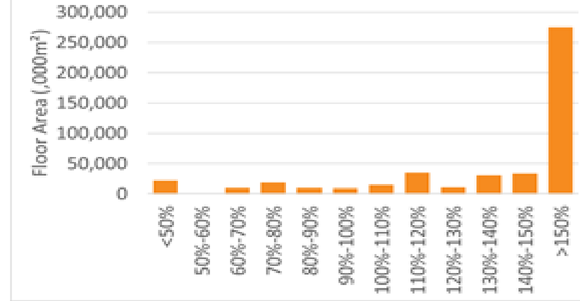
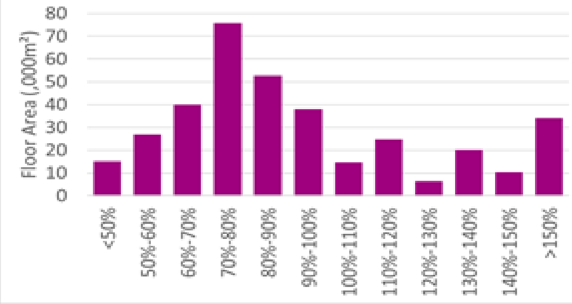
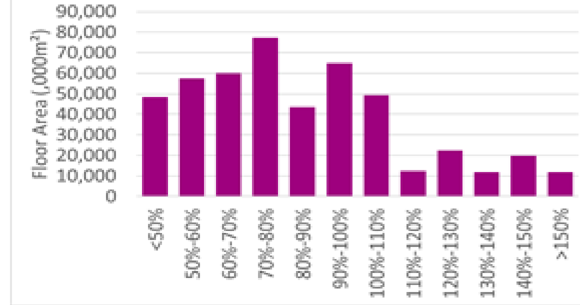
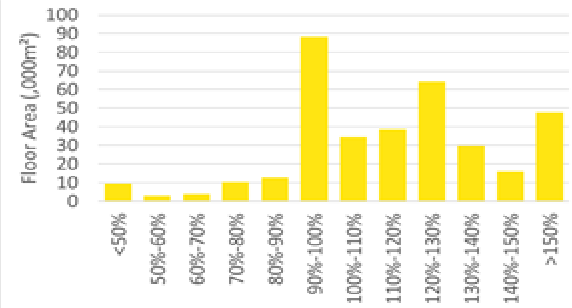
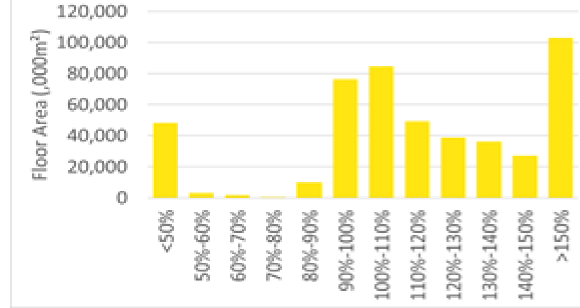
### 1.5.4 Routes to compliance

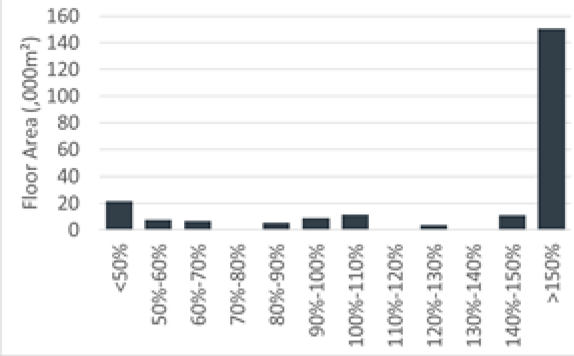
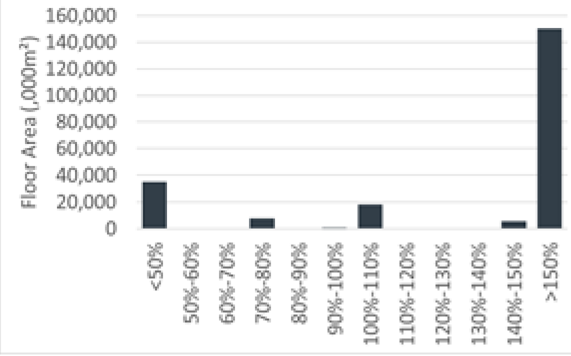
61. Table 11 shows graphs comparing the actual energy demands divided by the notional energy demands for each end use. From this analysis the following trends can be identified:

- **Heating demand:**
  - Naturally ventilated: Most commonly, the actual demand is similar to that of the notional building.
  - Mechanically ventilated/cooled: Generally, the actual demand is lower than the notional building.
- **Cooling demand:**
  - Mechanically ventilated/cooled: Tendency for the actual demand to be significantly lower than the notional building.
- **Fans and pumps energy demand:**
  - Naturally ventilated: Tendency for the actual demand to be significantly higher than the notional building.

  - Mechanically ventilated/cooled: Tendency for the actual demand to be significantly higher than the notional building.
- **Lighting energy demand:**
  - Naturally ventilated: Tendency for the actual demand to be significantly lower than the notional building.
  - Mechanically ventilated/cooled: Tendency for the actual demand to be significantly lower than the notional building.
- **Domestic hot water energy demand:**
  - Naturally ventilated: Tendency for the actual demand to be significantly higher than the notional building.
  - Mechanically ventilated/cooled: Tendency for the actual demand to be significantly higher than the notional building.
- **Displaced lighting energy demand:**
  - Naturally ventilated: Tendency for the actual demand to be significantly higher than the notional building.
  - Mechanically ventilated/cooled: Tendency for the actual demand to be significantly higher than the notional building.

**Table 11: Comparison of actual/notional ratio end-use energy demands**

| | Naturally Ventilated | Mechanically Ventilated/Cooled |
|---|---|---|
| Heating |  |  |
| Cooling | NA |  |
| Fans & Pumps |  |  |
| Lighting |  |  |
| Domestic Hot Water |  |  |

<table>
<tr><th></th><th>Naturally Ventilated</th><th>Mechanically Ventilated/Cooled</th></tr>
<tr><td>Displaced</td><td>
</td><td>
</td></tr>
</table>

62. On the basis of this analysis, the following approach has been taken to adjusting buildings to pass within 1% of the TER:

- **First alteration:** where ASHP is present increase the efficiency up to a maximum SCoP of 4.0 (i.e. 75th percentile shown in Table 8).
- **Second alteration:** where cooling is present increase the efficiency of the cooling up to a maximum SEER of 5.6 (i.e. 50th percentile shown in Table 10).
- **Third alteration:** where the previous alteration is insufficient, increase the efficiency of general lighting up to a maximum of 95 luminaire lumens per circuit watt.
- **Fourth alteration:** where the combination of the previous alterations is insufficient, increase the area of PV until compliance is achieved.

63. The current 2015 version of the NCM Modelling Guide specifies that the notional building will have a PV array with the area being the lesser of: (i) 4.5% of the Gross Internal Area (GIA) and (ii) 50% of the roof area. The Guide also specifies that the PV output will be 120kWh/$m^2$. An SBEM user cannot specify the output of the actual building PV array in this way so the output per square meter in the actual building is a function of the variables available to the user such as orientation, pitch, ventilation and panel type[3]. The default nominal efficiency for monocrystalline panels (the most efficient option available to the user) is 8.8%, and the user cannot change this. However, the efficiency required to achieve an annual output of 120kWh/$m^2$ is approximately 16% (depending on the variables listed above). Photovoltaic panels are available with efficiencies up to 20% so 16% is a reasonable value for the notional building to have adopted. One effect of this is that if the user inputs a PV array equivalent to 4.5% of the GIA (thus matching the area used by the notional building) then the modelled output in the actual building will be significantly less. If the user inputs the optimal values from the options available in SBEM (south facing, 30° inclination, no or very little shading, monocrystalline, strongly ventilated) then the ratio between the output per square meter

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[3] The user also has the option to input the $kW_{peak}$ value to define the PV array size as an alternative to inputting area and panel type. However, neither input option allows the user to define the inverter efficiency or the temperature coefficient of the panel among other key variables.

for the notional and actual buildings is 1.79 i.e. the output from the actual building is significantly below that of the notional building. This effect is shown in Table 12 below which demonstrates significant increases in PV array size or improved service specifications to achieve compliance compared to the notional building specifications.

### 1.5.5 Compliant Specifications

64. Adopting the method described above the sample models have been modified away from the notional building specification to achieve a BER within 1% of the TER. The deviations from the notional specifications used to achieve this are shown in Table 12, this is based on the hierarchy described in Paragraph 62:

**Table 12: Deviations from notional specification to achieve compliance**

| Building Sub-types | ASHP SCoP[4] Changed | Cooling SEER Changed | Lighting Efficacy Changed | PV Area Changed: Area Input by User | PV Area Changed: Equivalent Area Based on 120kWh/m² |
|---|---|---|---|---|---|
| Deep Office AC; Gas; AC | NA | 5.6 | 80llm/cW | Match notional | |
| Deep Office AC; Elec; AC | 4.0 | 5.6 | 72llm/cW | Match notional | |
| Hospital; Gas; NV | NA | NA | 54llm/cW | 0m² | 0m² |
| Hotel; Gas; NV | NA | NA | 95llm/cW | Match notional | |
| Hotel; Gas; AC | NA | 5.6 | 95llm/cW | 300m² | 168m² |
| Primary School; Biomass; NV | NA | NA | 75llm/cW | Match notional | |
| Primary School; Gas; MV | NA | NA | 80llm/cW | Match notional | |
| Primary School; Gas; NV | NA | NA | NA | 175m² | 98m² |
| Retail; Gas; AC | NA | 5.2 | NA | Match notional | |
| Retail; Elec; AC | 4.0 | 5.0 | NA | Match notional | |
| Shallow Office NV; Gas; NV | NA | NA | 70llm/cW | Match notional | |
| Warehouse Distribution; Gas; NV | NA | NA | 82llm/cW | Match notional | |

65. Key results from the modelling are set out in Table 13. The columns show the emissions rates and primary energy values as calculated in SBEMv5.6.a.1, using current carbon emission and primary energy factors.

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[4] Excluding system delivery losses.

**Table 13: $CO_2$ emissions rates using Section 6 2015 factors**

| Model Name | $CO_2$, BER | $CO_2$, TER | $CO_2$, Margin |
|---|---|---|---|
| Deep Office AC; Gas; AC | 21.5 | 21.4 | 0.5% |
| Deep Office AC; Elec; AC | 22.5 | 22.4 | 0.4% |
| Hospital; Gas; NV | 38.4 | 38.6 | -0.5% |
| Hotel; Gas; NV | 74.5 | 74.2 | 0.4% |
| Hotel; Gas; AC | 81.1 | 81.7 | -0.7% |
| Primary School; Biomass; NV | 5.5 | 5.5 | 0.0% |
| Primary School; Gas; MV | 11.0 | 11.1 | -0.9% |
| Primary School; Gas; NV | 13.1 | 13.0 | 0.8% |
| Retail; Gas; AC | 60.9 | 60.6 | 0.5% |
| Retail; Elec; AC | 61.5 | 61.2 | 0.5% |
| Shallow Office NV; Gas; NV | 14.6 | 14.7 | -0.7% |
| Warehouse Distribution; Gas; NV | 28.7 | 28.7 | 0.0% |

66. MHCLG has proposed updated factors which it is understood that the Scottish Government will also adopt. Table 14 and Table 15 show the proposed new factors. In contrast, the current Section 6 carbon emission and primary energy factors for all grid-supplied and grid-displaced electricity is 0.519kg$CO_2$/kWh and 3.07kWh/kWh respectively. MHCLG proposes that the new electricity factors should vary on a monthly basis rather than using a single figure for the whole year. This approach is intended to reflect the seasonal variations in the UK electricity grid which is increasingly influenced by the seasonal variation in renewable generation and variations in demand, see Table 15.

**Table 14: Current and proposed $CO_2$ and primary energy factors for combustion fuels**

| Fuel type | Current Section 6 2015 Factors (kg$CO_2$/kWh) | Proposed New Factors (kg$CO_2$/kWh) | Proposed New Factors (kWh/kWh) |
|---|---|---|---|
| Natural gas | 0.216 | 0.210 | 1.126 |
| LPG | 0.241 | 0.241 | 1.141 |
| Biogas | 0.098 | 0.024 | 1.286 |
| Fuel oil | 0.319 | 0.319 | 1.180 |
| Coal | 0.345 | 0.375 | 1.064 |
| Anthracite | 0.394 | 0.395 | 1.064 |
| Manufactured smokeless fuel (inc. Coke) | 0.433 | 0.366 | 1.261 |
| Dual fuel (mineral + wood) | 0.226 | 0.087 | 1.049 |
| Biomass | 0.031 | 0.029 | 1.037 |
| Waste heat | 0.058 | 0.015 | 1.063 |

### Table 15: Proposed new $CO_2$ and primary energy factors for electricity

| Month | Grid Supplied Electricity $kgCO_2/kWh$ | Grid Supplied Electricity kWh/kWh | PV-Generated Electricity $kgCO_2/kWh$ | PV-Generated Electricity kWh/kWh |
|---|---|---|---|---|
| **Jan** | 0.163 | 1.602 | 0.196 | 1.715 |
| **Feb** | 0.160 | 1.593 | 0.190 | 1.697 |
| **Mar** | 0.153 | 1.568 | 0.175 | 1.645 |
| **Apr** | 0.143 | 1.530 | 0.153 | 1.567 |
| **May** | 0.132 | 1.487 | 0.129 | 1.478 |
| **Jun** | 0.120 | 1.441 | 0.106 | 1.389 |
| **Jul** | 0.111 | 1.410 | 0.092 | 1.330 |
| **Aug** | 0.112 | 1.413 | 0.093 | 1.336 |
| **Sep** | 0.122 | 1.449 | 0.110 | 1.405 |
| **Oct** | 0.136 | 1.504 | 0.138 | 1.513 |
| **Nov** | 0.151 | 1.558 | 0.169 | 1.623 |
| **Dec** | 0.163 | 1.604 | 0.197 | 1.718 |
| **Average** | **0.139** | **1.513** | **0.146** | **1.535** |
| **2015 Factor** | **0.519** | **3.070** | **0.519** | **3.070** |

67. The compliant modelling results have been post-processed to show the effect of using the proposed new factors in Table 14 and Table 15; these adjusted results are shown in Table 16. The proposed new $CO_2$ factors for gas, biomass and electricity are all lower than those currently in use, the primary energy factors are mostly lower except biomass, and so the actual and notional building values shown in Table 16 are all lower than those in Table 13. The result is that the compliance margins increase in some cases and reduce in others; the sample buildings range between a 14.2% pass to a 4.5% fail.

68. A change to primary energy as the main target metric would 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 proposed $CO_2$ for electricity is significantly lower than that of gas (ratio of 0.66), the proposed average annual primary energy factor for electricity is higher than that of gas (ratio of 1.34). 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.

69. The proposed change in carbon emission and primary energy factors has a significant impact on the relative attractiveness of different renewable technologies in primary energy terms. The new lower factors for grid-supplied electricity will favour technologies which use electricity (such as heat pumps) and be less favourable for technologies which generate electricity such as CHPs and wind turbines. Conversely renewables which offset fossil fuel use (typically through the generation of heat) will be favoured by these changes, for example solar thermal systems are likely to become more appealing to building design teams. Electricity generated by solar PV arrays is allocated a different set of factors to other electricity; this is intended to reflect the diurnal variation in PV output; PV output occurs during daylight hours when the prevailing grid carbon factor is higher in winter but lower in summer. The net effect of these changes to the factors for solar PV is expected to reduce the attractiveness of this technology.

70. 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 1.16).

**Table 16: $CO_2$ emissions rates and primary energy values using proposed new factors**

| **Model Name** | **$CO_2$ BER, $kgCO_2/m^2$** | **$CO_2$ TER, $kgCO_2/m^2$** | **$CO_2$ Margin, $kgCO_2/m^2$** | **Primary Energy BPE, $kWh/m^2$** | **Primary Energy TPE, $kWh/m^2$** | **Primary Energy Margin, $kWh/m^2$** |
|---|---:|---:|---:|---:|---:|---:|
| Deep Office AC; Gas; AC | 7.3 | 7.0 | 4.5% | 67.8 | 66.5 | 1.9% |
| Deep Office AC; Elec; AC | 6.0 | 6.0 | 0.6% | 65.8 | 65.3 | 0.7% |
| Hospital; Gas; NV | 24.4 | 28.5 | -14.2% | 157.9 | 171.7 | -8.0% |
| Hotel; Gas; NV | 66.9 | 67.2 | -0.5% | 373.2 | 370.8 | 0.6% |
| Hotel; Gas; AC | 58.1 | 57.9 | 0.4% | 354.9 | 355.6 | -0.2% |
| Primary School; Biomass; NV | 2.7 | 2.6 | 3.8% | 66.3 | 68.2 | -2.8% |
| Primary School; Gas; MV | 6.9 | 7.1 | -2.4% | 44.7 | 45.8 | -2.5% |
| Primary School; Gas; NV | 9.3 | 9.9 | -6.1% | 57.0 | 58.8 | -3.1% |
| Retail; Gas; AC | 17.9 | 17.9 | -0.1% | 182.8 | 182.1 | 0.4% |
| Retail; Elec; AC | 16.4 | 16.2 | 1.0% | 179.2 | 177.9 | 0.7% |
| Shallow Office NV; Gas; NV | 9.2 | 9.2 | -0.1% | 60.4 | 60.0 | 0.6% |
| Warehouse Distribution; Gas; NV | 23.4 | 23.0 | 1.6% | 135.2 | 133.7 | 1.1% |

71. Further detail of the results from the compliant solutions is shown in the three tables below, which are broken down by fuel type and by energy end use. Table 17 shows the calculated energy demands; Table 18 shows these converted into primary energy using the proposed new factors and Table 19 shows the $CO_2$ emissions resulting from the proposed new factors. The totals shown sometimes differ slightly from the sum of the listed fuel demands, which is due to rounding to one decimal place.

## Table 17: Calculated energy demand and generation for compliant solutions (kWh/m$^2$)

| Model Name | Floor area (m$^2$) | Gas | Biomass | Grid-supplied Electricity | Displaced-electricity | Heating | Cooling | DHW | Auxiliary | Lighting | Total | Total minus Displaced |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Deep Office AC; Gas; AC | 12,000 | 10.3 | 0.0 | 43.7 | 5.4 | 7.2 | 8.5 | 3.1 | 16.7 | 18.5 | 54.0 | 48.6 |
| Deep Office AC; Elec; AC | 12,000 | 0.0 | 0.0 | 50.1 | 5.4 | 1.6 | 8.8 | 2.8 | 16.8 | 20.1 | 50.1 | 44.7 |
| Hospital; Gas; NV | 12,754 | 92.7 | 0.0 | 36.3 | 0.0 | 50.8 | 0.0 | 41.8 | 3.0 | 33.3 | 128.9 | 128.9 |
| Hotel; Gas; NV | 1,063 | 307.7 | 0.0 | 21.6 | 5.5 | 107.9 | 0.0 | 199.8 | 3.9 | 17.7 | 329.3 | 323.8 |
| Hotel; Gas; AC | 1,063 | 238.1 | 0.0 | 75.7 | 16.6 | 38.3 | 11.7 | 199.8 | 46.3 | 17.7 | 313.8 | 297.2 |
| Primary School; Biomass; NV | 2,353 | 0.0 | 52.7 | 13.2 | 5.3 | 33.2 | 0.0 | 19.5 | 2.0 | 11.2 | 65.9 | 60.6 |
| Primary School; Gas; MV | 2,353 | 24.9 | 0.0 | 16.6 | 5.4 | 9.9 | 0.0 | 15.0 | 5.8 | 10.9 | 41.6 | 36.2 |
| Primary School; Gas; NV | 2,353 | 37.1 | 0.0 | 14.9 | 4.7 | 22.1 | 0.0 | 15.0 | 2.0 | 12.9 | 52.0 | 47.3 |
| Retail; Gas; AC | 1,250 | 10.9 | 0.0 | 121.2 | 5.4 | 9.0 | 48.0 | 1.9 | 23.5 | 49.8 | 132.2 | 126.8 |
| Retail; Elec; AC | 1,250 | 0.0 | 0.0 | 127.0 | 5.4 | 2.1 | 50.1 | 0.9 | 23.5 | 50.4 | 127.0 | 121.6 |
| Shallow Office NV; Gas; NV | 2,160 | 35.1 | 0.0 | 19.3 | 5.4 | 32.1 | 0.0 | 3.1 | 1.8 | 17.6 | 54.6 | 49.2 |
| Warehouse Distribution; Gas; NV | 5,262 | 102.7 | 0.0 | 18.4 | 5.4 | 85.3 | 0.0 | 17.4 | 0.3 | 18.2 | 121.2 | 115.8 |

**Table 18: Primary energy demand and generation for compliant solutions using proposed new factors (kWh/m²)**

| Model Name | Floor area (m²) | Gas | Biomass | Grid-supplied Electricity | Displaced-electricity | Heating | Cooling | DHW | Auxiliary | Lighting | Total | Total minus Displaced |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Deep Office AC; Gas; AC | 12,000 | 11.6 | 0.0 | 64.3 | 8.0 | 8.1 | 12.4 | 24.6 | 27.3 | 3.4 | 75.8 | 67.8 |
| Deep Office AC; Elec; AC | 12,000 | 0.0 | 0.0 | 73.8 | 8.0 | 2.5 | 12.7 | 24.7 | 29.8 | 4.1 | 73.8 | 65.8 |
| Hospital; Gas; NV | 12,754 | 104.3 | 0.0 | 53.7 | 0.0 | 57.2 | 0.0 | 4.4 | 49.2 | 47.1 | 157.9 | 157.9 |
| Hotel; Gas; NV | 1,063 | 346.5 | 0.0 | 31.9 | 8.1 | 121.5 | 0.0 | 5.7 | 26.1 | 225.0 | 378.3 | 370.2 |
| Hotel; Gas; AC | 1,063 | 268.1 | 0.0 | 111.3 | 24.4 | 43.1 | 16.8 | 68.3 | 26.1 | 225.0 | 379.3 | 354.9 |
| Primary School; Biomass; NV | 2,353 | 0.0 | 54.6 | 19.6 | 7.9 | 34.4 | 0.0 | 3.0 | 16.6 | 20.2 | 74.2 | 66.3 |
| Primary School; Gas; MV | 2,353 | 28.1 | 0.0 | 24.7 | 8.0 | 11.2 | 0.0 | 8.5 | 16.1 | 16.9 | 52.7 | 44.7 |
| Primary School; Gas; NV | 2,353 | 41.7 | 0.0 | 22.1 | 6.9 | 24.9 | 0.0 | 3.0 | 19.1 | 16.9 | 63.9 | 57.0 |
| Retail; Gas; AC | 1,250 | 12.2 | 0.0 | 178.5 | 7.9 | 10.1 | 70.2 | 34.7 | 73.6 | 2.1 | 190.7 | 182.8 |
| Retail; Elec; AC | 1,250 | 0.0 | 0.0 | 187.2 | 8.0 | 3.3 | 73.2 | 34.7 | 74.6 | 1.4 | 187.2 | 179.2 |
| Shallow Office NV; Gas; NV | 2,160 | 39.6 | 0.0 | 28.7 | 7.9 | 36.1 | 0.0 | 2.6 | 26.1 | 3.5 | 68.3 | 60.4 |
| Warehouse Distribution; Gas; NV | 5,262 | 115.7 | 0.0 | 27.5 | 8.0 | 96.1 | 0.0 | 0.4 | 27.1 | 19.6 | 143.2 | 135.2 |

### Table 19: $CO_2$ emissions and offsets for compliant solutions using proposed new factors (kWh/m²)

| Model Name | Floor area (m²) | Gas | Biomass | Grid-supplied Electricity | Displaced-electricity | Heating | Cooling | DHW | Auxiliary | Lighting | Total | Total minus Displaced |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Deep Office AC; Gas; AC | 12,000 | 2.2 | 0.0 | 5.9 | 0.7 | 1.5 | 1.1 | 2.3 | 2.5 | 0.6 | 8.0 | 7.3 |
| Deep Office AC; Elec; AC | 12,000 | 0.0 | 0.0 | 6.8 | 0.7 | 0.2 | 1.1 | 2.3 | 2.7 | 0.4 | 6.7 | 6.0 |
| Hospital; Gas; NV | 12,754 | 19.5 | 0.0 | 4.9 | 0.0 | 10.7 | 0.0 | 0.4 | 4.5 | 8.8 | 24.4 | 24.4 |
| Hotel; Gas; NV | 1,063 | 64.6 | 0.0 | 2.9 | 0.7 | 22.7 | 0.0 | 0.5 | 2.4 | 42.0 | 67.6 | 66.9 |
| Hotel; Gas; AC | 1,063 | 50.0 | 0.0 | 10.1 | 2.1 | 8.0 | 1.5 | 6.3 | 2.4 | 42.0 | 60.2 | 58.1 |
| Primary School; Biomass; NV | 2,353 | 0.0 | 1.5 | 1.8 | 0.7 | 1.0 | 0.0 | 0.3 | 1.5 | 0.6 | 3.4 | 2.7 |
| Primary School; Gas; MV | 2,353 | 5.2 | 0.0 | 2.3 | 0.7 | 2.1 | 0.0 | 0.8 | 1.5 | 3.2 | 7.6 | 6.9 |
| Primary School; Gas; NV | 2,353 | 7.8 | 0.0 | 2.0 | 0.6 | 4.6 | 0.0 | 0.3 | 1.8 | 3.2 | 9.9 | 9.3 |
| Retail; Gas; AC | 1,250 | 2.3 | 0.0 | 16.3 | 0.7 | 1.9 | 6.3 | 3.2 | 6.8 | 0.4 | 18.6 | 17.9 |
| Retail; Elec; AC | 1,250 | 0.0 | 0.0 | 17.1 | 0.7 | 0.3 | 6.6 | 3.2 | 6.9 | 0.1 | 17.1 | 16.4 |
| Shallow Office NV; Gas; NV | 2,160 | 7.4 | 0.0 | 2.7 | 0.7 | 6.7 | 0.0 | 0.2 | 2.4 | 0.6 | 9.9 | 9.2 |
| Warehouse Distribution; Gas; NV | 5,262 | 21.6 | 0.0 | 2.6 | 0.7 | 17.9 | 0.0 | 0.0 | 2.5 | 3.7 | 24.1 | 23.4 |

# Task 2: Develop Improved Notional Building Specifications

## 1.6 Review of current notional buildings for design optimisation

72. We have considered how the current notional building may not encourage design optimisation of the actual building to reduce energy consumption and/or carbon emissions. The main area identified is where the notional building specification defaults to that of the actual building. This occurs both for the built form and fuel choice of the notional building. There is no benefit in optimising design for either factor.

73. The discussion below relates to the issue of built form. The lack of encouragement of low carbon heating fuels is discussed in Section 1.8.

74. Our view is that to introduce an incentive for built form would be complicated to implement successfully and would be likely to have unintended consequences. Significant further research would be necessary to assess and develop such an approach.

75. The optimal built form of a building is a complex function of many independent and widely varying parameters including:

- Activity:
  - Occupancy density;
  - Occupied hours/variation profiles;
  - Lux levels;
  - Heating and cooling setpoints.
- Climate;
- Servicing strategy;
- Heating and cooling fuel;
- Fuel factors;
- Efficiency of lighting and HVAC plant;
- Fabric performance:
  - U-values;
  - Thermal bridges.

76. Such complexity would make it difficult to implement, say, a fixed built form in the notional building that is reasonable and fair across the many types of non-domestic buildings. The fixed built form could be varied by building type and usage, but without further research, there may will need to be a significant number of built forms such that a reasonable design is included in the notional building in all cases. Some argue for an absolute performance standard as an alternative (e.g. a fixed energy demand in terms of kwh/m$^2$) to encourage a more energy efficient built form and, again, the complexity is tailoring any absolute standard such that it represents an equitable challenge across different building types (assuming that is Scottish Government's intent).

77. There is also the potential for unintended consequences when introducing an incentive to encourage improved building form. For example:

- **Building location:** Building form is strongly influenced by a constrained site; this is commonly a key factor for city-centre sites. If a new requirement was to be introduced it may effectively discourage the use of a particularly constrained city-centre site and thus encourage developed at out-of-town locations where increased use of private transport may be required.
- **Process requirements:** The form of many buildings is strongly influenced by their operational requirements, (e.g. hospitals, schools and factories). If a new requirement ran counter to these requirements, then the building may need to be larger than might otherwise be necessary and include redundant zones within the building. This would increase the cost and embodied energy impact of the building as well as being likely to increase its operational energy demands. This effect is true for all building types to some extent because building form influences the amount of circulation space needed.

78. It is also noted that the national calculation methodology (NCM) ignores or simplifies several ways in which building form will impact on real energy use and environmental impact of the building. This limits the ability that design optimisation is influenced by the notional building and may result in sub-optimal design. For example:

- **Vertical transportation:** Taller buildings are likely to have greater energy demands for lifts and escalators which are not currently included in the NCM.
- **Thermal bridging:** DSM compliance models do not normally include calculated thermal bridging values but rather simply apply a 10% allowance to all U-values. SBEM does account for this in more detail but it remains unusual for assessors to be provided with accurately calculated Ψ-values.
- **Pumping energy:** Build form will influence the length complexity of heating and cooling pipework and thus affect the pumping energy. DHW and CWS circulation and pressurisation systems will be similarly affected and strongly influenced by building height.

### 1.7 Identification of potential improved specifications

79. To provide an evidence base for potential improvements to the future notional building specification, the following steps have been taken to help ensure that decisions are well-supported by evidence and relevant to new buildings in Scotland.

- Review of EPC database;
- Review of England Part L proposals (Welsh proposals are still in development at the time of the analysis and are not included here);
- Review UK Cost Optimal Report 2018;
- Review of consultation responses;
- Review of research informing 2015 standards.

80. The principal source for this review is the EPC database. The analysis in Task 1 shows the distribution of buildings currently being constructed to different specifications. Specifications that would be representative of good practice could be taken as those around 75% of the distribution (i.e. only 25% of buildings have a better specification).

Best practice has been taken to be those specifications around 90% of the distribution (i.e. only 10% of buildings have a better specification).

81. The other sources identified above have been reviewed to confirm the conclusions of the review of the EPC database and/or provide additional insights.

82. The analysis undertaken to support the proposed changes to Part L in England took account of detailed feedback from industry representatives on the feasibility of achieving different component values, taking into account factors such as capital cost, cost-effectiveness, market availability and performance gap issues. This analysis also reviewed potential near-term future heating sources considering standards beyond 2020.

83. The UK Cost Optimal Report 2018 provides the second cost optimal assessment of energy performance requirements for the United Kingdom as required by the European Energy Performance of Buildings Directive. Analysis of Sections 11 and 12 of this reveal tipping points in the cost effectiveness of improvements to building fabric, services and renewables for different building types. This has been drawn upon to help select preferred standards for analysis.

84. We reviewed information from the consultation responses provided to the Scottish Government's 2018 Scottish Building Regulations: Review of Energy Standards: 'Call for Evidence'. This provides evidence on approaches to meeting 2015 standards.[5] We identified no relevant evidence that differed or added to learning from the EPC database analysis.

85. We reviewed information from the research informing the 2015 standards. This provides evidence on approaches to meeting 2015 standards.[6] We identified no relevant evidence that differed or added to learning from the EPC database analysis.

### 1.7.1 Fabric

86. Table 20 compares the 2015 Section 6 Notional fabric performance parameters with those from the other sources described above. The EPC database does not include U-values for individual building elements (wall, roof etc.) but rather includes the whole-building average U-value. The average U-value is a function of each individual element U-value and their relative areas; most importantly the glazed area varies significantly between different buildings and will be a strong influence on the whole-building U-value.

87. Table 21 shows U-values for each individual building element calculated on the basis of the percentage improvement in whole-building U-value; this is effectively assuming that

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[5] https://consult.gov.scot/local-government-and-communities/building-standards-energy/consultation/published_select_respondent

[6] https://www.webarchive.org.uk/wayback/archive/20160107091435/http:/www.gov.scot/Topics/Built-Environment/Building/Building-standards/publications/pubresearch/researchenergy/resenergyndph1

the glazed area is the same as the Notional in all cases; consequently, this table should be used with caution but is helpful in sense-checking the other sources.

**Table 20: Comparison of 2015 Section 6 Notional fabric performance parameters with those from other sources**

| | | Sec 6 Notional | | EPC Database | | | | | | Part L for England 2020 Proposal | | | Cost Optimal Report | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | MV & AC | | NV | | Data Peak (Mode) | | Side-lit | | Top-lit | Side-lit | Top-lit |
| Variable | | Heated & Naturally Ventilated | Heated & Cooled or Heated & Mechanically Ventilated | 75th percentile | 90th percentile | 75th percentile | 90th percentile | MV & AC | NV | Option 1 | Option 2 | | | |
| **Wall U-Value (W/m²K)** | | 0.23 | 0.20 | EPC Database does not provide this information directly, but an approximation can be inferred from the whole-building average U-value, see **Error! Not a valid result for table.**. | | | | | | 0.26 | 0.18 | 0.26 | 0.30 | 0.21 |
| **Roof U-Value (W/m²K)** | | 0.18 | 0.16 | | | | | | | 0.18 | 0.15 | 0.18 | 0.25 | 0.20 |
| **Floor U-Value (W/m²K)** | | 0.22 | 0.20 | | | | | | | 0.22 | 0.15 | 0.22 | 0.25 | 0.20 |
| **Window** | **U-Value (W/m²K)** | 1.80 | 1.60 | | | | | | | 1.60 | 1.40 | - | 1.80 | 1.40 |
| | **G-value** | 60% | 50% | | | | | | | 40% | 29% | 40% | Undefined | |
| | **Light transmittance** | 71% | 71% | | | | | | | 71% | 60% | 71% | | |
| **Rooflight[7]** | **U-Value (W/m²K)** | 1.80 | 1.80 | | | | | | | 1.80 | 1.50 | 1.80 | | |
| | **G-value** | 52% | 52% | | | | | | | 40% | 29% | 40% | | |
| | **Light transmittance** | 57% | 57% | | | | | | | 71% | 60% | 71% | | |
| **Air Tightness** | | 3, 5 or 7 | | 4.4 | 3.5 | 4.7 | 3.9 | 4.5 | 4.5 | 5 | 3 | 5 | 7 | 5 |
| **Average U-value change from Notional** | | 0% | | -27% | -37% | -34% | -41% | -20% | -31% | +16% | -13% | +16% | NA | NA |

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[7] U-values here are expressed as being in the vertical plane as is the convention under Section 6 2015. To align to changes to BS443 and associated standards it is proposed that the new Section 6 standard should express rooflight U-values standards in the horizontal plane.

**Table 21: Fabric performance parameters derived from percentage improvement in whole-building U-values in EPC database**

| | EPC database | | | | | |
|---|---|---|---|---|---|---|
| | MV & AC | | NV | | Peak | |
| **Variable** | 75th percentile | 90th percentile | 75th percentile | 90th percentile | MV & AC | NV |
| **Wall U-Value (W/m$^2$K)** | 0.15 | 0.13 | 0.13 | 0.12 | 0.16 | 0.14 |
| **Roof U-Value (W/m$^2$K)** | 0.12 | 0.10 | 0.11 | 0.09 | 0.13 | 0.11 |
| **Floor U-Value (W/m$^2$K)** | 0.15 | 0.13 | 0.13 | 0.12 | 0.16 | 0.14 |
| **Window U-Value (W/m$^2$K)** | 1.17 | 1.01 | 1.06 | 0.94 | 1.28 | 1.10 |
| **Rooflight U-Value (W/m$^2$K)** | 1.31 | 1.13 | 1.19 | 1.06 | 1.44 | 1.24 |

88. Table 22 shows proposed fabric standards for modelling analyses to support proposed changes to Section 6.

89. Previous work has identified tipping points in the costs and performance of building fabric elements. Key amongst these is the difference between double glazing and triple glazing. Double glazing can achieve U-values lower than 1.4W/m$^2$ (in the vertical plane) however below this U-value triple glazing is typically a more cost-effective option. However once triple glazing is adopted there is a strong argument for specifying a significantly improved U-value between 0.9 and 0.7W/m$^2$K. On this basis the proposed window U-values set out for analysis in Table 22 are 1.6, 1.4 and 0.9W/m$^2$K. Achieving lower U-values for rooflights is more challenging so the high option has been omitted for rooflights.

90. The current Section 6 Notional specification uses different U-values for naturally and mechanically ventilated buildings; mechanically ventilated buildings receive the lower/more challenging U-value standards. It is understood that there is a desire to simplify and improve the specification of the Notional building. Therefore the “Low” option set out in Table 22 adopts the current mechanically ventilated fabric standard and applies it to all ventilation strategies.

91. Reviewing Table 20 it can be seen that the opaque U-values identified in the cost optimal report are equal to or higher than the Section 6 2015 standards for mechanically ventilated buildings, however Option 2 from the Part L 2020 consultation for England is a significant improvement on this. Therefore, this Option 2 specification has been selected as the “medium” option for analysis as shown in Table 22. The specification draws on previous unpublished analysis which identified a tipping point for masonry wall construction. Between U-values of 0.18 and 0.15W/m$^2$K the cavity in a typical masonry wall build-up drops below 40mm consequently requiring measures to mitigate the transfer of moisture.

92. Table 21 should be used with caution (see Paragraph 86), however the figures shown implies that many Scottish buildings may be achieving U-values significantly lower than those proposed for Option 2 under the English Part L 2020 consultation (U-values in the range of 0.15 to 0.09W/m$^2$K). Given the relative uncertainty around the data in Table 21, U-values have been selected for the “high” option based on the 75th percentile rather than the 90th percentile; these are listed in Table 22.

93. The current 2015 Section 6 standard for air tightness is a function of the building size and activity type (side-lit or top-lit) varying between 3 and 7m$^3$/m$^2$/hr @50Pa. It is understood that there is a desire to simplify the specification of the Notional building so it is proposed that a single air tightness value should be used. Reviewing Table 20 it can be seen that The cost optimal report identified values of 5 and 3m$^3$/m$^2$/hr @50Pa whilst the Part L for England Consultation is proposing 5 or 3m$^3$/m$^2$/hr @50Pa. The Scottish EPC database records the air permeabilities achieved in completed buildings, this shows that 25% of floor area in new building achieved air tightness ratings of 4.4 or lower for mechanically ventilated buildings and 4.7 or lower for naturally ventilated buildings. Table 22 proposes values of 5, 4 and 3m$^3$/m$^2$/hr @50Pa for the “high”, “medium” and “low” options. Section 1.5.2.1 shows that less than 5% of non-domestic floor area achieves an air tightness of less than 3m$^3$/m$^2$/hr @50Pa. Reducing air-tightness below this value generally achieves only a small improvement in the modelled building performance. However, the method by which air tightness is modelled in SBEM and DSMs is approximated, it is therefore possible that real-world building performance is more sensitive to this parameter than modelling suggests.

**Table 22: Proposed Low, Medium and High fabric specifications for modelling**

| | | **Sec 6 Notional** | | **Suggested Options** | | |
|---|---|---|---|---|---|---|
| **Variable** | | **Heated & Naturally Ventilated** | **Heated & Cooled or Heated & Mechanically Ventilated** | **Low** | **Medium** | **High** |
| **Wall U-Value (W/m$^2$K)** | | 0.23 | 0.20 | 0.20 | 0.18 | 0.15 |
| **Roof U-Value (W/m$^2$K)** | | 0.18 | 0.16 | 0.16 | 0.15 | 0.11 |
| **Floor U-Value (W/m$^2$K)** | | 0.22 | 0.20 | 0.20 | 0.15 | 0.13 |
| **Window** | **U-Value (W/m$^2$K)** | 1.80 | 1.60 | 1.60 | 1.40 | 0.90 |
| | **G-value** | 60% | 50% | 50% | 29% | 29% |
| | **Light Transmittance** | 71% | 71% | 71% | 60% | 60% |
| **Rooflight** | **U-Value (W/m$^2$K)** | 1.80 | 1.80 | 1.80 | 1.50 | |
| | **G-value** | 52% | 52% | 52% | 29% | |
| | **Light Transmittance** | 57% | 57% | 57% | 60% | |
| **Air Tightness** | | 3, 5 or 7 | | 5 | 4 | 3 |

94. There is a synergy between high fabric performance and the use of heat pumps. Heat pumps operate more efficiently when providing heat at lower temperatures; the low heating demands that enhanced fabric achieves facilitates the use of low temperature heating systems. Section 1.8 discusses the possibility of using gas boilers and PV to achieve similar $CO_2$ and primary energy performance to an ASHP system; this challenge is made easier when enhanced fabric is used.

### 1.7.2 Services

95. Table 23 compares the 2015 Section 6 Notional building service performance parameters with those from the other sources described above. The EPC database does not include data for lighting efficacies or automatic controls; neither does it include information on ventilation performance parameters. However, it does contain data on the efficiency of the heating and cooling sources used.

96. Table 24 shows proposed “Low”, “Medium” and “High” building service standards for modelling analyses to support proposed changes to Section 6.

#### 1.7.2.1 Space Heating

##### 1.7.2.1.1 Gas Boiler

97. Gas boiler technology is mature and not expected to see significant improvements in the next five years. The market for manufacture installation and maintenance of gas boilers is well established and competitive. The gas boiler efficiencies from the EPC database show that 25% of buildings include boilers with seasonal efficiencies of 97% or higher and 10% achieve 98% or higher. These are efficiencies are at the upper end of what is achievable with current technology. It is possible that some lodged EPCs may be incorrectly based on net rather than gross efficiencies; this would artificially inflate the reported efficiencies in the database. All the other sources shown in Table 23 suggest gas boiler efficiencies significantly lower than this, ranging between 91% and 93%; this is a very narrow range. The current 2015 Section 6 Notional building uses 91% which is at the bottom of the narrow range suggested by the other analyses; it is therefore proposed that 93% is considered for the Section 6 2020 analysis.

##### 1.7.2.1.2 Radiant Heating

98. For naturally ventilated top-lit spaces (such as distribution warehouses) radiant gas heaters are the dominant heating type. This technology is mature and not expected to see significant improvements in performance in the next five years. The market for manufacture, installation and maintenance of gas radiant heaters is well established and competitive. The gas radiant heater efficiencies from the EPC database show that 25% of buildings include gas radiant heaters with seasonal efficiencies of 92% or higher and 10% achieve 93% or higher. These are efficiencies are at the upper end of what is achievable with current technology. Both the Part L for England proposals and the Cost Optimal Report suggest values of 86%. The current 2015 Section 6 Notional building also uses 86% which is less efficient than around 80% of radiant heating systems recorded in the EPC database. It is therefore proposed that 92% is considered for the Section 6 2020 analysis.

#### 1.7.2.1.3 Air Source Heat Pumps (ASHPs)

99. ASHPs have represented a small part of the heating market for several decades; recent increased concern about climate change has been a strong driver for the increased use of this technology and have encouraged improvements in efficiency and reductions in capital and maintenance costs. Many global manufacturers are actively developing improved products using refrigerants with reduced Global Warming Potential (GWP). Table 23 shows that the current 2015 Section 6 Notional efficiency for an ASHP is much lower than those recorded in the EPC database and the English Part L analysis. On this basis Table 24 shows the proposed “Low”, “Medium” and “High” options which are aligned to the 50th, 75th and 90th percentiles from the EPC database.

100. ASHPs can be used for both space heating and hot water. The efficiency of a heat pump is higher when supplying lower temperatures. A common temperature regime for a wet heating system is 80ºC flow and 60ºC return; very few heat pumps can achieve flow temperatures above 70ºC so a lower temperature system is required. To improve the heat pump efficiency, it is common to design heating system with flow temperatures around 50ºC or even lower.

101. Figure 16 shows four curves illustrating the relationship between heating flow temperature and Seasonal Coefficient of Performance (SCoP); the green and blue curves show the idealised theoretical relationship based on two different Carnot efficiencies, and the purple and orange curves show the calculated relationship for two real heat pumps based on detailed performance data supplied by manufacturers and the TRY weather for Glasgow. It can be seen that the performance of real ASHPs is similar to, but differs slightly from, the idealised performance.

102. The current 2015 Section 6 performance requirements (as well as the EU ErP and several other standards) for ASHPs are based on the products’ efficiency when measured in accordance with EN 14511. This standard makes standardised assumptions about the ambient air temperature (i.e. the temperature of the source from which the heat pump extracts heat) and the heating system flow temperatures. These standard assumptions mean that the “official” efficiency will differ from that calculated using project-specific values such as the location weather data and system flow temperature. EN 14511 requires that performance is measured at a minimum of one of four heating system flow temperatures (35ºC, 45ºC, 55ºC and 65ºC). Figure 16 shows several thousand reported efficiencies from the Eurovent database measured at each of these temperatures; it can be seen that these broadly align with the curves described above.

103. Figure 16 shows three horizontal black dotted lines corresponding to the 50th, 75th and 90th percentiles reported in the EPC database (see Section 1.5.3.1.2). Comparing these dotted-lines with the Eurovent data (and assuming that modellers are inputting the appropriate values in the EPC models) it can be inferred that many ASHP heating systems are being designed with flow temperatures below 55ºC. The 50th and 75th percentile values appear to only be achieved by system operating at 45ºC or lower, whilst the 90th percentile is only achieved by systems at 35ºC. As the EPC database does not report heating system flow temperature it is not possible to validate this.

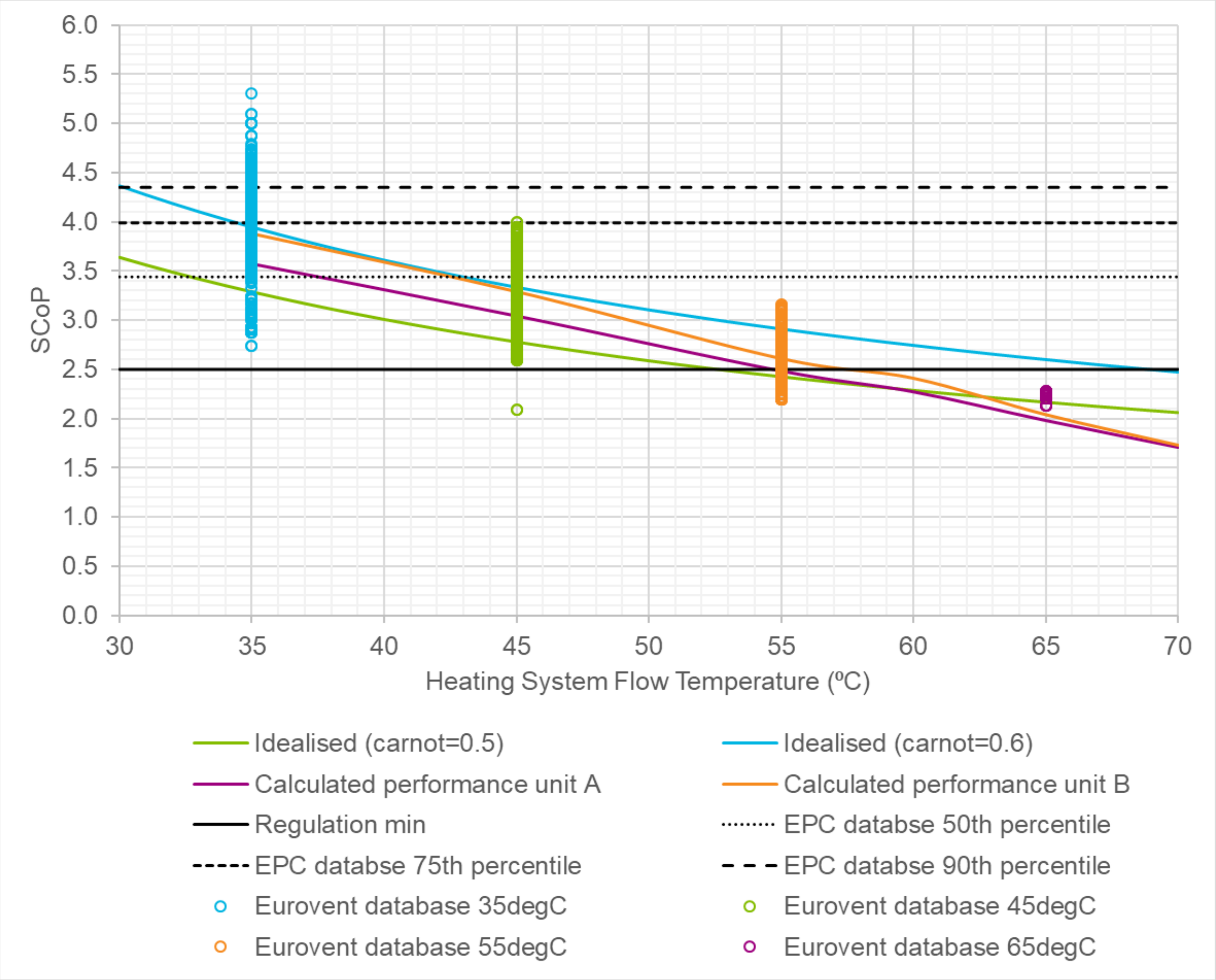

**Figure 16: Relationship between Heating system flow temperature and SCoP.**

### 1.7.2.2 Domestic Hot Water (DHW)

104. The efficiency of gas boilers and other combustion-base heat generators supplying DHW systems is generally similar to that of the same or equivalent heat generators providing space heating. However, the efficiency of equivalent heat pumps serving these two load types varies more significantly. This section considers what efficiency to include in the notional buildings for ASHPs serving DHW systems.

105. Domestic Hot Water (DHW) systems are often designed to heat water to 60ºC to mitigate legionella risks associated with storing hot water at lower temperatures. DHW systems which heat water instantaneously upon demand can avoid this because the warmed water is not stored for long periods. Heat pump DHW systems generally include water storage and so are often designed to heat water to 60ºC, and this relatively high temperature results in a reduced heat pump efficiency. It is possible to design heat pump DHW systems which heat water instantaneously however this approach is not widely adopted. Therefore, for the purposes of developing a widely accepted heat pump DHW solution for the notional building, it is proposed that when the notional building uses heat pumps, there should be separate heat pumps for space heating and DHW and the respective efficiencies of these two heat pumps reflect the different temperatures at which they are likely to operate. EN 14511 and the related

standards do not include generation of DHW and the current Section 6 Non-Domestic Building Service Compliance Guide does not appear to specify a test method but simply sets a minimum standard of 2.0. This implies that it is up to the design team to determine the efficiency by whatever means they choose.

106. The SCoP of an ASHP providing space heating is weighted towards the unit's performance in cooler weather when the heating demand is higher. DHW demand is typically required all year round and so the average air temperature when the unit is running is higher for DHW than for space heating. The efficiency of ASHPs providing DHW is therefore increased by the average air temperature and reduced by the need to provide water at 60ºC. Using the same calculation method as was used to produce the orange and purple curves in Figure 16 above, it has been found that the net impact of these two effects is approximately 10%, i.e. the average efficiency of an ASHP providing space heating at 55ºC in Glasgow can be approximately 10% higher than that of the same unit being used to provide DHW. However, if the space heating system has a lower flow temperature then the effect of the higher temperature requirements of DHW become dominant so the difference between DHW and space heating efficiency will increase. As is described in paragraph 103, it can be inferred that the majority of ASHP heating systems in the EPC database are using flow temperatures below 55ºC. A reduction factor can be applied to the ASHP DHW efficiency used in the notional building to reflect this.

107. Figure 17 shows the approximate relationship between DHW and space heating SCoP for a widely-used heat pump from a leading manufacturer, based on a range of assumed space heating efficiencies.

- If we assume that the 50th percentile in Figure 16 (SCOP = 3.44) is likely to represent systems operating at 45ºC the equivalent DHW SCoP may be assumed to be approximately 73% of this value (i.e. 2.5).
- Similarly if we assume that the 75th and 90th percentiles are more representative of heating systems operating at 35ºC then the adjustment is around 62%, so the 75th percentile value for space heating (SCOP=4.0) is adjusted an equivalent DHW SCoP of 2.5 and the 90th percentile for space heating (SCOP = 4.35) is adjusted to an equivalent DHW SCoP of 2.7.

108. These three adjusted values for the 50th, 75th and 90th percentiles respectively are proposed for the “Low”, “Medium” and “High” options for ASHPs serving DHW systems.

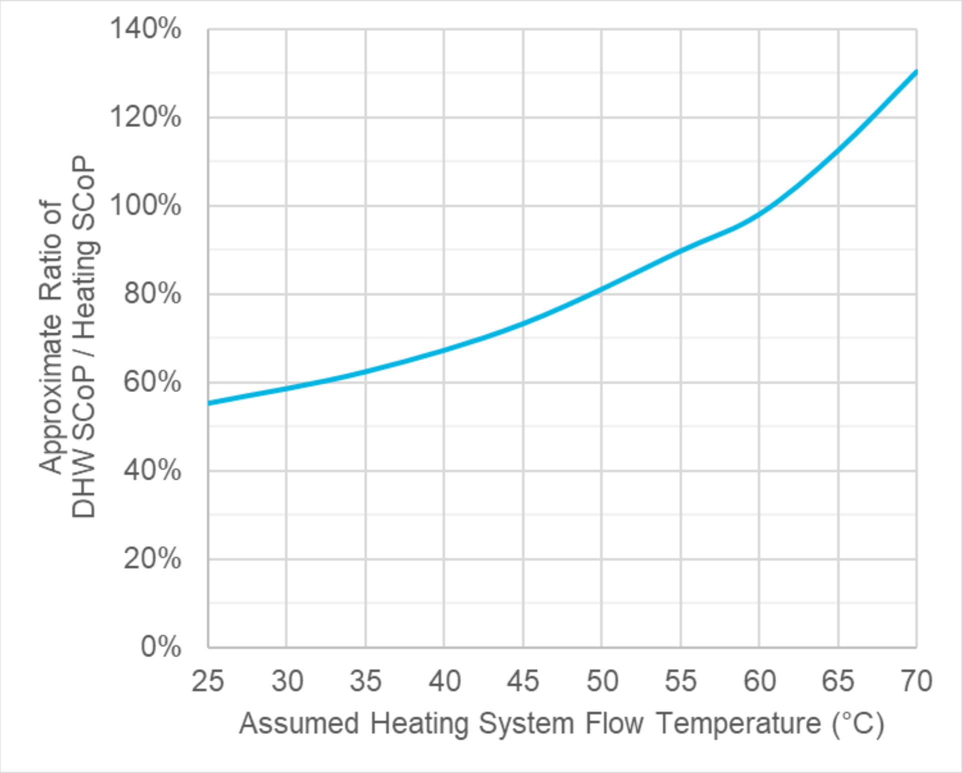

**Figure 17: Indicative relationship between ASHP SCoP for space heating and DHW provision across a range of space heating flow temperatures**

#### 1.7.2.3 Cooling

109. Demand for cooling has increased significantly over the last two decades driven by higher comfort expectations of building occupants, reduced costs and economic forces encouraging the development of deep-plan mechanically ventilated buildings. Being closely related to ASHPs, chiller technology is also undergoing similar developments to improve efficiency and reduce the GWP of refrigerants used. The current SEER for the 2015 Section 6 Notional building is 4.5; the English Part L consultation proposes a higher value of 5.5. The EPC database shows that the 75th and 90th percentiles are significantly higher at 6.4 and 7.1. On this basis the proposed “Low”, “Medium” and “High” options are 5.5, 6.4 and 7.1 respectively.

#### 1.7.2.4 Lighting

110. The efficacy of luminaires in the 2015 notional building is 60llm/cW for naturally ventilated buildings and 65llm/cW where mechanical ventilation or cooling is included. Over the last few years the rapid development of LED technology has driven a large improvement in the efficiency of installed lighting systems. LED technology is still developing rapidly and is predicted to continue to do so for many years. The English Part L consultation proposes an efficacy of 95llm/cW to reflect LED technology; this same value was identified in the cost optimal report. Even in the few months since these analyses LEDs have continued to improve, so it is proposed that the should be towards the upper end of what is widely available today, we believe this to be in the region of 125llm/cW. AECOM’s lighting specialists advise that market analysts widely expect efficacies in the range 200-270llm/cW by 2025. It may therefore be worth

considering whether there is a mechanism by which lighting efficacy (and other notional building performance parameters) can be improved in the period between the principal Section 6 updates. The English Part L analysis identified that LEDs have effectively removed the justification for a difference in efficacy between general and most display lighting. However, the improvement in the efficacy of some types of reflector lamp lag behind that of other lighting types. Nevertheless, it is proposed that the notional efficacy of general and display lighting values should be aligned.

#### 1.7.2.5 Ventilation

111. Where the 2015 Section 6 Notional building uses mechanical ventilation with supply and extract, it has a heat recovery efficiency of 70% and fans are controlled based on gas-sensors linked to inverter drives. This heat recovery efficiency is now superseded by the European Eco-Design Directive which stipulates that such heat recovery should have a minimum efficiency of 73%[8]. Heat recovery systems can achieve efficiencies in excess of 90%, however the size and cost of systems that can achieve this are large. The English Part L 2020 consultation proposes an efficiency of 76%, therefore this figure is proposed in Table 24. Gas-sensors with inverter speed control is the most efficient option currently available in SBEM so this solution is applied across all three options.

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[8] Except for run-around coiler for which this the Eco-Design Directive stipulates a minimum efficiency of 68%.

## Table 23: Comparison of 2015 Section 6 Notional building service performance parameters with those from other sources

| | | Sec 6 Notional | | EPC Database | | | | | | Part L for England[9] 2020 Proposal | | | Cost Optimal Report | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | MV & AC | | NV | | Data Peak | | Side-lit | | | | |
| Variable | | Heated & Naturally Ventilated | Heated & Cooled or Heated & Mechanically Ventilated | 75th percentile | 90th percentile | 75th percentile | 90th percentile | MV & AC | NV | Option 1 | Option 2 | Top-lit | Side-lit | Top-lit |
| Heating & Cooling | Gas boiler | 91% | | 97% | 98% | 97% | 98% | 95% | 95% | 86% | | NA | 91% | NA |
| | ASHP | 1.75 | | 4.00 | 4.35 | 4.00 | 4.35 | 3.25 | 3.25 | 3.2 | | | NA | |
| | Radiant gas heater (top-lit) | 86% | | NA | NA | 92% | 93% | NA | 95% | NA | | 86% | NA | 86% |
| | Cooling SEER | 4.50 | | 6.40 | 7.10 | NA | NA | 6.50 | NA | 5.5 | | | 3.60 | |
| Domestic Hot Water | Gas Boiler | 91% | | 97% | 98% | 97% | 98% | 95% | 95% | 93% | | | 91% | |
| | ASHP | 1.75 | | 2.50 | 2.70 | 2.50 | 2.70 | 2.40 | 2.40 | 3.55 | | | NA | |
| Lighting & Ventilation | Lighting luminaire (llm/cW) | 60 | 65 | EPC Database does not provide this information. | | | | | | 95 | | | 95 | 75 |
| | Daylight lighting control | Single zone daylight dimming | | | | | | | | Single zone daylight dimming | | | Yes but undefined | |
| | Occupancy Lighting Control | Manual on auto off | | | | | | | | Auto on auto off | | | Yes but undefined | |
| | Parasitic Power | 0.3W/m² or 3% for daylight<br>0.3W/m² for occupancy | | | | | | | | 0.1W/m² | | | Undefined | |
| | Display Lighting (llm/cW) | 22 | | | | | | | | 95 | | | Undefined | |
| | Display Lighting Control | none | | | | | | | | time switch | | | Undefined | |
| | Ventilation Heat Recovery | 70% | | | | | | | | 76% | | | Undefined | |
| | Demand Control Ventilation | gas-sensors, inverters | | | | | | | | gas-sensors, inverters | | | Undefined | |

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[9] The Welsh Part L 2020 analysis is still ongoing at the time of writing.

**Table 24: Proposed Low Medium and High building service specifications for modelling**

| | | Sec 6 Notional | | Suggested Options | | |
|---|---|---|---|---|---|---|
| Variable | | Heated & Naturally Ventilated | Heated & Cooled or Heated & Mechanically Ventilated | Low | Medium | High |
| Heating & Cooling | Gas Boiler | 91% | | 93% | | |
| | ASHP | 1.75 | | 3.44 | 4.00 | 4.35 |
| | Cooling SEER | 4.50 | | 5.50 | 6.40 | 7.10 |
| Domestic Hot Water | Gas Boiler | 91% | | 93% | | |
| | ASHP | 1.75 | | 2.50 | 2.50 | 2.70 |
| Lighting & Ventilation | Lighting Luminaire (llm/cW) | 60 | 65 | 125 | | |
| | Daylight Lighting Control | Single zone daylight dimming | | Single zone daylight dimming | | |
| | Occupancy Lighting Control | Manual on auto off | | Manual on auto off | | |
| | Parasitic Power | 0.3W/m$^2$ or 3% for daylight<br>0.3W/m$^2$ for occupancy | | 0.1W/m$^2$ | | |
| | Display Lighting (llm/cW) | 22 | | 125 | | |
| | Display Lighting Control | none | | time switch | | |
| | Ventilation Heat Recovery | 70% | | 76% | | |
| | Demand Control Ventilation | gas-sensors, inverters | | gas-sensors, inverters | | |

### 1.7.3 On-site Generation

112. Table 25 compares the 2015 Section 6 Notional photovoltaic (PV) array size with those from the other sources described above. Table 26 shows proposed “Low”, “Medium” and “High” photovoltaic arrays sizes for modelling analyses to support proposed changes to Section 6.

113. The 2015 Section 6 notional building has a PV array sized to the lesser of 4.5% of the GIA and 50% of the roof area. The cost optimal report effectively identified the optimal size of PV array as being as large as possible however the modelled options limited this to 40% of roof area[10]. The Part L consultation proposed 40% of roof area for top-lit spaces and 20% for side-lit spaces on the basis that side-lit spaces often have a

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[10] BEIS cost data gathered through the MCS scheme shows that capital cost per kilowatt falls as PV array size increases.

greater proportion of the roof area occupied by plant. Analysis of the EPC database shows that PV is more widely used for naturally ventilated building than mechanically ventilated/cooled buildings. The approximate percentages of GIA and roof area have been derived from the EPC database by comparing the PV outputs with those of the notional building; this approach suggests that 25% of naturally ventilated buildings have a PV array which is larger than either 2.6% of the GIA or 29% of the roof area whilst 10% of these buildings have PV areas greater than 13% of the GIA or 145% of the roof. This last figure implies that either some of the PV is ground-mounted or the buildings are tall and so the percentage of GIA is the limiting factor.

114. To determine how much PV the notional building should have it is necessary to decide whether the aim is to encourage developers to put as much PV on roofs as is practical or to link the incentive to the size and energy use of the building. If the aim is to encourage the use of on-site generation then linking this to roof area is desirable; if the aim is to link this to size and energy use, then GIA is a helpful metric. The proposed approach is to develop a notional building specification which includes PV when gas is the heating and DHW fuel but to not include PV when ASHPs are used for heating and DHW. PV is included for gas heating only to broadly equalise the level of challenge associated with achieving compliance whether gas heating or an ASHP is used; this is discussed from Paragraph 155.

**Table 25: Comparison of 2015 Section 6 Notional photovoltaic array sizes with those from other sources**

| | | **Sec 6 Notional** | | **EPC Database** | | | | **Part L for England[11] 2020 Proposal** | | | **Cost Optimal Report** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | **MV & AC** | | **NV** | | **Side-lit** | | **Top-lit** | | |
| **Variable** | | **Heated & Naturally Ventilated** | **Heated & Cooled or Heated & Mechanically Ventilated** | **75th percentile** | **90th percentile** | **75th percentile** | **90th percentile** | **Option 1** | **Option 2** | | **Side-lit** | **Top-lit** |
| **PV Area: Lesser of:** | **% of GIA** | 4.5% | | 0% | 6.3% | 2.6% | 13.0% | NA | | NA | NA | |
| | **% of roof area** | 50% | | 0% | 70% | 29% | 145% | 20% | | 40% | 40% | |

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[11] The Welsh Part L 2020 analysis is still ongoing at the time of writing.

115. Note that the values in Table 26 are based on the same PV output as is currently used for the notional building under Section 6 2015 (i.e. 120kWh/m²) which is equivalent to a nominal efficiency of approximately 16%.

**Table 26: Proposed Low Medium and High onsite generation specifications for modelling**

| | | Sec 6 Notional | | Suggested Options | | |
|---|---|---|---|---|---|---|
| **Variable** | | **Heated & Naturally Ventilated** | **Heated & Cooled or Heated & Mechanically Ventilated** | **Low** | **Medium** | **High** |
| **PV Area: Lesser of:** | **% of GIA** | 4.5% | | 6.5% | 13.0% | |
| | **% of roof area** | 50.0% | | 50.0% | 50.0% | |

### 1.7.4 Trends in Heating Fuel Selection

116. The EPC database has been analysed to assess recent trends in heating fuel selection for new buildings. This analysis is intended to inform the choice of heating fuel and technology in the proposed notional specification by assessing the current uptake of different technologies. Figure 18 shows the quarterly variation in floor area served by each heating fuel. This is based on the EPC model inputs for each HVAC system in each building, rather than using the single heating fuel for the whole building which is reported on the EPC. This approach has been taken to capture the effect of many buildings having multiple heating fuels serving different areas of the building. For example, a building may have gas boilers serving most of the floor area but use ASHPs to provide heating (and cooling) to a small number of rooms.

117. Figure 18 shows the following key trends over the period of the analysis:

- Use of natural gas declines from 2013 to 2015 and then remains fairly constant.
- Use of ASHPs increases from 2013 to 2015 and then decreases.
- Use of oil is low from 2013 to 2015 and then increases significantly.
- Biomass is used for around 40% of floor area in Q1 of 2013 and 25% in Q1 of 2014. In general there is a downward trend in biomass use across the whole period.

The use of other heating fuels is insignificant in most quarters, with no clear trend being apparent.

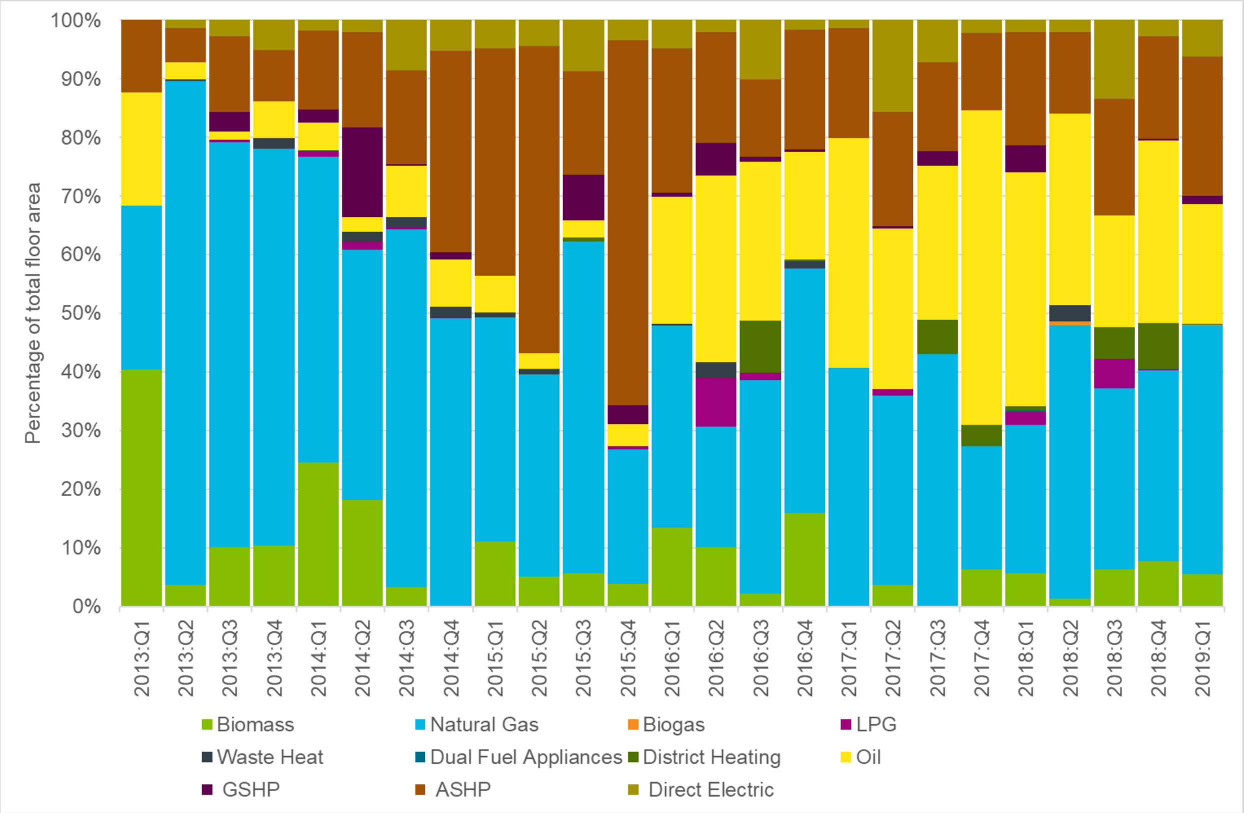

**Figure 18: Quarterly variation in floor area served by each heating fuel based on lodged EPCs**

118. It is noted that the database covers a period in which spans two different version of Section 6, i.e. versions that first came into effect in 2010 and 2015. The analysis of Figure 18 set out above appears to show that post 2015, a greater proportion of new build floor area was served with oil-fired heating whilst a lesser proportion of floor area was heated by ASHPs. In some quarters the new floor area heated by oil is greater than that heated by gas.

### 1.8 Consideration of low carbon heating and renewable technologies

119. The notional building under the current (2015) version of Section 6 uses the same heating fuel as the actual building in all cases. In the context of the Scottish Government's ambition to radically reduce the use of fossil fuels in new buildings this approach is to be reviewed. As part of this review the possibility to use a low carbon heat source in all has been considered.

120. As part of the Scottish Governments strategy to decarbonise heat, district heat networks are being encouraged and supported. It is therefore preferred that the changes to Section 6 allow new buildings to connect to both new and existing district heat networks.

121. The above ambitions may be moderated by the desire to avoid the negative impacts of a sudden change to the building servicing strategies implemented in new buildings. Negative impacts could stem from supply change constraints affecting low carbon heat sources, economic impacts of falling demand for fossil-fuelled plant, skills shortages in relation to the design, installation, commissioning and maintenance of low carbon heat

sources which operate in significantly different ways to fossil-fuelled plant. Whilst there is a wide range of low-carbon heat sources, all of these require the building location to have certain characteristics, these are summarised in Table 27. To help address these concerns it is proposed that the analysis should identify routes to compliance which use fossil-fuelled systems in combination with onsite generation from renewable sources such as PV.

122. The analysis below explores the relative viability of achieving carbon reductions through the use of low/zero-carbon heat sources compared to using fossil fuelled heating combined with PV. We understand from the client’s brief that the latter should be a reasonable and viable option.

123. Table 27 sets out the limitations and constraints associated with the most widely used low/zero-carbon heat sources. This comparison helps to select those heat sources which may be considered to be viable to the most non-domestic buildings.

**Table 27: Summary of site constraints for low-carbon heating sources**

| Low -Carbon Heat Source | Limitations & Site Constraints |
|---|---|
| Heat Pump - Air-source (ASHP) | Requires access to external air; may be challenging for units within larger buildings. However, this is a relatively unusual barrier and can be overcome through a coordinated design with the larger building. |
| Heat Pump - Water-source (WSHP) | Requires access to a suitable body of water which is rarely available. |
| Heat Pump - Ground-source (GSHP) | Requires suitable ground conditions, this can be viewed as a large unquantified project risk until ground investigations can be undertaken. The costs and uncertainty may discourage the use of this technology. |
| Heat Pump - Sewer-source (SSHP) | Requires access to a suitable sewer and cooperation from sewer owner/operator[12]. Such reliance on a third party may be deemed to be an unacceptable project risk. This technology is still deemed to be relatively innovative. |
| Biomass boiler | Requires suitable access for fuel delivery and storage. Ongoing maintenance and operational requirements may be deemed to be burdensome for building occupants/owners. |
| Solar water heating | Generally only suitable for domestic hot water provision although innovative systems can provide space heating as well. |

124. Based on the constraints identified in Table 27, it is proposed that, where applicable, the preferred low carbon heat source for the notional building should be an ASHP as

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[12] Whilst utility companies are mandated to cooperate with reasonable requests for connection to their infrastructure this requirement does not extend to unorthodox uses of their property such as SSHPs. However there are examples of this technology being successfully deployed in Scotland.

this technology has the least challenging constraints and is therefore likely to be technically viable in more cases than the other technologies considered.

125. ASHPs can be used for both space heating and hot water. The efficiency of a heat pump is higher when supplying lower temperatures. A common temperature regime for a wet heating system is 80ºC flow and 60ºC return; very few heat pumps can achieve flow temperatures above 70ºC so a lower temperature system is required. To improve the heat pump efficiency, it is common to design heating system with flow temperatures around 50ºC or even lower. Some countries require that space heating systems are designed with flow temperatures no greater than a specified threshold, for example in Sweden regulations introduced in 1984 stipulate a maximum temperature of 55ºC[13]. This requirement was initially indented to simply reduce energy demands but it also facilitated the later retro-fitting of heat pumps[14]. The relationship between heating flow temperature and heat pump efficiency is characterised as a power relationship with no significant step changes and so there is no strong technical justification for a particular heating flow temperature to be selected. The 55ºC threshold stipulated in Sweden has the advantage that it aligns to the current EN 14511 standard as well as several related standards (see paragraph 102). Figure 16 shows that relatively few ASHP report their performance at the higher temperature of 65ºC and that, at this temperature, none of these meet the current minimum standard of 2.5. At 55ºC the majority of ASHP meet the 2.5 requirement and at 45ºC almost all do.

126. The use of an ASHP will result in lower $CO_2$ and primary energy values than those achieved by a gas boiler system. Using the proposed $CO_2$ and primary energy factors, analysis has been undertaken to assess the amount of PV required to reduce the total $CO_2$ and primary energy values of a building using gas boilers with those of the same building using an ASHP. This analysis has initially been based upon the efficiencies of these technologies in the current 2015 Section 6 notional building (gas boiler 95% efficiency and ASHP SEER of 3.44). The results of this analysis are shown in Table 28 expressed as the area of 20% efficient PV needed per unit area of gross internal floor area (GIA). Single storey buildings with roofs that are close to being flat will have a roof area equal to the GIA, in multi-storey buildings the ratio of roof area to GIA reduces. Table 28 shows that the ratio of PV area to GIA exceeds 1 for $CO_2$ when the heat demand exceeds around 65kWh/m²/yr, for primary energy this threshold is in excess of 145kWh/m²/yr. When this threshold is passed the area of PV needed is greater than can be accommodated on the roof of a single-storey building if the roof is covered completely. When these ratios exceed 0.5 the PV can no longer be accommodated on a two-storey building when the roof is completely covered. The current 2015 Section 6

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[13] Karlsson, Fredrik, Monica Axell, and Per Fahlén. 2003. “Heat Pump Systems in Sweden - Country Report for IEA HPP Annex 28.” Borås, Sweden: SP Swedish Technical Research Institute. https://www.researchgate.net/publication/238661515_Heat_Pump_Systems_in_Sweden

[14] Simon Rees and Robin Curtis 2014. “National Deployment of Domestic Geothermal Heat Pump Technology: Observations on the UK Experience 1995–2013” Institute of Energy and Sustainable Development, De Montfort University. GeoScience Ltd.

notional building has PV up to a maximum of 50% of the roof area. It is recognised that in many cases it may not be viable to completely cover the roof area with PV, for example there may be rooflights or roof-top plant that reduces the available area. In the case of roof-top plant it may be possible to put PV on a frame above the plant but this will increase the cost and visibility of the PV. It is also possible to locate PV on areas other than the roof, for example façade-integrated PV or on a canopy over parking areas.

**Table 28: Analysis of Area of PV required to equalise $CO_2$ and primary energy performance of buildings with gas boilers (efficiency=91%) and ASHPs (SEER=3.44)**

| Annual Heat Demand (kWh/m$^2$/yr) | Area of PV required to equalise total $CO_2$ (m$^2$PV/m$^2$GIA) | Area of PV required to equalise total primary energy (m$^2$PV/m$^2$GIA) |
|---|---|---|
| 5 | 0.073 | 0.027 |
| 15 | 0.220 | 0.082 |
| 25 | 0.367 | 0.136 |
| 35 | 0.514 | 0.191 |
| 45 | 0.661 | 0.245 |
| 55 | 0.808 | 0.299 |
| 65 | 0.955 | 0.354 |
| 75 | 1.102 | 0.408 |
| 85 | 1.249 | 0.463 |
| 95 | 1.396 | 0.517 |
| 105 | 1.543 | 0.572 |
| 115 | 1.690 | 0.626 |
| 125 | 1.837 | 0.681 |
| 135 | 1.984 | 0.735 |
| 145 | 2.131 | 0.789 |

127. Figure 19 shows the distribution of the space heating demand for gas-heated buildings in the EPC database. This shows that the majority of gas-heated buildings have a space heating demand below 40kWh/m$^2$/yr and less than 10% of buildings have a space heating demand greater than 80kWh/m$^2$/yr.

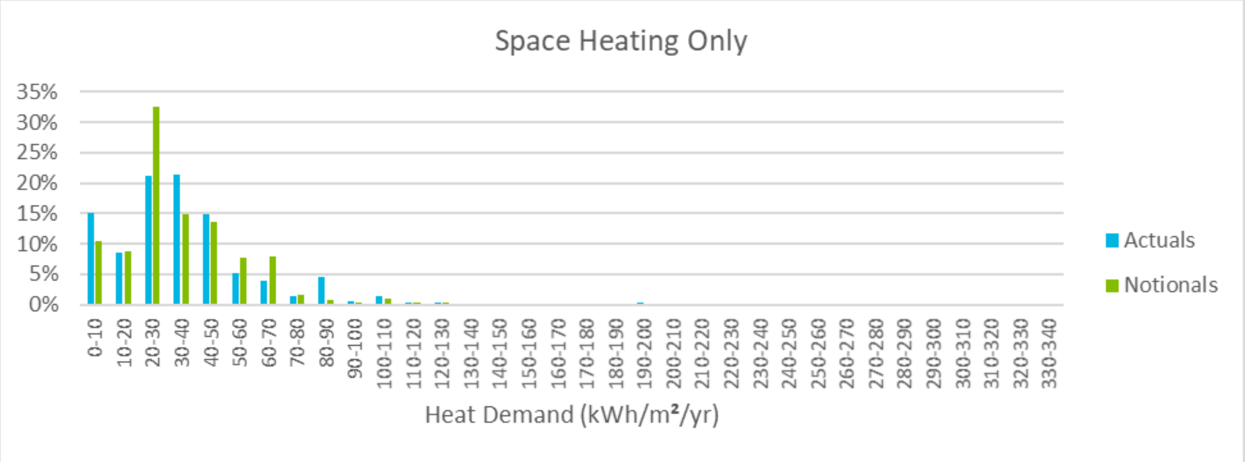

**Figure 19: Distribution of space heating demand of gas heated buildings in the EPC database**

128. Figure 20 shows the distribution of the total of space heating and DHW demand for gas-heated buildings in the EPC database. This shows that around half of gas-heated buildings have a combined space heating and DHW demand below 80kWh/m²/yr and that the remaining buildings principally have a combined heat demand between 80 and 300kWh/m²/yr.

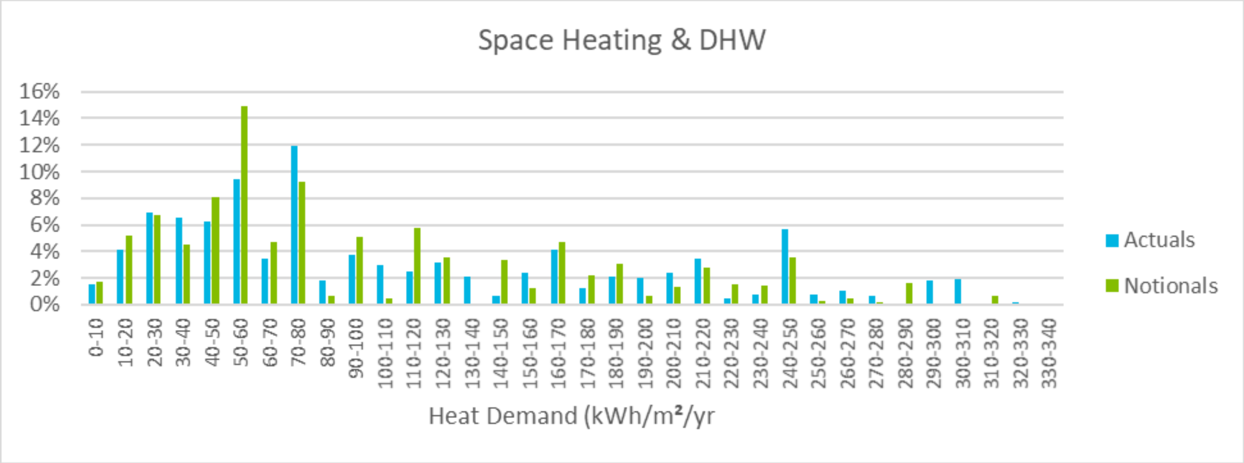

**Figure 20: Distribution of total of space heating and DHW demand of gas heated buildings in the EPC database**

129. This analysis suggests that, with no other improvements, the majority of single-storey buildings with gas heating and PV would be able to improve upon the $CO_2$ performance of a notional building using an ASHP for space heating only. Similarly, the majority of single-storey buildings with gas heating and PV may be able to improve upon the primary energy performance of a notional building using an ASHP for space heating and DHW if the ASHPs providing space heating and DHW can achieve this overall combined efficiency, for buildings where the DHW demand dominates this will be particularly challenging. However as more storeys are added to the building this route to compliance becomes increasingly challenging. Nevertheless, there are many other routes to achieving compliance such as improving energy efficiency and other low carbon technologies.

130. The amount of PV required to comply can be reduced by setting the notional ASHP to a lower SEER. The analysis above was based on the proposed notional ASHP SEER of 3.44 (see Table 8), Table 29 shows this the effect of changing the proposed notional ASHP SEER to 2.0[15]. It can be seen that whilst the amount of PV required to comply for primary energy is approximately halved, that needed to comply for $CO_2$ is only reduced by around 22%; this is caused by the differences in gas and electricity factors for $CO_2$ and primary energy.

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[15] i.e. the current Section 6 2015 minimum standard for ASHPs providing DHW.

**Table 29: Analysis of Area of PV required to equalise $CO_2$ and primary energy performance of buildings with gas boilers (efficiency=91%) and ASHPs (SEER=2.0)**

| Annual Heat Demand (kWh/m²/yr) | Area of PV required to equalise total $CO_2$ (m²PV/m²GIA) | Area of PV required to equalise total primary energy (m²PV/m²GIA) |
|---|---|---|
| 5 | 0.060 | 0.016 |
| 15 | 0.181 | 0.047 |
| 25 | 0.302 | 0.078 |
| 35 | 0.423 | 0.110 |
| 45 | 0.544 | 0.141 |
| 55 | 0.665 | 0.172 |
| 65 | 0.786 | 0.204 |
| 75 | 0.907 | 0.235 |
| 85 | 1.028 | 0.266 |
| 95 | 1.149 | 0.298 |
| 105 | 1.270 | 0.329 |
| 115 | 1.391 | 0.360 |
| 125 | 1.512 | 0.392 |
| 135 | 1.633 | 0.423 |
| 145 | 1.754 | 0.454 |

131. The analysis above has considered the technical viability of using PV to achieve reductions in $CO_2$ and primary energy. The analysis below considers the cost effectiveness of this approach as a means of reducing the carbon emissions of a building[16].

132. The capital cost data and modelling results for the analysis to support the English Part L consultation have been analysed to review the relative cost effectiveness of ASHPs and gas heating and PV. The result of this analysis is summarised in Table 30, this suggests that the capital cost effectiveness of ASHPs is greater than gas heating and PV in buildings with larger heat demands but lower in those buildings with lower heating demands. This is likely to be due to the ASHPs being better utilised in buildings with larger heating demands.

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[16] This is distinct from cost-effectiveness for the building occupants/owners which is a measure of the return on investment in PV.

**Table 30: Analysis of whether gas heating and PV or ASHP is more cost effective in terms of savings per pound of capital cost for a range of buildings modelled for the English Part L 2020 analysis**

| More cost-effective technology (Gas+PV or ASHP) | Office – deep plan, air conditioned | Hotel | Hospital | Secondary School | Retail Warehouse | Distribution Warehouse |
|---|---|---|---|---|---|---|
| Primary Energy | Gas + PV | ASHP | Gas + PV | Gas + PV | Gas + PV | ASHP |
| $CO_2$ | Gas + PV | ASHP | ASHP | Gas + PV | ASHP | ASHP |

133. The analysis above (paragraphs 126 to 130) compared the technical ability of gas heating with PV against an ASHP and identified that buildings with lower heat demands can more easily use PV to achieve the same $CO_2$ and primary energy savings as an ASHP whilst those with higher heat demands may not have sufficient roof space to achieve this. The results in Table 30 align to this finding by suggesting that ASHPs are a more cost-effective improvement for buildings with higher heat demands (i.e. when they are also more technically viable) and that PV is more cost effective in buildings with lower heat demands (i.e. where PV is a viable means of achieving the same improvements), this is summarised in Table 31.

**Table 31: Summary of comparison of PV and ASHP technical viability and cost-effectiveness**

| Criterion | High heat demand | Low heat demand |
|---|---|---|
| **Technical viability** | Table 28, Table 29, Figure 19 and Figure 20 suggest that ASHP can generally achieve greater $CO_2$ and primary energy savings than PV because PV is limited by the roof area available. | Table 28, Table 29, Figure 19 and Figure 20 suggest that PV (combined with gas-boiler) is likely to be able to achieve similar $CO_2$ and primary energy savings to those achieved by an ASHP. |
| **Cost-effectiveness** | Table 30 suggests that ASHP is generally the more cost effective of these two technologies. | Table 30 suggests that PV is generally the more cost effective of these two technologies. |

134. The analysis above (paragraphs 126 to 130) has assessed the viability of using gas heating and PV to achieve the same savings as achieved by an ASHP used just for space heating or for space heating and DHW. A key factor in this analysis is the approach that the notional building takes to fuel selection and delivery losses in the DHW system. The English Part L consultation proposes that the DHW system in the notional building be determined by the fuel type and the magnitude of the DHW demand as set out in Table 32. This approach responds to the increase in renewables on the electricity grid and the resultant drop in primary energy and $CO_2$ factors. This change in grid generation mix means that the use of electric point-of-use water heaters is no longer a high-carbon or high-primary-energy solution compared to natural gas. In

buildings with low DHW demand the use of a centralised DHW system can result in higher primary energy and $CO_2$ because of the relatively high losses from DHW storage and secondary circulation loops. In buildings with higher DHW demand the relative magnitude of these losses is reduced. Centralised DHW systems also facilitate the use of lower carbon heat sources such as waste heat or bio-fuels.

**Table 32: Summary of DHW systems proposed in the Part L 2020 consultation for England**

| DHW Fuel in the Actual building | Notional building DHW fuel *for centralised systems* | DHW system type | |
|---|---|---|---|
| | | High DHW demand activities | Low DHW demand activities |
| Bio-fuel | Bio-fuel | Centralised | Centralised |
| Dual fuel (mineral + wood) | Dual fuel (mineral + wood) | | |
| Waste heat | Waste heat | | |
| Natural gas | Natural gas | | Electric point-of-use |
| LPG | | | |
| Fuel oil | | | |
| Non-electric heat pump | | | |
| Other fuels whose emission factor > emission factor of natural gas | | | |
| Electric heat pump | Electric heat pump | | |
| Electricity (direct) | NA | Electric point-of-use | |

135. In light of this analysis it is suggested that the analysis consider the effects of setting the notional building to use an ASHP for space heating. The DHW system could adopt any of the following options:

- Gas-fired;
- Point-of-use electric;
- Hybrid approach proposed for England;
- Separate heat pumps for space heating and DHW.

136. The proposed approach is set out in Table 34 and Table 35. It is a simplified approach compared to England in that the notional building is based on two fuel types. In doing so, buildings using biomass, dual-fuel and waste heat will find it a little easier to comply as for each of these fuels the primary energy factor is slightly lower, by around 6-8%[17]. However, this is not considered such a large difference that it will drive a significance change in the use of heating fuels, and biomass and dual-fuel boilers are often a few percent less efficient than gas boilers which partly negates the benefit of having a lower

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[17] The carbon emission factor for these fuels is much lower than gas but as there is less difference between the primary energy factors for these fuels, the primary energy metric is of more significance.

primary energy factor. This may be further mitigated by enhancing the backstop limits on fabric and plant efficiency.

## 1.9 Selection of improved notional buildings

137. Scottish Government requested that up to three options (low/medium/high) be taken forwards for modelling. These should be informed by the findings set out above.

138. The potential specifications set out in Sections 1.7 have been used to create three options for 2021 standards. Table 33 summarises the options shortlisted for modelling and agreed with the client.

**Table 33: Low, Medium and High specifications for modelling**

<table>
<tr><th colspan="2" rowspan="2">Variable</th><th colspan="2">Sec 6 Notional</th><th colspan="3">Suggested Options</th></tr>
<tr><th>Heated & Naturally Ventilated</th><th>Heated & Cooled or Heated & Mechanically Ventilated</th><th>Low</th><th>Medium</th><th>High</th></tr>
<tr><td colspan="2">Wall U-Value (W/m²K)</td><td>0.23</td><td>0.20</td><td>0.20</td><td>0.18</td><td>0.15</td></tr>
<tr><td colspan="2">Roof U-Value (W/m²K)</td><td>0.18</td><td>0.16</td><td>0.16</td><td>0.15</td><td>0.11</td></tr>
<tr><td colspan="2">Floor U-Value (W/m²K)</td><td>0.22</td><td>0.20</td><td>0.20</td><td>0.15</td><td>0.13</td></tr>
<tr><td rowspan="3">Window</td><td>U-Value (W/m²K)</td><td>1.80</td><td>1.60</td><td>1.60</td><td>1.40</td><td>0.90</td></tr>
<tr><td>G-value</td><td>60%</td><td>50%</td><td>50%</td><td>29%</td><td>29%</td></tr>
<tr><td>Light Transmittance</td><td>71%</td><td>71%</td><td>71%</td><td>60%</td><td>60%</td></tr>
<tr><td rowspan="3">Rooflight</td><td>U-Value (W/m²K)</td><td>1.80</td><td>1.80</td><td>1.80</td><td colspan="2">1.50</td></tr>
<tr><td>G-value</td><td>52%</td><td>52%</td><td>52%</td><td colspan="2">29%</td></tr>
<tr><td>Light Transmittance</td><td>57%</td><td>57%</td><td>57%</td><td colspan="2">60%</td></tr>
<tr><td colspan="2">Air Tightness</td><td colspan="2">3, 5 or 7 [1]</td><td>5</td><td>4</td><td>3</td></tr>
<tr><td rowspan="4">Heating & Cooling</td><td>Gas Boiler</td><td colspan="2">91%</td><td colspan="3">93%</td></tr>
<tr><td>ASHP</td><td colspan="2">1.75</td><td>3.44</td><td>4.00</td><td>4.35</td></tr>
<tr><td>Radiant gas heater (top-lit)</td><td colspan="2">86%</td><td colspan="3">92%</td></tr>
<tr><td>Cooling SEER</td><td colspan="2">4.50</td><td>5.50</td><td>6.40</td><td>7.10</td></tr>
<tr><td rowspan="3">Domestic Hot Water</td><td>Gas Boiler</td><td colspan="2">91%</td><td colspan="3">93%</td></tr>
<tr><td>ASHP</td><td colspan="2">1.75</td><td>2.50</td><td>2.50</td><td>2.70</td></tr>
<tr><td>Distribution</td><td colspan="2">NA (implicitly near point of use)</td><td colspan="3">See Table 34 and Table 35</td></tr>
<tr><td rowspan="8">Lighting & Ventilation</td><td>Lighting Luminaire (llm/cW)</td><td>60</td><td>65</td><td colspan="3">125</td></tr>
<tr><td>Daylight Lighting Control</td><td colspan="2">Single zone daylight dimming</td><td colspan="3">Single zone daylight dimming</td></tr>
<tr><td>Occupancy Lighting Control</td><td colspan="2">Manual on auto off</td><td colspan="3">Manual on auto off</td></tr>
<tr><td>Parasitic Power</td><td colspan="2">0.3W/m² or 3% for daylight;<br>0.3W/m² for occupancy</td><td colspan="3">0.1W/m²</td></tr>
<tr><td>Display Lighting (llm/cW)</td><td colspan="2">22</td><td colspan="3">125</td></tr>
<tr><td>Display Lighting Control</td><td colspan="2">none</td><td colspan="3">time switch</td></tr>
<tr><td>Ventilation Heat Recovery</td><td colspan="2">70%</td><td colspan="3">76%</td></tr>
<tr><td>Demand Control Ventilation</td><td colspan="2">gas-sensors, inverters</td><td colspan="3">gas-sensors, inverters</td></tr>
<tr><td rowspan="2">PV Area [2] (gas notional only), Lesser of:</td><td>% of GIA</td><td colspan="2">4.5%</td><td>6.5%</td><td colspan="2">13.0%</td></tr>
<tr><td>% of roof area</td><td colspan="2">50.0%</td><td>50.0%</td><td colspan="2">50.0%</td></tr>
</table>

Notes:
1. Function of floor area and activity type (see Table 4 of NCM Modelling Guide).
2. Based on an assumed output of 120kWh/m² (approximately equivalent to a nominal efficiency of 16%).

139. Table 34 shows the proposed space heating fuels for the notional building mapping these against each space heating fuel that the actual building may use. Similarly, Table 35 shows the proposed domestic hot water (DHW) fuels for the notional building. Table 35 also shows the proposed DHW system types (centralised or point of use) that the notional building will use in different circumstances.

**Table 34: Proposed space heating fuel for notional building**

| Actual building space heating fuel | Notional building space heating fuel |
|---|---|
| Bio-fuel | Natural gas |
| Dual fuel (mineral + wood) | |
| Waste heat | |
| Natural gas | |
| LPG | |
| Fuel oil | |
| Non-electric heat pump | |
| Other fuel & supplied heat | |
| Electricity (direct) | |
| Electric (heat pump) | Electric (heat pump) |

**Table 35: Proposed domestic hot water (DHW) fuel and system type for notional building**

| Actual building DHW fuel | Notional building DHW fuel *for centralised systems* | DHW system type | |
|---|---|---|---|
| | | High DHW demand activities | Low DHW demand activities |
| Bio-fuel | Natural gas | Centralised | Electric point-of-use |
| Dual fuel (mineral + wood) | | | |
| Waste heat | | | |
| Natural gas | | | |
| LPG | | | |
| Fuel oil | | | |
| Non-electric heat pump | | | |
| Other fuel & supplied heat | | | |
| Electricity (direct) | | | |
| Electric (heat pump) | Electric (heat pump) | | |

# Task 3: Modelling Options for a New Notional Building Specification

## 1.10 Modelling of national profile to improved standards

140. This section assesses the impact of the improved notional buildings determined in the previous section. The improved standards are applied to the twelve sample buildings identified in Task 1 to reflect the national build mix and the change in benefits and costs are evaluated.

141. The current (2015) Section 6 notional building U-value specification is different for buildings that are naturally ventilated rather than mechanically ventilated or cooled; these differences are set out in Table 33. Similarly, the notional building air tightness value varies in response to the building floor area and whether the activity type is classified as side-lit, top-lit or no-lit. The proposals for the next revision to Section 6 are seeking to simplify as well as tighten the requirements and so it is proposed that this variation between different servicing strategies, floor areas and activity types should be removed. Therefore, the proposed low, medium and high fabric specifications set out in Table 33 apply across all building types regardless of servicing strategy, floor area and activity type.

### 1.10.1 SBEM Modelling Results

142. The twelve building sub-types set out in Table 62 were modelled using SBEM v5.6a for both the fossil (gas) and non-fossil (ASHP) for all three levels of specifications set out in Table 33 (low, medium and high). A summary of the cases modelled for each building type is set out below:

- Gas + PV + Low building fabric and services improvements
- Gas + PV + Medium building fabric and services improvements
- Gas + PV + High building fabric and services improvements
- ASHP + Low building fabric and services improvements
- ASHP + Medium building fabric and services improvements
- ASHP + High building fabric and services improvements

143. Key results from the modelling are set out in Table 36 to Table 47. The columns show the BPE and BER calculated using SBEM v5.6a with the proposed carbon emission and primary energy factors shown in Table 14 and Table 15. These are compared to the equivalent results for the 2015 compliant base cases previously presented in section 1.5.5. An adjustment has been applied to the DHW demand in primary schools to reflect the proposed changes to the NCM Activity Database for this building type. BPE is shown first here as this is proposed to be the main target metric.

144. Two of the twelve sample buildings use an electric ASHP as the base case heating scenario. For these two building the results for the three gas-heated options, listed above, have been omitted as not necessary for the analysis.

### Table 36: Deep-plan Office, AC, gas heating base case modelled $CO_2$ emissions rates and primary energy values

| Model Name | Primary Energy, BPE | Primary Energy, Margin | $CO_2$, BER | $CO_2$, Margin |
|---|---|---|---|---|
| 2015 compliant | 69.6 | 0% | 7.5 | 0% |
| Gas+PV Low | 54.3 | 22% | 6.0 | 20% |
| Gas+PV Medium | 43.7 | 37% | 4.9 | 34% |
| Gas+PV High | 39.2 | 44% | 4.1 | 45% |
| ASHP Low | 58.6 | 16% | 5.4 | 28% |
| ASHP Medium | 53.9 | 22% | 5.0 | 34% |
| ASHP High | 52.5 | 25% | 4.8 | 36% |

### Table 37: Deep-plan Office, AC, electric ASHP heating base case modelled $CO_2$ emissions rates and primary energy values

| Model Name | Primary Energy, BPE | Primary Energy, Margin | $CO_2$, BER | $CO_2$, Margin |
|---|---|---|---|---|
| 2015 compliant | 67.7 | 0% | 6.2 | 0% |
| Gas+PV Low | NA | NA | NA | NA |
| Gas+PV Medium | NA | NA | NA | NA |
| Gas+PV High | NA | NA | NA | NA |
| ASHP Low | 58.6 | 13% | 5.4 | 14% |
| ASHP Medium | 53.9 | 20% | 5.0 | 20% |
| ASHP High | 52.5 | 23% | 4.8 | 23% |

### Table 38: Hospital, naturally ventilated, gas heating base case modelled $CO_2$ emissions rates and primary energy values

| Model Name | Primary Energy, BPE | Primary Energy, Margin | $CO_2$, BER | $CO_2$, Margin |
|---|---|---|---|---|
| 2015 compliant | 159.4 | 0% | 24.5 | 0% |
| Gas+PV Low | 124.2 | 22% | 21.7 | 12% |
| Gas+PV Medium | 112.1 | 30% | 20.4 | 17% |
| Gas+PV High | 105.7 | 34% | 19.2 | 22% |
| ASHP Low | 73.5 | 54% | 6.9 | 72% |
| ASHP Medium | 69.7 | 56% | 6.5 | 74% |
| ASHP High | 64.5 | 60% | 6.0 | 76% |

### Table 39: Hotel, naturally ventilated, gas heating base case modelled $CO_2$ emissions rates and primary energy values

| Model Name | Primary Energy, BPE | Primary Energy, Margin | $CO_2$, BER | $CO_2$, Margin |
|---|---|---|---|---|
| 2015 compliant | 371.0 | 0% | 66.9 | 0% |
| Gas+PV Low | 357.0 | 4% | 65.0 | 3% |
| Gas+PV Medium | 348.7 | 6% | 64.4 | 4% |
| Gas+PV High | 323.8 | 13% | 59.8 | 11% |
| ASHP Low | 182.3 | 51% | 17.0 | 75% |
| ASHP Medium | 176.7 | 52% | 16.4 | 75% |
| ASHP High | 158.1 | 57% | 14.7 | 78% |

### Table 40: Hotel, AC, gas heating base case modelled $CO_2$ emissions rates and primary energy values

| Model Name | Primary Energy, BPE | Primary Energy, Margin | $CO_2$, BER | $CO_2$, Margin |
|---|---|---|---|---|
| 2015 compliant | 357.8 | 0% | 58.2 | 0% |
| Gas+PV Low | 358.7 | 0% | 58.1 | 0% |
| Gas+PV Medium | 335.7 | 6% | 55.9 | 4% |
| Gas+PV High | 316.4 | 12% | 52.4 | 10% |
| ASHP Low | 230.5 | 36% | 21.2 | 64% |
| ASHP Medium | 215.9 | 40% | 19.9 | 66% |
| ASHP High | 200.7 | 44% | 18.4 | 68% |

### Table 41: Primary School, naturally ventilated, biomass heating base case modelled $CO_2$ emissions rates and primary energy values

| Model Name | Primary Energy, BPE | Primary Energy, Margin | $CO_2$, BER | $CO_2$, Margin |
|---|---|---|---|---|
| 2015 compliant | 59.8 | 0% | 2.5 | 0% |
| Gas+PV Low | 48.5 | 19% | 8.1 | -225% |
| Gas+PV Medium | 36.0 | 40% | 6.8 | -174% |
| Gas+PV High | 30.2 | 50% | 5.7 | -130% |
| ASHP Low | 35.8 | 40% | 3.4 | -35% |
| ASHP Medium | 33.8 | 44% | 3.2 | -27% |
| ASHP High | 31.0 | 48% | 2.9 | -16% |

### Table 42: Primary School, mechanically ventilated, gas heating base case modelled $CO_2$ emissions rates and primary energy values

| Model Name | Primary Energy, BPE | Primary Energy, Margin | $CO_2$, BER | $CO_2$, Margin |
|---|---|---|---|---|
| 2015 compliant | 39.5 | 0% | 5.8 | 0% |
| Gas+PV Low | 40.4 | -2% | 6.1 | -5% |
| Gas+PV Medium | 27.4 | 31% | 4.7 | 19% |
| Gas+PV High | 21.6 | 45% | 3.6 | 38% |
| ASHP Low | 36.4 | 8% | 3.4 | 41% |
| ASHP Medium | 34.9 | 12% | 3.3 | 44% |
| ASHP High | 32.5 | 18% | 3.0 | 48% |

### Table 43: Primary School, naturally ventilated, gas heating base case modelled $CO_2$ emissions rates and primary energy values

| Model Name | Primary Energy, BPE | Primary Energy, Margin | $CO_2$, BER | $CO_2$, Margin |
|---|---|---|---|---|
| 2015 compliant | 51.7 | 0% | 8.2 | 0% |
| Gas+PV Low | 48.5 | 6% | 8.1 | 1% |
| Gas+PV Medium | 36.1 | 30% | 6.8 | 16% |
| Gas+PV High | 30.2 | 42% | 5.7 | 30% |
| ASHP Low | 35.8 | 31% | 3.4 | 59% |
| ASHP Medium | 33.8 | 34% | 3.2 | 61% |
| ASHP High | 31.0 | 40% | 2.9 | 65% |

### Table 44: Retail Unit, AC, gas heating base case modelled $CO_2$ emissions rates and primary energy values

| Model Name | Primary Energy, BPE | Primary Energy, Margin | $CO_2$, BER | $CO_2$, Margin |
|---|---|---|---|---|
| 2015 compliant | 187.4 | 0% | 18.3 | 0% |
| Gas+PV Low | 109.8 | 41% | 11.4 | 38% |
| Gas+PV Medium | 91.7 | 51% | 9.5 | 48% |
| Gas+PV High | 88.0 | 53% | 8.9 | 52% |
| ASHP Low | 111.7 | 40% | 10.2 | 44% |
| ASHP Medium | 106.0 | 43% | 9.7 | 47% |
| ASHP High | 104.1 | 44% | 9.5 | 48% |

### Table 45: Retail Unit, AC, electric ASHP heating base case modelled $CO_2$ emissions rates and primary energy values

| Model Name | Primary Energy, BPE | Primary Energy, Margin | $CO_2$, BER | $CO_2$, Margin |
|---|---|---|---|---|
| 2015 compliant | 184.0 | 0% | 16.9 | 0% |
| Gas+PV Low | NA | NA | NA | NA |
| Gas+PV Medium | NA | NA | NA | NA |
| Gas+PV High | NA | NA | NA | NA |
| ASHP Low | 111.9 | 39% | 10.2 | 39% |
| ASHP Medium | 106.1 | 42% | 9.7 | 42% |
| ASHP High | 104.2 | 43% | 9.5 | 43% |

### Table 46: Shallow-plan Office, naturally ventilated, gas heating base case modelled $CO_2$ emissions rates and primary energy values

| Model Name | Primary Energy, BPE | Primary Energy, Margin | $CO_2$, BER | $CO_2$, Margin |
|---|---|---|---|---|
| 2015 compliant | 61.0 | 0% | 9.4 | 0% |
| Gas+PV Low | 49.1 | 20% | 8.1 | 13% |
| Gas+PV Medium | 37.9 | 38% | 7.1 | 25% |
| Gas+PV High | 26.8 | 56% | 5.0 | 47% |
| ASHP Low | 36.2 | 41% | 3.4 | 64% |
| ASHP Medium | 34.3 | 44% | 3.2 | 66% |
| ASHP High | 30.1 | 51% | 2.8 | 70% |

### Table 47: Distribution Warehouse, naturally ventilated, gas heating base case modelled $CO_2$ emissions rates and primary energy values

| Model Name | Primary Energy, BPE | Primary Energy, Margin | $CO_2$, BER | $CO_2$, Margin |
|---|---|---|---|---|
| 2015 compliant | 135.9 | 0% | 23.5 | 0% |
| Gas+PV Low | 131.6 | 3% | 23.3 | 1% |
| Gas+PV Medium | 112.3 | 17% | 20.8 | 12% |
| Gas+PV High | 98.8 | 27% | 18.2 | 22% |
| ASHP Low | 94.7 | 30% | 9.0 | 62% |
| ASHP Medium | 83.2 | 39% | 7.9 | 67% |
| ASHP High | 73.7 | 46% | 7.0 | 70% |

145. Further results from the modelling of potential 2021 standards are set out in Table 48 to Table 59. The tables show energy consumption by end-use, and energy generation from onsite PV (where applicable) as calculated using the SBEM v5.6a methodology. Again, these results are compared to the equivalent results for the 2015 compliant base cases.

146. There are several features in these results which may not be immediately intuitive; these are explained here:

- There are many cases where the heating demand of the “2015 compliant” case is lower than one or more of the subsequent options. This is primarily due to the large improvement in lighting efficacy which results in lower internal heat gains and thus an increased heating demand.
- In some cases (e.g. the office buildings), the DHW demand remains the same across all six of the assessed options. This is in cases where the DHW demand is entirely on the “low” demand system type as described from Paragraph 134 onwards. In these cases, the DHW system uses electric point-of-use heated across all the Gas+PV and ASHP options.
- In some cases, the lighting energy for the two “Low” options is slightly lower than the “Medium” and “High”. The lighting efficacy is the same across all of these options. However, the G-value of the glazing reduces slightly for the “Medium” and “High” options, so the benefit of daylight-sensing controls is slightly reduced. In most cases this difference is too small to be shown in the rounded values in these tables.
- The auxiliary energy demand of the “2015 compliant” case is sometimes lower than those of the subsequent six options. This is primarily caused by a switch to centralised DHW which includes a secondary circulation pump.

147. Table 51 and Table 52 show the results for the naturally ventilated and air-conditioned hotels. Comparing these two tables, the heating demand for the naturally ventilated hotel is much higher than that of the air-conditioned hotel. This shows the benefit of the heat recovery which is included in the air-conditioned scenario. The auxiliary demand is lower for the naturally ventilated hotel because it needs no fans for ventilation, so the small auxiliary demand is associated solely with the heating circulation pumps. Examining these two differences together it can be seen that the total energy demand for the ASHP options are lower for the naturally ventilated hotel. This shows that when the heating is very efficient (e.g. through the use of an ASHP) it can be better to accept a higher heat demand by omitting mechanical ventilation with heat recovery because the associated increase in auxiliary energy can be greater than the savings achieved by the heat recovery.

148. Table 59 shows the result for the distribution warehouse; this shows a substantial increase in the auxiliary energy demand for the three ASHP options. The reason for this increase is that the base-case gas heating system for the main warehouse area is a direct gas-fired radiant system. This system type is not compatible with an ASHP so the three ASHP options include a change to a wet heating system. The distribution warehouse is the only sample building where this occurs.

**Table 48: Deep-plan Office, AC, gas heating base case modelled energy consumption by end-use and onsite generation. Units - Energy (kWh/m²)**

| Model Name | Heating | Cooling | Aux | Lighting | DHW | Total | PV gen. | Total minus gen. |
|---|---|---|---|---|---|---|---|---|
| 2015 compliant | 7.2 | 8.5 | 16.7 | 18.5 | 3.1 | **54.0** | 5.4 | **48.6** |
| Gas+PV Low | 9.4 | 5.6 | 16.5 | 11.5 | 2.6 | **45.6** | 7.4 | **38.2** |
| Gas+PV Medium | 8.4 | 4.2 | 15.2 | 11.6 | 2.6 | **42.0** | 11.2 | **30.8** |
| Gas+PV High | 4.2 | 4.4 | 15.2 | 11.6 | 2.6 | **38.0** | 11.2 | **26.7** |
| ASHP Low | 2.5 | 5.6 | 16.5 | 11.5 | 2.6 | **38.7** | 0.0 | **38.7** |
| ASHP Medium | 1.9 | 4.2 | 15.2 | 11.6 | 2.6 | **35.6** | 0.0 | **35.6** |
| ASHP High | 0.9 | 4.4 | 15.2 | 11.6 | 2.6 | **34.7** | 0.0 | **34.7** |

**Table 49: Deep-plan Office, AC, electric ASHP heating base case modelled energy consumption by end-use and onsite generation. Units - Energy (kWh/m²)**

| Model Name | Heating | Cooling | Aux | Lighting | DHW | Total | PV gen. | Total minus gen. |
|---|---|---|---|---|---|---|---|---|
| 2015 compliant | 1.6 | 8.8 | 16.8 | 20.1 | 2.8 | **50.1** | 5.4 | **44.7** |
| Gas+PV Low | NA | NA | NA | NA | NA | **NA** | NA | **NA** |
| Gas+PV Medium | NA | NA | NA | NA | NA | **NA** | NA | **NA** |
| Gas+PV High | NA | NA | NA | NA | NA | **NA** | NA | **NA** |
| ASHP Low | 2.5 | 5.6 | 16.5 | 11.5 | 2.6 | **38.7** | 0.0 | **38.7** |
| ASHP Medium | 1.9 | 4.2 | 15.2 | 11.6 | 2.6 | **35.6** | 0.0 | **35.6** |
| ASHP High | 0.9 | 4.4 | 15.2 | 11.6 | 2.6 | **34.7** | 0.0 | **34.7** |

**Table 50: Hospital, naturally ventilated, gas heating base case modelled energy consumption by end-use and onsite generation. Units - Energy (kWh/m²)**

| Model Name | Heating | Cooling | Aux. | Lighting | DHW | Total | PV gen. | Total minus gen. |
|---|---|---|---|---|---|---|---|---|
| 2015 compliant | 50.8 | 0.0 | 3.0 | 33.3 | 41.8 | **129.0** | 0.0 | **129.0** |
| Gas+PV Low | 55.7 | 0.0 | 3.1 | 14.4 | 40.9 | **114.1** | 7.7 | **106.4** |
| Gas+PV Medium | 54.0 | 0.0 | 3.1 | 14.5 | 40.9 | **112.5** | 14.6 | **97.9** |
| Gas+PV High | 48.3 | 0.0 | 3.1 | 14.5 | 40.9 | **106.7** | 14.6 | **92.1** |
| ASHP Low | 15.1 | 0.0 | 3.1 | 14.4 | 15.5 | **48.1** | 0.0 | **48.1** |
| ASHP Medium | 12.6 | 0.0 | 3.1 | 14.5 | 15.5 | **45.7** | 0.0 | **45.7** |
| ASHP High | 10.3 | 0.0 | 3.1 | 14.5 | 14.4 | **42.3** | 0.0 | **42.3** |

### Table 51: Hotel, naturally ventilated, gas heating base case modelled energy consumption by end-use and onsite generation. Units - Energy (kWh/m²)

| Model Name | Heating | Cooling | Aux. | Lighting | DHW | Total | PV gen. | Total minus gen. |
|---|---|---|---|---|---|---|---|---|
| 2015 compliant | 107.9 | 0.0 | 3.9 | 17.7 | 199.8 | **329.3** | 5.5 | **323.8** |
| Gas+PV Low | 106.5 | 0.0 | 5.0 | 12.8 | 195.6 | **319.8** | 7.0 | **312.9** |
| Gas+PV Medium | 108.2 | 0.0 | 5.0 | 12.9 | 195.6 | **321.6** | 14.0 | **307.7** |
| Gas+PV High | 86.1 | 0.0 | 5.0 | 12.9 | 195.6 | **299.5** | 14.0 | **285.6** |
| ASHP Low | 28.8 | 0.0 | 5.0 | 12.8 | 73.0 | **119.6** | 0.0 | **119.6** |
| ASHP Medium | 25.2 | 0.0 | 5.0 | 12.9 | 73.0 | **116.1** | 0.0 | **116.1** |
| ASHP High | 18.4 | 0.0 | 5.0 | 12.9 | 67.7 | **103.9** | 0.0 | **103.9** |

### Table 52: Hotel, AC, gas heating base case modelled energy consumption by end-use and onsite generation. Units - Energy (kWh/m²)

| Model Name | Heating | Cooling | Aux. | Lighting | DHW | Total | PV gen. | Total minus gen. |
|---|---|---|---|---|---|---|---|---|
| 2015 compliant | 38.3 | 11.7 | 46.3 | 17.7 | 199.8 | **313.8** | 16.6 | **297.2** |
| Gas+PV Low | 40.9 | 7.9 | 47.4 | 12.7 | 195.6 | **304.4** | 7.0 | **297.5** |
| Gas+PV Medium | 40.1 | 4.9 | 42.3 | 12.8 | 195.6 | **295.7** | 14.0 | **281.8** |
| Gas+PV High | 23.1 | 5.5 | 41.6 | 12.8 | 195.6 | **278.6** | 14.0 | **264.7** |
| ASHP Low | 11.0 | 7.9 | 47.4 | 12.7 | 73.0 | **152.1** | 0.0 | **152.1** |
| ASHP Medium | 9.3 | 4.9 | 42.3 | 12.8 | 73.0 | **142.4** | 0.0 | **142.4** |
| ASHP High | 4.9 | 5.5 | 41.6 | 12.8 | 67.7 | **132.6** | 0.0 | **132.6** |

### Table 53: Primary School, naturally ventilated, biomass heating base case modelled energy consumption by end-use and onsite generation. Units - Energy (kWh/m²)

| Model Name | Heating | Cooling | Aux. | Lighting | DHW | Total | PV gen. | Total minus gen. |
|---|---|---|---|---|---|---|---|---|
| 2015 compliant | 33.2 | 0.0 | 2.0 | 11.2 | 12.7 | **59.1** | 5.3 | **53.8** |
| Gas+PV Low | 25.9 | 0.0 | 2.6 | 6.6 | 12.6 | **47.7** | 7.3 | **40.4** |
| Gas+PV Medium | 24.3 | 0.0 | 2.6 | 6.7 | 12.6 | **46.2** | 14.6 | **31.6** |
| Gas+PV High | 19.1 | 0.0 | 2.6 | 6.7 | 12.6 | **41.0** | 14.6 | **26.4** |
| ASHP Low | 7.0 | 0.0 | 2.6 | 6.6 | 7.1 | **23.3** | 0.0 | **23.3** |
| ASHP Medium | 5.6 | 0.0 | 2.6 | 6.7 | 7.1 | **22.0** | 0.0 | **22.0** |
| ASHP High | 4.1 | 0.0 | 2.6 | 6.7 | 6.8 | **20.2** | 0.0 | **20.2** |

### Table 54: Primary School, mechanically ventilated, gas heating base case modelled energy consumption by end-use and onsite generation. Units - Energy (kWh/m²)

| Model Name | Heating | Cooling | Aux. | Lighting | DHW | Total | PV gen. | Total minus gen. |
|---|---|---|---|---|---|---|---|---|
| 2015 compliant | 9.9 | 0.0 | 5.8 | 10.9 | 9.8 | **36.4** | 5.4 | **31.0** |
| Gas+PV Low | 13.6 | 0.0 | 6.3 | 6.7 | 12.6 | **39.2** | 7.3 | **31.9** |
| Gas+PV Medium | 11.5 | 0.0 | 6.3 | 6.8 | 12.6 | **37.2** | 14.6 | **22.6** |
| Gas+PV High | 6.4 | 0.0 | 6.3 | 6.8 | 12.6 | **32.1** | 14.6 | **17.5** |
| ASHP Low | 3.7 | 0.0 | 6.3 | 6.7 | 7.1 | **23.8** | 0.0 | **23.8** |
| ASHP Medium | 2.7 | 0.0 | 6.3 | 6.8 | 7.1 | **22.9** | 0.0 | **22.9** |
| ASHP High | 1.4 | 0.0 | 6.3 | 6.8 | 6.8 | **21.3** | 0.0 | **21.3** |

### Table 55: Primary School, naturally ventilated, gas heating base case modelled energy consumption by end-use and onsite generation. Units - Energy (kWh/m²)

| Model Name | Heating | Cooling | Aux. | Lighting | DHW | Total | PV gen. | Total minus gen. |
|---|---|---|---|---|---|---|---|---|
| 2015 compliant | 22.1 | 0.0 | 2.0 | 12.9 | 9.8 | **46.8** | 4.7 | **42.1** |
| Gas+PV Low | 25.9 | 0.0 | 2.6 | 6.7 | 12.6 | **47.8** | 7.3 | **40.5** |
| Gas+PV Medium | 24.3 | 0.0 | 2.6 | 6.8 | 12.6 | **46.2** | 14.6 | **31.6** |
| Gas+PV High | 19.1 | 0.0 | 2.6 | 6.8 | 12.6 | **41.0** | 14.6 | **26.4** |
| ASHP Low | 7.0 | 0.0 | 2.6 | 6.7 | 7.1 | **23.4** | 0.0 | **23.4** |
| ASHP Medium | 5.6 | 0.0 | 2.6 | 6.8 | 7.1 | **22.1** | 0.0 | **22.1** |
| ASHP High | 4.1 | 0.0 | 2.6 | 6.8 | 6.8 | **20.3** | 0.0 | **20.3** |

### Table 56: Retail Unit, AC, gas heating base case modelled energy consumption by end-use and onsite generation. Units - Energy (kWh/m²)

| Model Name | Heating | Cooling | Aux. | Lighting | DHW | Total | PV gen. | Total minus gen. |
|---|---|---|---|---|---|---|---|---|
| 2015 compliant | 9.0 | 48.0 | 23.5 | 49.8 | 1.9 | **132.1** | 5.4 | **126.7** |
| Gas+PV Low | 12.6 | 26.1 | 22.4 | 20.3 | 1.6 | **83.1** | 7.3 | **75.9** |
| Gas+PV Medium | 9.6 | 23.7 | 21.6 | 21.0 | 1.6 | **77.5** | 14.6 | **62.9** |
| Gas+PV High | 6.9 | 23.4 | 21.4 | 21.0 | 1.6 | **74.3** | 14.6 | **59.6** |
| ASHP Low | 3.4 | 26.1 | 22.4 | 20.3 | 1.6 | **73.9** | 0.0 | **73.9** |
| ASHP Medium | 2.2 | 23.7 | 21.6 | 21.0 | 1.6 | **70.1** | 0.0 | **70.1** |
| ASHP High | 1.5 | 23.4 | 21.4 | 21.0 | 1.6 | **68.9** | 0.0 | **68.9** |

### Table 57: Retail Unit, AC, electric ASHP heating base case modelled energy consumption by end-use and onsite generation. Units - Energy (kWh/m²)

| Model Name | Heating | Cooling | Aux. | Lighting | DHW | Total | PV gen. | Total minus gen. |
|---|---|---|---|---|---|---|---|---|
| 2015 compliant | 2.1 | 50.1 | 23.5 | 50.4 | 0.9 | **127.0** | 5.4 | **121.6** |
| Gas+PV Low | NA | NA | NA | NA | NA | **NA** | NA | **NA** |
| Gas+PV Medium | NA | NA | NA | NA | NA | **NA** | NA | **NA** |
| Gas+PV High | NA | NA | NA | NA | NA | **NA** | NA | **NA** |
| ASHP Low | 3.5 | 26.1 | 22.4 | 20.3 | 1.6 | **74.0** | 0.0 | **74.0** |
| ASHP Medium | 2.3 | 23.7 | 21.6 | 21.0 | 1.6 | **70.2** | 0.0 | **70.2** |
| ASHP High | 1.5 | 23.4 | 21.4 | 21.0 | 1.6 | **68.9** | 0.0 | **68.9** |

### Table 58: Shallow-plan Office, naturally ventilated, gas heating base case modelled energy consumption by end-use and onsite generation. Units - Energy (kWh/m²)

| Model Name | Heating | Cooling | Aux. | Lighting | DHW | Total | PV gen. | Total minus gen. |
|---|---|---|---|---|---|---|---|---|
| 2015 compliant | 32.1 | 0.0 | 1.8 | 17.6 | 3.1 | **54.5** | 5.4 | **49.1** |
| Gas+PV Low | 33.6 | 0.0 | 1.8 | 10.1 | 2.7 | **48.1** | 7.3 | **40.8** |
| Gas+PV Medium | 33.0 | 0.0 | 1.8 | 10.3 | 2.7 | **47.7** | 14.6 | **33.1** |
| Gas+PV High | 23.1 | 0.0 | 1.8 | 10.3 | 2.7 | **37.8** | 14.6 | **23.2** |
| ASHP Low | 9.1 | 0.0 | 1.8 | 10.1 | 2.7 | **23.6** | 0.0 | **23.6** |
| ASHP Medium | 7.7 | 0.0 | 1.8 | 10.3 | 2.7 | **22.4** | 0.0 | **22.4** |
| ASHP High | 4.9 | 0.0 | 1.8 | 10.3 | 2.7 | **19.7** | 0.0 | **19.7** |

### Table 59: Distribution Warehouse, naturally ventilated, gas heating base case modelled energy consumption by end-use and onsite generation. Units - Energy (kWh/m²)

| Model Name | Heating | Cooling | Aux. | Lighting | DHW | Total | PV gen. | Total minus gen. |
|---|---|---|---|---|---|---|---|---|
| 2015 compliant | 85.3 | 0.0 | 0.3 | 18.2 | 17.4 | **121.1** | 5.4 | **115.7** |
| Gas+PV Low | 92.1 | 0.0 | 0.4 | 12.0 | 16.1 | **120.6** | 7.3 | **113.3** |
| Gas+PV Medium | 84.7 | 0.0 | 0.4 | 11.9 | 16.1 | **113.1** | 14.6 | **98.5** |
| Gas+PV High | 72.7 | 0.0 | 0.4 | 11.9 | 16.1 | **101.1** | 14.6 | **86.5** |
| ASHP Low | 35.8 | 0.0 | 5.2 | 12.0 | 8.5 | **61.4** | 0.0 | **61.4** |
| ASHP Medium | 28.5 | 0.0 | 5.2 | 11.9 | 8.5 | **54.1** | 0.0 | **54.1** |
| ASHP High | 22.8 | 0.0 | 5.2 | 11.9 | 8.1 | **48.0** | 0.0 | **48.0** |

149. The majority of the sample buildings modelled include a wet heating system in the base case. The exception to this is the distribution warehouse which uses a radiant gas-fired heating system in the main storage area although a wet system is used in the adjoining office areas. A gas-fired radiant heating system is not compatible with an ASHP so the three ASHP options shown in Table 59 are based on this heating system being converted to a wet radiant heating system; this can be seen in Table 59 as the auxiliary energy (primarily the LTHW pump) increases for the ASHP options.

150. When comparing the results shown in Table 48 to Table 59 it is important to remember that the base case compliant buildings vary in terms of lighting efficacy, PV area and, where applicable, cooling and ASHP efficiency (see Table 12). One example of where this can be seen is in comparing the results for the naturally ventilated primary school heating with biomass and the variation heated with gas (Table 53 and Table 55). In comparing these two results it can be seen that the base case heating, lighting and PV output all vary. This, combined with the effects of changing the heating fuels, has a knock-on effect on the calculated savings achieved by the six improvement options.

151. The results show that the $CO_2$ emissions increase in the case of the biomass-heated primary school. This is due to the very low emission factor for biomass compared to the higher emission rate for gas and electricity, see Table 14 and Table 15. The primary energy factors for these fuels is similar so the primary energy results do show a saving for all six options considered.

152. To aid comparison of the many results shown in Table 36 to Table 59 two summary tables have been produced; Table 60 and Table 61 show the calculated improvement margins on the base case models for primary energy and $CO_2$ respectively. These results are shown graphically in Figure 21 and Figure 22.

**Table 60: Summary of Primary Energy improvement margins**

| Building Sub-type | Deep Office; Gas; AC | Deep Office; Elec; AC | Hospital; Gas; NV | Hotel; Gas; NV | Hotel; Gas; AC | Primary School; Biomass; NV | Primary School; Gas; MV | Primary School; Gas; NV | Retail; Gas; AC | Retail; Elec; AC | Shallow Office; Gas; NV | Warehouse Distribution; Gas; NV | Minimum | Maximum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gas+PV Low | 22% | NA | 22% | 4% | 0% | 19% | -2% | 6% | 41% | NA | 20% | 3% | -2% | 41% |
| Gas+PV Medium | 37% | NA | 30% | 6% | 6% | 40% | 31% | 30% | 51% | NA | 38% | 17% | 6% | 51% |
| Gas+PV High | 44% | NA | 34% | 13% | 12% | 50% | 45% | 42% | 53% | NA | 56% | 27% | 12% | 56% |
| ASHP Low | 16% | 13% | 54% | 51% | 36% | 40% | 8% | 31% | 40% | 39% | 41% | 30% | 8% | 51% |
| ASHP Medium | 22% | 20% | 56% | 52% | 40% | 44% | 12% | 34% | 43% | 42% | 44% | 39% | 12% | 52% |
| ASHP High | 25% | 23% | 60% | 57% | 44% | 48% | 18% | 40% | 44% | 43% | 51% | 46% | 18% | 57% |

**Table 61: Summary of $CO_2$ improvement margins**

| Building Sub-type | Deep Office; Gas; AC | Deep Office; Elec; AC | Hospital; Gas; NV | Hotel; Gas; NV | Hotel; Gas; AC | Primary School; Biomass; NV | Primary School; Gas; MV | Primary School; Gas; NV | Retail; Gas; AC | Retail; Elec; AC | Shallow Office; Gas; NV | Warehouse Distribution; Gas; NV | Minimum [excl. biomass primary school] | Maximum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gas+PV Low | 20% | NA | 12% | 3% | 0% | -225% | -5% | 1% | 38% | NA | 13% | 1% | -5% | 38% |
| Gas+PV Medium | 34% | NA | 17% | 4% | 4% | -174% | 19% | 16% | 48% | NA | 25% | 12% | 4% | 48% |
| Gas+PV High | 45% | NA | 22% | 11% | 10% | -130% | 38% | 30% | 52% | NA | 47% | 22% | 10% | 52% |
| ASHP Low | 28% | 14% | 72% | 75% | 64% | -35% | 41% | 59% | 44% | 39% | 64% | 62% | 14% | 75% |
| ASHP Medium | 34% | 20% | 74% | 75% | 66% | -27% | 44% | 61% | 47% | 42% | 66% | 67% | 20% | 75% |
| ASHP High | 36% | 23% | 76% | 78% | 68% | -16% | 48% | 65% | 48% | 43% | 70% | 70% | 23% | 78% |

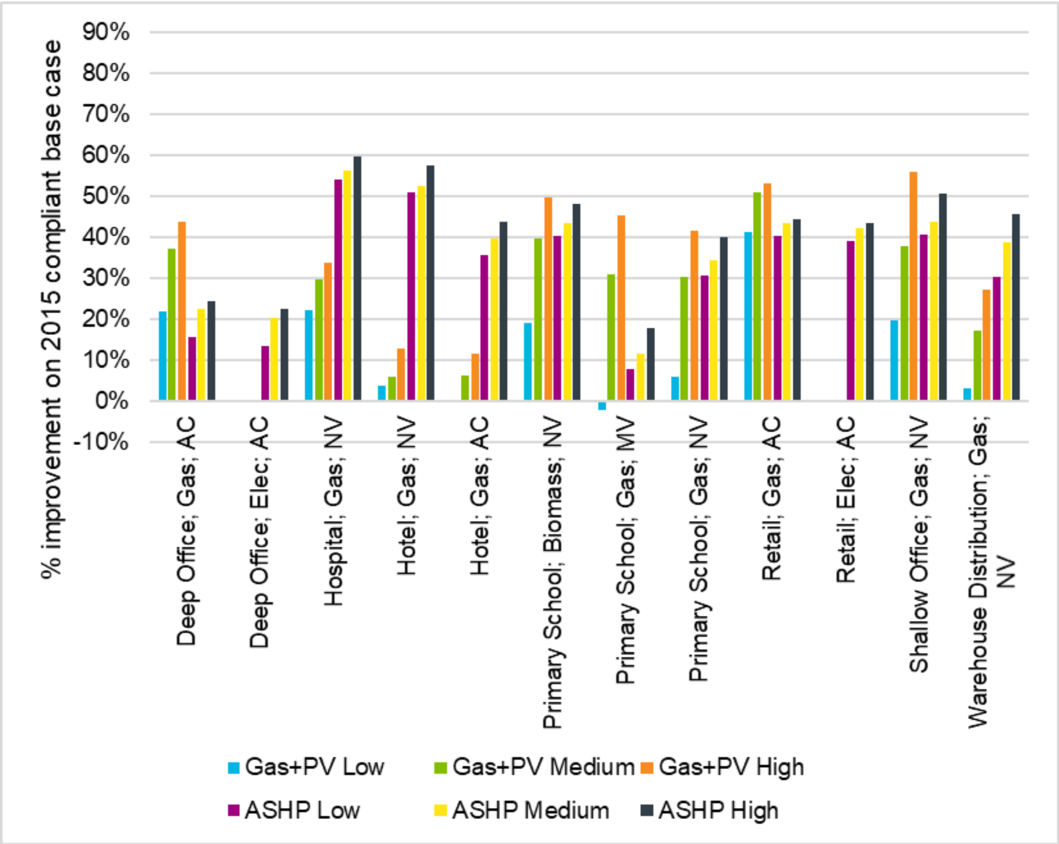

**Figure 21: Summary of primary energy improvement margins**

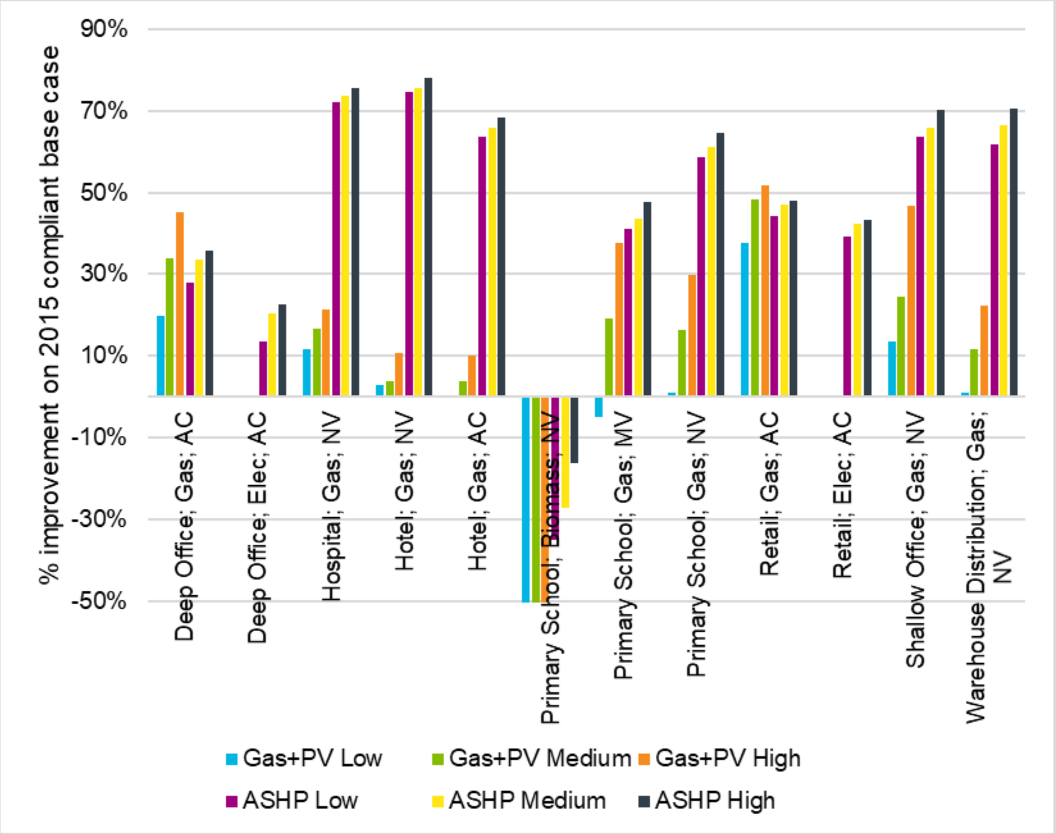

**Figure 22: Summary of $CO_2$ improvement margins**

153. The analysis identified the following key findings:

- Savings in both primary energy and $CO_2$ improve from “Low” to “Medium” and from “Medium” to “High” in all cases.
- Primary energy savings over the base case are achieved in every case except the “Gas+PV Low” option for the mechanically ventilated primary school (this is due to an increase in DHW energy associated with the centralized system (see Section 1.9).
- $CO_2$ savings over the base case are achieved in all cases except the same “Gas+PV Low” option for the mechanically ventilated primary school (see above) and all the options for the biomass-heated primary school (see Paragraph 151).

154. There is no clear correlation between the Gas+PV and ASHP results. For example, it is not possible to say that one of the Gas+PV options is approximately equal to one of the ASHP options in all cases.

155. In most cases the ASHP options achieve greater percentage savings than the equivalent Gas+PV options. This means that if one of the Gas+PV options is adopted for the new standard then a building using an ASHP is generally going to be able to comply. However, this is not the case for the primary energy of the deep-plan office with gas heating. In this instance the greater primary energy savings are achieved by the Gas+PV option because these options include PV and, in this case, the PV is more effective than the ASHP.

156. The reason for this is that there is only a weak link between the factors which influence the savings achieved by an ASHP and PV. As is explained in Paragraphs 126 and 133, the ability of an ASHP on the notional building to achieve energy and carbon savings is driven by the building's demand for space heating and DHW; these in turn are influenced by the built-form and the NCM activities (which define DHW loads, heating set points and occupancy hours etc.). The ability of the notional building's PV array to achieving savings is influenced by the size of the array which is defined in terms of either the roof area or the GIA (see Table 33) and this is a function of the build-form alone. These relationships are illustrated in Figure 23:

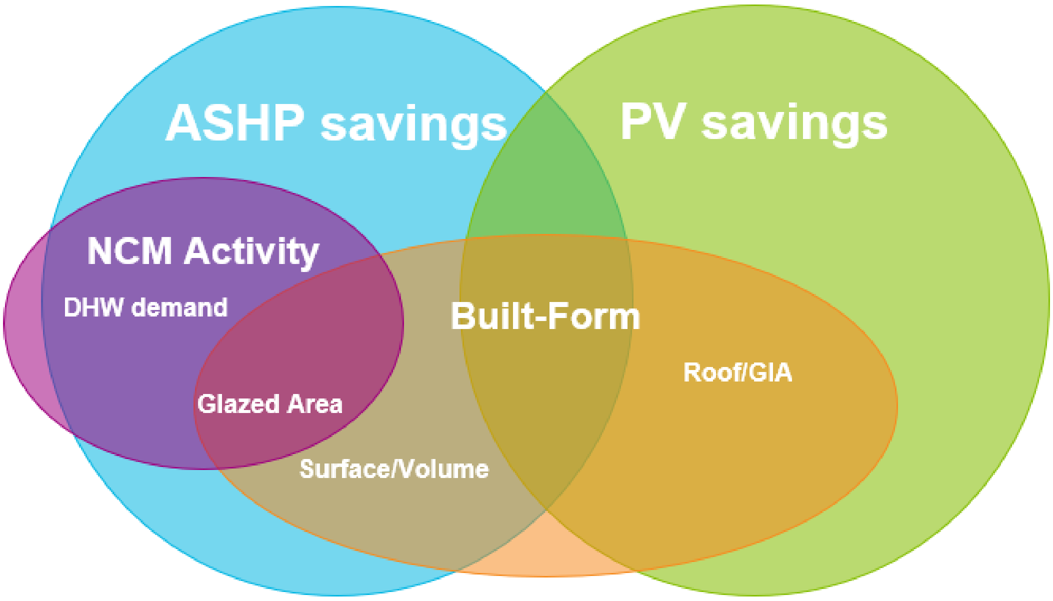

**Figure 23: Illustration of interdependencies influencing ASHP and PV energy and $CO_2$ savings**

157. The only factor linking ASHP savings to PV savings is the built form. However, it is different elements of the built form which influence the savings of the two technologies. The space heating demand is influence by the surface to volume ratio of the building whilst the area of PV is influenced by the roof/GIA ratio. In some cases, there is a weak link between these two parameters, for example a large low-rise building such as a warehouse will have a high roof/GIA ratio and a high surface/volume ratio. However, Figure 24 shows that it is possible to alter one of these ratios without changing the other and so they are fundamentally independent variables.

158. For this reason, it is not possible to select an area of PV which will equalize the savings achieved (or the ease of compliance) by the Gas+PV and ASHP options.

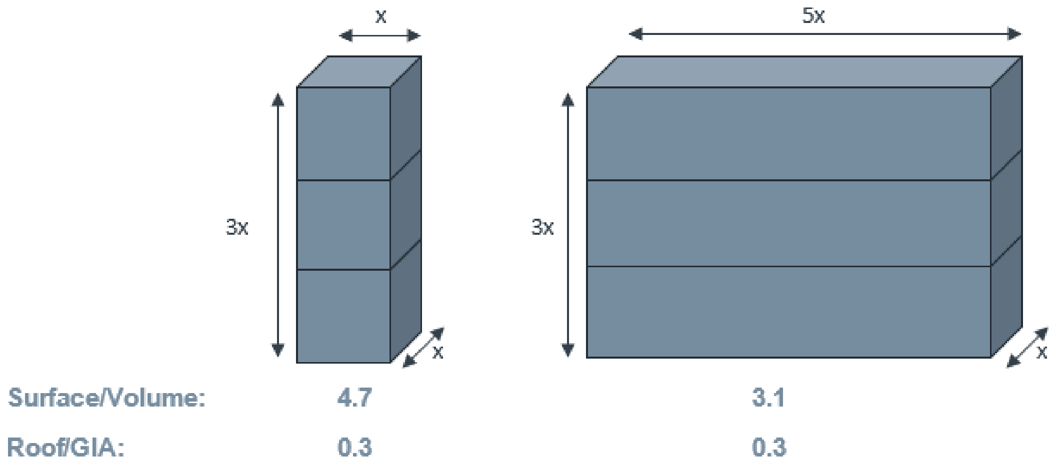

**Figure 24: Illustration of how surface/volume ratio and roof/GIA ratio are independent**

159. The results show that some of the “Gas+PV Low” options may result in an increase in primary energy and $CO_2$ relative to the current 2015 standard; this is particularly likely for buildings with large floor areas with a high DHW demand such as education buildings. For this reason, this option is not recommended.

### 1.10.2 Fuel Mix

160. The SBEM modelling results were used to assess the benefits at a national level. The 12 sample buildings 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.

161. Two alternative fuel mix scenarios, agreed with the Scottish Government, were considered. In both cases, these were modelled separately for the low, medium and high cases, and a full transition to the new standards is assumed to be achieved by 2025, as explained below. The fuel mix scenarios are:

- A core ‘with fossil fuels’ case.
- A ‘without fossil fuels’ case.

162. Table 62 sets out the fuels assumed for the twelve sample buildings selected in Task 1 under each fuel mix scenario. The table shows:

- The baseline fuels which are adopted in the current compliant solution (see Task 1).
- The ‘with fossil fuels’ case based on the “Low”, “Medium” and “High” notional buildings which continue to allow for higher carbon fuels. In general, the same heating system is adopted as for the baseline. The exception to this is the biomass boiler used for one of the baseline primary schools. Given the introduction of a primary energy metric, there is significantly less benefit of adopting biomass compared to gas heating. For the purpose of this analysis, it is assumed that the primary school will now adopt gas heating. In cases where the notional building uses

gas it will also include PV; where the building uses ASHP then PV will not be included[18].

- The ‘without fossil fuels’ case assumes that in the future the gas notional building is excluded and so the most viable route to compliance is likely to include low carbon heating. For the purpose of this analysis, it is assumed that all of the buildings will be heated with an ASHP.

**Table 62: Twelve building sub-types selected for to reflect national build profile – fuel mix assumptions**

| Building Sub-types - baseline | Floor Area (m²) | Floor Area (%) | Heating and DHW fuels | | |
|---|---|---|---|---|---|
| | | | Baseline | For ‘with fossil fuels’ case | For ‘without fossil fuels’ case |
| Deep Office AC; Gas; AC | 52,289 | 8% | Gas boiler | Gas boiler | ASHP |
| Deep Office AC; Elec; AC | 56,345 | 8% | ASHP | ASHP | ASHP |
| Hospital; Gas; NV | 51,382 | 8% | Gas boiler | Gas boiler | ASHP |
| Hotel; Gas; NV | 22,548 | 3% | Gas boiler | Gas boiler | ASHP |
| Hotel; Gas; AC | 29,285 | 4% | Gas boiler | Gas boiler | ASHP |
| Primary School; Biomass; NV | 39,732 | 6% | Biomass boiler | Gas boiler | ASHP |
| Primary School; Gas; MV | 80,818 | 12% | Gas boiler | Gas boiler | ASHP |
| Primary School; Gas; NV | 151,577 | 23% | Gas boiler | Gas boiler | ASHP |
| Retail; Gas; AC | 56,069 | 8% | Gas boiler | Gas boiler | ASHP |
| Retail; Elec; AC | 39,465 | 6% | ASHP | ASHP | ASHP |
| Shallow Office NV; Gas; NV | 49,111 | 7% | Gas boiler | Gas boiler | ASHP |
| Warehouse Distribution; Gas; NV | 43,494 | 6% | Radiant gas heater | Radiant gas heater | ASHP |
| **TOTAL:** | **672,115** | **100%** | | | |

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[18] The allocation of PV to the notional building will be based on the actual building’s system for space heating; DHW systems will not affect this. Where the actual building uses a mixture of heat pumps and fossil fuels then the notional building PV allocation will be calculated on a pro-rata basis based on the applicable floor areas. Where a bivalent system is used then the PV area will be calculated based on the respective heat load share of the heat generating technologies.

### 1.10.3 Transitional Period

163. 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 63.

**Table 63: Transitional period assumptions for 2021 standards**

| Proportions of new non-domestic buildings 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.

## 1.11 National impacts (benefits) with fossil fuels

164. 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 Section 1.10.1 were applied to the national build profile, taking into account the assumptions on build/fuel mix and build rates set out in Sections 1.10.2 and 1.10.3. Initially the core ‘with fossil fuels’ scenario was assessed.

165. A 25-year analysis period was used. The three counterfactual cases (“Low”, “Medium” and “High”) were compared to the 2015 compliant base case. The carbon emission factors applied for gas and electricity 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 64. The factor for gas is 0.184kg$CO_2$e/kWh. The Green Book does not include a carbon emission factor for biomass so the value proposed for Section 6 is used in this analysis (0.029kg$CO_2$e/kWh), this only affects one of the schools (weighted to 6% of the national build floor area) so this is not expected to have a large impact on the results.

**Table 64: Carbon emission factors used in benefit analysis – electricity (kg$CO_2$e/kWh)**

| **Year** | **2021** | **2022** | **2023** | **2024** | **2025** | **2026** | **2027** | **2028** | **2029** | **2030** | **2031** | **2032** | **2033** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Consumption | 0.278 | 0.264 | 0.250 | 0.236 | 0.220 | 0.203 | 0.186 | 0.167 | 0.148 | 0.127 | 0.113 | 0.101 | 0.090 |
| **Year (cont.)** | **2034** | **2035** | **2036** | **2037** | **2038** | **2039** | **2040** | **2041** | **2042** | **2043** | **2044** | **2045** | |
| Consumption | 0.080 | 0.071 | 0.064 | 0.057 | 0.051 | 0.045 | 0.040 | 0.039 | 0.038 | 0.036 | 0.035 | 0.034 | |

*Notes* For non-domestic buildings it has been assumed that all PV output is used onsite with negligible export; therefore the PV output is assumed to offset electricity demand using the same $CO_2$ factor.

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

166. It should be noted that the carbon emission factors are different from those used in SBEM. 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 the proposed carbon emission factors (for a single year) is given in Section 1.14.

167. The results by year are presented in Table 65. Total emissions increase over time as the total cumulative floor area 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 66. This shows that the “Low”, “Medium” and “High” cases are estimated to achieve a 7%, 14% and 21% reduction in carbon emissions compared to the base case respectively.

**Table 65: Annual carbon emissions for base case and counterfactual cases – ‘with fossil fuels’ scenario (ktCO$_2$e/yr)**

| **Year** | **2021** | **2022** | **2023** | **2024** | **2025** | **2026** | **2027** | **2028** | **2029** | **2030** | **2031** | **2032** | **2033** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Base** | 13 | 25 | 38 | 49 | 61 | 72 | 83 | 93 | 103 | 112 | 121 | 130 | 138 |
| **Low** | 12 | 24 | 36 | 46 | 56 | 66 | 76 | 85 | 94 | 102 | 111 | 119 | 127 |
| **Medium** | 12 | 23 | 34 | 43 | 52 | 61 | 69 | 77 | 85 | 93 | 101 | 108 | 116 |
| **High** | 12 | 23 | 33 | 42 | 50 | 58 | 65 | 73 | 80 | 87 | 94 | 101 | 107 |
| **Year (cont.)** | **2034** | **2035** | **2036** | **2037** | **2038** | **2039** | **2040** | **2041** | **2042** | **2043** | **2044** | **2045** | **ALL** |
| **Base** | 146 | 154 | 162 | 169 | 177 | 184 | 191 | 199 | 206 | 213 | 220 | 227 | **3,286** |
| **Low** | 135 | 143 | 150 | 158 | 165 | 172 | 179 | 187 | 194 | 201 | 208 | 215 | **3,061** |
| **Medium** | 123 | 130 | 137 | 144 | 151 | 158 | 165 | 172 | 178 | 185 | 192 | 199 | **2,811** |
| **High** | 114 | 120 | 127 | 133 | 139 | 145 | 151 | 157 | 163 | 169 | 175 | 181 | **2,599** |

**Table 66: Total carbon emissions for counterfactual cases – ‘with fossil fuels’ scenario**

| | **Total carbon saving (ktCO$_2$e/yr)** | **% reduction compared to base case** |
|---|---|---|
| **Low** | 225 | 7% |
| **Medium** | 475 | 14% |
| **High** | 688 | 21% |

### 1.12 National impacts (benefits) without fossil fuels

168. 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 1.10 and 1.11. The results by year are presented in Table 67. The estimated total carbon savings for the counterfactual cases across the analysis period are summarised in Table 68.

169. This shows that under the ‘without fossil fuels’ scenario, the “Low”, “Medium” and “High” cases are estimated to achieve a 39%, 42% and 44% reduction in carbon emissions compared to the base case respectively. As would be expected, this is significantly higher than the estimated reductions under the ‘with fossil fuels’ scenarios, where most new buildings are assumed to be gas-heated over the analysis period.

**Table 67: Annual carbon emissions for base case and counterfactual cases – ‘without fossil fuels’ scenario (ktCO$_2$e/yr)**

| **Year** | **2021** | **2022** | **2023** | **2024** | **2025** | **2026** | **2027** | **2028** | **2029** | **2030** | **2031** | **2032** | **2033** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Base** | 13 | 25 | 38 | 49 | 61 | 72 | 83 | 93 | 103 | 112 | 121 | 130 | 138 |
| **Low** | 12 | 23 | 33 | 41 | 48 | 55 | 61 | 66 | 71 | 75 | 79 | 82 | 85 |
| **Medium** | 12 | 23 | 32 | 40 | 47 | 53 | 59 | 64 | 68 | 72 | 75 | 78 | 81 |
| **High** | 12 | 22 | 32 | 39 | 46 | 51 | 57 | 61 | 66 | 69 | 72 | 75 | 78 |
| **Year (cont.)** | **2034** | **2035** | **2036** | **2037** | **2038** | **2039** | **2040** | **2041** | **2042** | **2043** | **2044** | **2045** | **ALL** |
| **Base** | 146 | 154 | 162 | 169 | 177 | 184 | 191 | 199 | 206 | 213 | 220 | 227 | **3,286** |
| **Low** | 87 | 90 | 92 | 93 | 95 | 97 | 98 | 99 | 100 | 101 | 103 | 104 | **1,888** |
| **Medium** | 84 | 86 | 88 | 89 | 91 | 92 | 94 | 95 | 96 | 97 | 98 | 99 | **1,813** |
| **High** | 80 | 82 | 84 | 85 | 87 | 88 | 89 | 90 | 92 | 93 | 94 | 94 | **1,738** |

**Table 68: Total carbon emissions for counterfactual cases – ‘without fossil fuels’ scenario**

| | **Total carbon saving (ktCO$_2$e)** | **% reduction compared to base case** |
|---|---|---|
| **Low** | 1,398 | 43% |
| **Medium** | 1,474 | 44% |
| **High** | 1,548 | 47% |

### 1.13 National impacts (costs)

170. The capital costs (in 2020 prices) of each building type for the 2015, low, medium and high cases, and for both gas heating and ASHP, are shown in Table 69 to Table 80. Two of the twelve sample buildings use an electric ASHP as the base case heating scenario. For these two building the results for the three gas-heated options, listed above, have been omitted as not necessary for the analysis.

**Table 69: Capital costs by case and fuel type – Deep-plan Office, AC, gas heating base case**

| | Cost category | | | | | | **Percentage uplift on 2015** |
|---|---|---|---|---|---|---|---|
| | Fabric | Heating and cooling | Lighting and ventilation | Photovoltaics | Balance of construction cost | Total | |
| BS2015 | £3,041,890 | £701,147 | £738,100 | £101,517 | £34,742,346 | £39,325,000 | 0% |
| Gas+PV low | £2,982,600 | £705,587 | £1,004,300 | £146,636 | £34,742,346 | £39,581,469 | 1% |
| Gas+PV medium | £3,085,060 | £735,553 | £1,004,300 | £233,051 | £34,742,346 | £39,800,310 | 1% |
| Gas+PV high | £3,248,350 | £761,524 | £1,004,300 | £233,051 | £34,742,346 | £39,989,571 | 2% |
| ASHP low | £2,982,600 | £1,046,560 | £1,004,300 | £0 | £34,742,346 | £39,775,806 | 1% |
| ASHP medium | £3,085,060 | £867,622 | £1,004,300 | £0 | £34,742,346 | £39,699,328 | 1% |
| ASHP high | £3,248,350 | £1,145,217 | £1,004,300 | £0 | £34,742,346 | £40,140,214 | 2% |

**Table 70: Capital costs by case and fuel type – Deep-plan Office, AC, electric heating base case**

| | Cost category | | | | | | **Percentage uplift on 2015** |
|---|---|---|---|---|---|---|---|
| | Fabric | Heating and cooling | Lighting and ventilation | Photovoltaics | Balance of construction cost | Total | |
| BS2015 | £3,041,890 | £1,046,560 | £738,100 | £0 | £34,686,000 | £39,512,550 | 0% |
| Gas+PV low | NA | NA | NA | NA | NA | NA | NA |
| Gas+PV medium | NA | NA | NA | NA | NA | NA | NA |
| Gas+PV high | NA | NA | NA | NA | NA | NA | NA |
| ASHP low | £2,982,600 | £1,046,560 | £1,004,300 | £0 | £34,686,000 | £39,719,460 | 1% |
| ASHP medium | £3,085,060 | £1,097,365 | £1,004,300 | £0 | £34,686,000 | £39,872,726 | 1% |
| ASHP high | £3,248,350 | £1,145,217 | £1,004,300 | £0 | £34,686,000 | £40,083,868 | 1% |

### Table 71: Capital costs by case and fuel type – Hospital, NV, gas heating base case

| | **Cost category** | | | | | | **Percentage uplift on 2015** |
|---|---|---|---|---|---|---|---|
| | Fabric | Heating and cooling | Lighting and ventilation | Photovoltaics | Balance of construction cost | Total | |
| BS2015 | £3,820,649 | £573,175 | £814,730 | £0 | £50,817,674 | £56,026,227 | 0% |
| Gas+PV low | £3,866,373 | £580,395 | £1,149,569 | £162,237 | £50,817,674 | £56,576,247 | 1% |
| Gas+PV medium | £3,970,791 | £580,395 | £1,149,569 | £315,124 | £50,817,674 | £56,833,553 | 1% |
| Gas+PV high | £4,133,877 | £580,395 | £1,149,569 | £315,124 | £50,817,674 | £56,996,639 | 2% |
| ASHP low | £3,866,373 | £1,155,300 | £1,149,569 | £0 | £50,817,674 | £56,988,916 | 2% |
| ASHP medium | £3,970,791 | £1,189,187 | £1,149,569 | £0 | £50,817,674 | £57,127,222 | 2% |
| ASHP high | £4,133,877 | £1,224,769 | £1,149,569 | £0 | £50,817,674 | £57,325,889 | 2% |

### Table 72: Capital costs by case and fuel type – Hotel, NV, gas heating base case

| | **Cost category** | | | | | | **Percentage uplift on 2015** |
|---|---|---|---|---|---|---|---|
| | Fabric | Heating and cooling | Lighting and ventilation | Photovoltaics | Balance of construction cost | Total | |
| BS2015 | £613,885 | £47,440 | £80,057 | £9,118 | £2,079,397 | £2,829,897 | 0% |
| Gas+PV low | £620,209 | £48,140 | £101,390 | £13,170 | £2,079,397 | £2,862,305 | 1% |
| Gas+PV medium | £638,190 | £48,140 | £101,390 | £26,340 | £2,079,397 | £2,893,456 | 2% |
| Gas+PV high | £668,626 | £48,140 | £101,390 | £26,340 | £2,079,397 | £2,923,892 | 3% |
| ASHP low | £620,209 | £104,620 | £101,390 | £0 | £2,079,397 | £2,905,616 | 3% |
| ASHP medium | £638,190 | £107,906 | £101,390 | £0 | £2,079,397 | £2,926,882 | 3% |
| ASHP high | £668,626 | £111,355 | £101,390 | £0 | £2,079,397 | £2,960,767 | 4% |

### Table 73: Capital costs by case and fuel type – Hotel, AC, gas heating base case

| | **Cost category** | | | | | | **Percentage uplift on 2015** |
|---|---|---|---|---|---|---|---|
| | Fabric | Heating and cooling | Lighting and ventilation | Photovoltaics | Balance of construction cost | Total | |
| BS2015 | £625,534 | £58,881 | £80,057 | £31,322 | £2,236,238 | £3,032,033 | 0% |
| Gas+PV low | £620,209 | £60,852 | £101,390 | £13,170 | £2,236,238 | £3,031,859 | 0% |
| Gas+PV medium | £638,190 | £62,759 | £101,390 | £26,340 | £2,236,238 | £3,064,916 | 1% |
| Gas+PV high | £668,626 | £64,411 | £101,390 | £26,340 | £2,236,238 | £3,097,005 | 2% |
| ASHP low | £620,209 | £117,332 | £101,390 | £0 | £2,236,238 | £3,075,169 | 1% |
| ASHP medium | £638,190 | £122,525 | £101,390 | £0 | £2,236,238 | £3,098,342 | 2% |
| ASHP high | £668,626 | £127,627 | £101,390 | £0 | £2,236,238 | £3,133,880 | 3% |

## Table 74: Capital costs by case and fuel type – Primary School, NV, biomass heating base case

| | **Cost category** | | | | | | **Percentage uplift on 2015** |
|---|---|---|---|---|---|---|---|
| | Fabric | Heating and cooling | Lighting and ventilation | Photovoltaics | Balance of construction cost | Total | |
| BS2015 | £1,618,866 | £250,283 | £143,533 | £19,741 | £3,219,472 | £5,251,896 | 0% |
| Gas+PV low | £1,634,129 | £103,236 | £195,299 | £28,515 | £3,219,472 | £5,180,651 | -1% |
| Gas+PV medium | £1,671,717 | £103,236 | £195,299 | £57,030 | £3,219,472 | £5,246,754 | 0% |
| Gas+PV high | £1,734,691 | £103,236 | £195,299 | £57,030 | £3,219,472 | £5,309,728 | 1% |
| ASHP low | £1,634,129 | £215,867 | £195,299 | £0 | £3,219,472 | £5,264,768 | 0% |
| ASHP medium | £1,671,717 | £222,462 | £195,299 | £0 | £3,219,472 | £5,308,950 | 1% |
| ASHP high | £1,734,691 | £229,386 | £195,299 | £0 | £3,219,472 | £5,378,848 | 2% |

## Table 75: Capital costs by case and fuel type – Primary School, MV, gas heating base case

| | **Cost category** | | | | | | **Percentage uplift on 2015** |
|---|---|---|---|---|---|---|---|
| | Fabric | Heating and cooling | Lighting and ventilation | Photovoltaics | Balance of construction cost | Total | |
| BS2015 | £1,645,659 | £101,831 | £143,533 | £19,741 | £3,997,619 | £5,908,383 | 0% |
| Gas+PV low | £1,634,129 | £103,236 | £195,299 | £28,515 | £3,997,619 | £5,958,798 | 1% |
| Gas+PV medium | £1,671,717 | £103,236 | £195,299 | £57,030 | £3,997,619 | £6,024,901 | 2% |
| Gas+PV high | £1,734,691 | £103,236 | £195,299 | £57,030 | £3,997,619 | £6,087,875 | 3% |
| ASHP low | £1,634,129 | £215,867 | £195,299 | £0 | £3,997,619 | £6,042,915 | 2% |
| ASHP medium | £1,671,717 | £222,462 | £195,299 | £0 | £3,997,619 | £6,087,097 | 3% |
| ASHP high | £1,734,691 | £229,386 | £195,299 | £0 | £3,997,619 | £6,156,995 | 4% |

### Table 76: Capital costs by case and fuel type – Primary School, NV, gas heating base case

| | Cost category | | | | | | Percentage uplift on 2015 |
|---|---|---|---|---|---|---|---|
| | Fabric | Heating and cooling | Lighting and ventilation | Photovoltaics | Balance of construction cost | Total | |
| BS2015 | £1,618,866 | £101,831 | £138,827 | £18,271 | £3,592,930 | £5,470,725 | 0% |
| Gas+PV low | £1,634,129 | £103,236 | £195,299 | £28,515 | £3,592,930 | £5,554,109 | 2% |
| Gas+PV medium | £1,671,717 | £103,236 | £195,299 | £57,030 | £3,592,930 | £5,620,212 | 3% |
| Gas+PV high | £1,734,691 | £103,236 | £195,299 | £57,030 | £3,592,930 | £5,683,186 | 4% |
| ASHP low | £1,634,129 | £215,867 | £195,299 | £0 | £3,592,930 | £5,638,225 | 3% |
| ASHP medium | £1,671,717 | £222,462 | £195,299 | £0 | £3,592,930 | £5,682,408 | 4% |
| ASHP high | £1,734,691 | £229,386 | £195,299 | £0 | £3,592,930 | £5,752,306 | 5% |

### Table 77: Capital costs by case and fuel type – Retail, AC, gas heating base case

| | Cost category | | | | | | Percentage uplift on 2015 |
|---|---|---|---|---|---|---|---|
| | Fabric | Heating and cooling | Lighting and ventilation | Photovoltaics | Balance of construction cost | Total | |
| BS2015 | £1,079,070 | £80,365 | £121,250 | £10,487 | £3,083,828 | £4,375,000 | 0% |
| Gas+PV low | £1,072,945 | £80,770 | £173,250 | £15,148 | £3,083,828 | £4,425,941 | 1% |
| Gas+PV medium | £1,091,398 | £85,120 | £173,250 | £30,297 | £3,083,828 | £4,463,892 | 2% |
| Gas+PV high | £1,115,739 | £88,890 | £173,250 | £30,297 | £3,083,828 | £4,492,003 | 3% |
| ASHP low | £1,072,945 | £110,767 | £173,250 | £0 | £3,083,828 | £4,440,790 | 1% |
| ASHP medium | £1,091,398 | £117,018 | £173,250 | £0 | £3,083,828 | £4,465,494 | 2% |
| ASHP high | £1,115,739 | £122,784 | £173,250 | £0 | £3,083,828 | £4,495,601 | 3% |

## Table 78: Capital costs by case and fuel type – Retail, AC, electric heating base case

| | Cost category | | | | | | Percentage uplift on 2015 |
|---|---|---|---|---|---|---|---|
| | Fabric | Heating and cooling | Lighting and ventilation | Photovoltaics | Balance of construction cost | Total | |
| BS2015 | £1,079,070 | £110,767 | £121,250 | £0 | £3,063,913 | £4,375,000 | 0% |
| Gas+PV low | NA | NA | NA | NA | NA | NA | NA |
| Gas+PV medium | NA | NA | NA | NA | NA | NA | NA |
| Gas+PV high | NA | NA | NA | NA | NA | NA | NA |
| ASHP low | £1,072,945 | £110,767 | £173,250 | £0 | £3,063,913 | £4,420,875 | 1% |
| ASHP medium | £1,091,398 | £117,018 | £173,250 | £0 | £3,063,913 | £4,445,579 | 2% |
| ASHP high | £1,115,739 | £122,784 | £173,250 | £0 | £3,063,913 | £4,475,686 | 2% |

## Table 79: Capital costs by case and fuel type – Shallow Plan Office, NV, gas heating base case

| | Cost category | | | | | | Percentage uplift on 2015 |
|---|---|---|---|---|---|---|---|
| | Fabric | Heating and cooling | Lighting and ventilation | Photovoltaics | Balance of construction cost | Total | |
| BS2015 | £764,536 | £90,200 | £131,760 | £18,122 | £4,017,382 | £5,022,000 | 0% |
| Gas+PV low | £769,990 | £91,080 | £179,280 | £26,176 | £4,017,382 | £5,083,908 | 1% |
| Gas+PV medium | £797,465 | £91,080 | £179,280 | £52,353 | £4,017,382 | £5,137,559 | 2% |
| Gas+PV high | £841,433 | £91,080 | £179,280 | £52,353 | £4,017,382 | £5,181,527 | 3% |
| ASHP low | £769,990 | £159,456 | £179,280 | £0 | £4,017,382 | £5,126,108 | 2% |
| ASHP medium | £797,465 | £163,586 | £179,280 | £0 | £4,017,382 | £5,157,713 | 3% |
| ASHP high | £841,433 | £167,923 | £179,280 | £0 | £4,017,382 | £5,206,017 | 4% |

**Table 80: Capital costs by case and fuel type – Warehouse Distribution, NV, gas heating base case**

| | Cost category | | | | | | Percentage uplift on 2015 |
|---|---|---|---|---|---|---|---|
| | Fabric | Heating and cooling | Lighting and ventilation | Photovoltaics | Balance of construction cost | Total | |
| BS2015 case | £2,222,175 | £114,188 | £272,914 | £41,631 | £5,655,598 | £8,306,505 | 0% |
| Gas+PV low | £2,301,416 | £114,746 | £322,535 | £60,134 | £5,655,598 | £8,454,427 | 2% |
| Gas+PV medium | £2,434,775 | £115,583 | £322,535 | £120,267 | £5,655,598 | £8,648,757 | 4% |
| Gas+PV high | £2,549,856 | £116,308 | £322,535 | £120,267 | £5,655,598 | £8,764,563 | 5% |
| ASHP low | £2,301,416 | £340,268 | £322,535 | £0 | £5,655,598 | £8,619,816 | 4% |
| ASHP medium | £2,434,775 | £349,037 | £322,535 | £0 | £5,655,598 | £8,761,944 | 5% |
| ASHP high | £2,549,856 | £358,091 | £322,535 | £0 | £5,655,598 | £8,886,079 | 7% |

171. 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[19] the following indexed adjustments on the base central belt costs (index of 100) 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 primary school with gas for the different cases is shown in Table 81 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

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

**Table 81: Potential variation in build costs for non-domestic buildings built in the Western Isles – Primary School, NV, gas heating base case**

| | Central cost | Cost for projects in Western Isles | Variation in overall cost from 2015 base |
|---|---|---|---|
| BS2015 case | £5,470,725 | £7,111,943 | £0 |
| Gas+PV low | £5,542,579 | £7,205,353 | £93,410 |
| Gas+PV medium | £5,608,682 | £7,291,287 | £179,344 |
| Gas+PV high | £5,671,656 | £7,373,153 | £261,210 |
| ASHP low | £5,626,696 | £7,314,704 | £202,762 |
| ASHP medium | £5,670,878 | £7,372,142 | £260,199 |
| ASHP high | £5,740,776 | £7,463,009 | £351,066 |

172. The capital, maintenance and renewal, energy (variable cost) and lifetime costs of each case and fuel type are shown in Table 82. These costs are the net present value costs over a 60-year period for a building constructed in 2021 (in 2021 prices). Information is presented for each building type against the relevant 2015 base case specification and fuel type. 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: Cost Breakdown. 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. fan coils, lifts, etc.).

## Table 82: Lifetime costs by building, case and heating type (£ present value per building)

| Building type and case | Change in capital cost | Change in energy cost | Change in renewals cost | Change in maintenance cost | Change in lifetime cost |
|---|---|---|---|---|---|
| Deep Office AC; Gas | | | | | |
| Gas low case | £256,469 | -£296,677 | £325,814 | £0 | £285,605 |
| Gas medium case | £475,310 | -£500,088 | £391,932 | £0 | £367,154 |
| Gas high case | £664,571 | -£526,398 | £446,084 | £0 | £584,258 |
| ASHP low case | £450,806 | -£285,833 | £610,590 | £0 | £775,563 |
| ASHP medium case | £604,072 | -£500,100 | £667,187 | £0 | £771,158 |
| ASHP high case | £815,214 | -£528,801 | £743,581 | £0 | £1,029,994 |
| Deep Office AC; Elec | | | | | |
| Gas low case | NA | NA | NA | NA | NA |
| Gas medium case | NA | NA | NA | NA | NA |
| Gas high case | NA | NA | NA | NA | NA |
| ASHP low case | £206,910 | -£427,625 | £304,700 | £0 | £83,985 |
| ASHP medium case | £360,176 | -£652,344 | £361,296 | £0 | £69,127 |
| ASHP high case | £571,318 | -£682,446 | £437,690 | £0 | £326,563 |
| Hospital; Gas; NV | | | | | |
| Gas low case | £550,020 | -£894,876 | £451,688 | £0 | £106,833 |
| Gas medium case | £807,326 | -£1,153,387 | £519,851 | £0 | £173,790 |
| Gas high case | £970,411 | -£1,201,031 | £552,553 | £0 | £321,934 |
| ASHP low case | £962,689 | -£621,413 | £965,248 | £0 | £1,306,524 |
| ASHP medium case | £1,100,995 | -£954,872 | £1,013,533 | £0 | £1,159,655 |
| ASHP high case | £1,299,662 | -£1,074,093 | £1,082,403 | £0 | £1,307,971 |
| Hotel; Gas; NV | | | | | |
| Gas low case | £32,408 | -£17,849 | £26,928 | £0 | £41,488 |
| Gas medium case | £63,559 | -£36,678 | £35,189 | £0 | £62,070 |
| Gas high case | £93,995 | -£51,557 | £42,890 | £0 | £85,328 |
| ASHP low case | £75,719 | £71,939 | £78,477 | £0 | £226,135 |
| ASHP medium case | £96,985 | £41,468 | £85,398 | £0 | £223,851 |
| ASHP high case | £130,870 | £6,442 | £96,606 | £0 | £233,919 |
| Hotel; Gas; AC | | | | | |
| Gas low case | -£173 | £5,429 | £19,532 | £0 | £24,788 |
| Gas medium case | £32,884 | -£38,303 | £28,938 | £0 | £23,519 |
| Gas high case | £64,972 | -£50,053 | £37,632 | £0 | £52,551 |
| ASHP low case | £43,137 | £88,146 | £71,082 | £0 | £202,365 |
| ASHP medium case | £66,310 | £39,948 | £79,148 | £0 | £185,406 |
| ASHP high case | £101,848 | £11,448 | £91,348 | £0 | £204,643 |
| Primary School; Biomass; NV | | | | | |
| Gas low case | -£71,245 | -£59,594 | -£105,004 | -£773 | -£236,617 |
| Gas medium case | -£5,142 | -£107,221 | -£88,231 | -£773 | -£201,368 |
| Gas high case | £57,832 | -£114,785 | -£73,069 | -£773 | -£130,796 |
| ASHP low case | £12,872 | -£41,857 | -£3,115 | -£773 | -£32,873 |
| ASHP medium case | £57,054 | -£95,604 | £10,229 | -£773 | -£29,095 |
| ASHP high case | £126,952 | -£107,705 | £32,430 | -£773 | £50,903 |

| **Building type and case** | **Change in capital cost** | **Change in energy cost** | **Change in renewals cost** | **Change in maintenance cost** | **Change in lifetime cost** |
|---|---|---|---|---|---|
| Primary School; Gas; MV | | | | | |
| Gas low case | £50,415 | £5,244 | £63,979 | £0 | £119,638 |
| Gas medium case | £116,518 | -£43,150 | £80,751 | £0 | £154,120 |
| Gas high case | £179,492 | -£50,579 | £95,914 | £0 | £224,826 |
| ASHP low case | £134,532 | £20,110 | £165,868 | £0 | £320,510 |
| ASHP medium case | £178,714 | -£31,489 | £179,211 | £0 | £326,437 |
| ASHP high case | £248,612 | -£41,965 | £201,412 | £0 | £408,059 |
| Primary School; Gas; NV | | | | | |
| Gas low case | £83,384 | -£11,766 | £70,828 | £0 | £142,446 |
| Gas medium case | £149,487 | -£59,391 | £87,601 | £0 | £177,696 |
| Gas high case | £212,461 | -£66,954 | £102,763 | £0 | £248,270 |
| ASHP low case | £167,500 | £5,968 | £172,717 | £0 | £346,185 |
| ASHP medium case | £211,683 | -£47,774 | £186,061 | £0 | £349,970 |
| ASHP high case | £281,581 | -£59,871 | £208,262 | £0 | £429,971 |
| Retail; Gas; AC | | | | | |
| Gas low case | £50,941 | -£173,500 | £61,640 | £0 | -£60,919 |
| Gas medium case | £88,892 | -£208,990 | £70,787 | £0 | -£49,310 |
| Gas high case | £117,003 | -£212,727 | £77,214 | £0 | -£18,510 |
| ASHP low case | £65,790 | -£171,935 | £85,722 | £0 | -£20,423 |
| ASHP medium case | £90,494 | -£209,007 | £91,419 | £0 | -£27,095 |
| ASHP high case | £120,601 | -£213,168 | £99,874 | £0 | £7,307 |
| Retail; Elec; AC | | | | | |
| Gas low case | NA | NA | NA | NA | NA |
| Gas medium case | NA | NA | NA | NA | NA |
| Gas high case | NA | NA | NA | NA | NA |
| ASHP low case | £45,875 | -£182,238 | £59,521 | £0 | -£76,842 |
| ASHP medium case | £70,579 | -£219,439 | £65,217 | £0 | -£83,643 |
| ASHP high case | £100,686 | -£223,684 | £73,672 | £0 | -£49,326 |
| Shallow Office NV; Gas | | | | | |
| Gas low case | £61,908 | -£40,920 | £58,797 | £0 | £79,785 |
| Gas medium case | £115,559 | -£82,459 | £73,688 | £0 | £106,788 |
| Gas high case | £159,527 | -£95,616 | £85,939 | £0 | £149,850 |
| ASHP low case | £104,108 | -£33,728 | £117,175 | £0 | £187,554 |
| ASHP medium case | £135,713 | -£82,562 | £126,964 | £0 | £180,115 |
| ASHP high case | £184,017 | -£98,172 | £143,623 | £0 | £229,469 |
| Distribution; Gas; NV | | | | | |
| Gas low case | £147,922 | -£47,887 | £106,318 | £0 | £206,352 |
| Gas medium case | £342,251 | -£168,598 | £192,647 | £0 | £366,300 |
| Gas high case | £458,058 | -£205,438 | £245,276 | £0 | £497,896 |
| ASHP low case | £313,311 | £226,266 | £312,796 | £4,651 | £857,023 |
| ASHP medium case | £455,438 | £32,681 | £385,822 | £4,651 | £878,591 |
| ASHP high case | £579,574 | -£47,764 | £446,916 | £4,651 | £983,376 |

### 1.14 Comparison with Sullivan Report recommendations

173. The overall reduction in carbon emissions across the build mix for the six counterfactual cases has been compared to the Sullivan Report recommendations. For non-domestic buildings, the Sullivan Report recommends at least 75% on 2007 standards. This equates to an aggregate emissions reduction of at least 37% on 2015 standards across a notional annual build mix.

174. For this comparison, carbon emission savings were estimated using a single analysis year and proposed SBEM carbon emission factors. The same build rates and fuel mix were used as for the analyses with and without fossil fuels above (see Table 62), and it is assumed that 100% of buildings are built to 2021 standards in the year assessed.

175. The six counterfactual cases were again compared to the 2015 compliant base case:

- Gas+PV Low
- Gas+PV Medium
- Gas+PV High
- ASHP Low
- ASHP Medium
- ASHP High

176. The estimated total carbon emissions and savings for the year are summarised in Table 83. The percentage reductions are higher than in the benefit analysis for the core scenario presented in Sections 1.11 and 1.12 above mainly due to differences in the carbon emission factors used for the different analyses. The figures show that the three ASHP options considered exceed the recommendations of the Sullivan Report (i.e. a commitment to achieve a 37% improvement on 2015 standards) whilst none of the Gas+PV options achieve this standard.

**Table 83: Total carbon emissions and savings for base, low, medium and high cases – Sullivan Report comparison (based on a single year and proposed SBEM 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 |
|---|---|---|---|
| 2015 compliant | 10.20 | 0.00 | 0% |
| Gas+PV Low | 9.39 | 0.81 | 8% |
| Gas+PV Medium | 8.53 | 1.67 | 16% |
| Gas+PV High | 7.66 | 2.54 | 25% |
| ASHP Low | 4.40 | 5.80 | 57% |
| ASHP Medium | 4.12 | 6.08 | 60% |
| ASHP High | 3.85 | 6.35 | 62% |
| **Sullivan Report Commitment** | **6.43** | **3.77** | **37%** |

### 1.15 Sensitivity analysis

177. Analysis of the EPC database extract provided by Scottish Government showed that gas-heating, ASHP-heating and biomass-heating account for over 93% of non-domestic floor area in Scotland. However, sensitivity analysis was undertaken to investigate the ability of buildings to comply with potential 2021 standards where other fuel/heating types are specified. The heating types chosen for assessment were in part based upon analysis of the EPC database and 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.

**Table 84: Mapping of dominant heating fuel types**

| Heating Fuel | Floor Area (%) | Notes |
|---|---|---|
| Natural Gas | 62.4% | Included in core analysis |
| Grid Supplied Electricity | 23.0% | |
| Biomass | 8.0% | |
| District Heating | 3.3% | Included in sensitivity analysis |
| LPG | 1.8% | |
| Oil | 1.2% | |
| Waste Heat | 0.3% | Deemed negligible |
| Other | 0.1% | |
| Biogas | 0.0% | |
| Dual Fuel Appliances (Mineral + Wood) | 0.0% | |

178. Table 84 shows that the most common other heating types used are district heating, LPG and oil. Analysis of the EPC database shows that naturally ventilated education buildings are the dominant sub-type for buildings heated with each of these three sources. Based on this analysis, the sensitivity analysis considers the impact of using each of these three fuels on the sample naturally ventilated primary school building used in the core analysis.

179. As shown in Table 85, the $CO_2$ and primary energy factors for both LPG and oil are higher than that of gas. However, there is a greater percentage increase for primary energy which would be expected to result in a primary energy target being more challenging than an equivalent carbon target.

**Table 85: Proposed primary energy and $CO_2$ factors for selected fuels**

| Fuel type | $kgCO_2/kWh$ | kWh/kWh |
|---|---|---|
| Gas | 0.210 | 1.126 |
| LPG | 0.241 | 1.141 |
| Oil | 0.319 | 1.180 |

180. For gas CHP district heating, 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. With electricity emission factors reducing over time, the carbon savings 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. 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.

181. The following sensitivity cases were modelled. In each case the same individual built forms were used as in the core modelling, and compliance is assessed the potential 2021 standards in terms of primary energy. Carbon emissions were also compared to aid in the assessment of a potential secondary carbon metric.

- DHN+PV Low
- DHN+PV Medium
- DHN+PV High
- LPG+PV Low
- LPG+PV Medium
- LPG+PV High
- Oil+PV Low
- Oil+PV Medium
- Oil+PV High

182. For each of the new fuels the following inputs have been used:

- DHN: $CO_2$ emissions factor = 0.41kg$CO_2$/kWh primary energy emission factor = 1.57 kWh/kWh[20].
- LPG: Same boiler efficiency as is used for the core gas L/M/H options.
- Oil: Same boiler efficiency as is used for the core gas L/M/H options.

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[20] These values are based on the proposed factors for gas and electricity and assuming that: a gas CHP providing 75% of the annual load with the reminder being provided by gas boilers. Thermal efficiency of CHP=41%, Electrical efficiency of CHP=37%, Boiler efficiency=90%, Delivery losses=15%. This is slightly different to the basis for the DHN in the 2015 Section 6 requirements but is typical practise for new networks and aligned to other standards.

183. The results of the sensitivity tests are compared with those of the core modelling in Table 86. In addition, Figure 25 shows the primary energy results whilst Figure 26 shows those for $CO_2$.

**Table 86: Comparison of core modelling and sensitivity test results**

| Model Name | Primary Energy | | $CO_2$ | | Model category |
|---|---|---|---|---|---|
| | BPE | Margin on 2015 | BER | Margin on 2015 | |
| 2015 compliant | 57.5 | 0% | 9.28 | 0% | Core modelling |
| Gas+PV Low | 56.5 | 2% | 9.44 | -2% | |
| Gas+PV Medium | 44.0 | 23% | 8.16 | 12% | |
| Gas+PV High | 38.2 | 34% | 7.07 | 24% | |
| ASHP Low | 41.5 | 28% | 3.90 | 58% | |
| ASHP Medium | 39.5 | 31% | 3.70 | 60% | |
| ASHP High | 36.5 | 37% | 3.41 | 63% | |
| CHP-DHN+PV Low | 70.2 | -22% | 16.17 | -74% | Sensitivity test |
| CHP-DHN+PV Medium | 57.2 | 1% | 14.63 | -58% | |
| CHP-DHN+PV High | 49.5 | 14% | 12.65 | -36% | |
| LPG+PV Low | 57.1 | 1% | 10.65 | -15% | |
| LPG+PV Medium | 44.6 | 22% | 9.33 | -1% | |
| LPG+PV High | 38.7 | 33% | 8.08 | 13% | |
| Oil+PV Low | 58.6 | -2% | 13.72 | -48% | |
| Oil+PV Medium | 46.0 | 20% | 12.28 | -32% | |
| Oil+PV High | 39.9 | 31% | 10.62 | -14% | |

184. The sensitivity analysis shows that in all cases, the alternative heat sources (CHP-fired district heating, LPG and oil boilers) would not comply with a similarly specified gas or ASHP notional building. For example, in no cases could a “Low” specification for one of the other heating fuels comply with a notional building based on either a “Low” gas or ASHP specification.

185. From this analysis it can be deduced that if the selected 2021 standard was to be:

- “Gas+PV Low” or “Gas+PV Medium” then, with a higher degree of energy efficiency and PV generation:
  - LPG could still achieve compliance for both primary energy **and** $CO_2$.
  - Oil could still achieve compliance for primary energy **only**.
- “ASHP Low” then, with a higher degree of energy efficiency and PV generation:
  - LPG could still achieve compliance for primary energy **only**.
  - Oil could still achieve compliance for primary energy **only**.

It also particularly highlights the challenges facing the future adoption of gas CHP.

186. It should be noted that most of the sensitivity options exceed the $CO_2$ emissions of the 2015 compliant solution. This implies that even if the only changes to the regulations

were to be to change the emissions factors and the heating fuel of the notional building then the use of CHP, LPG and Oil would be constrained.

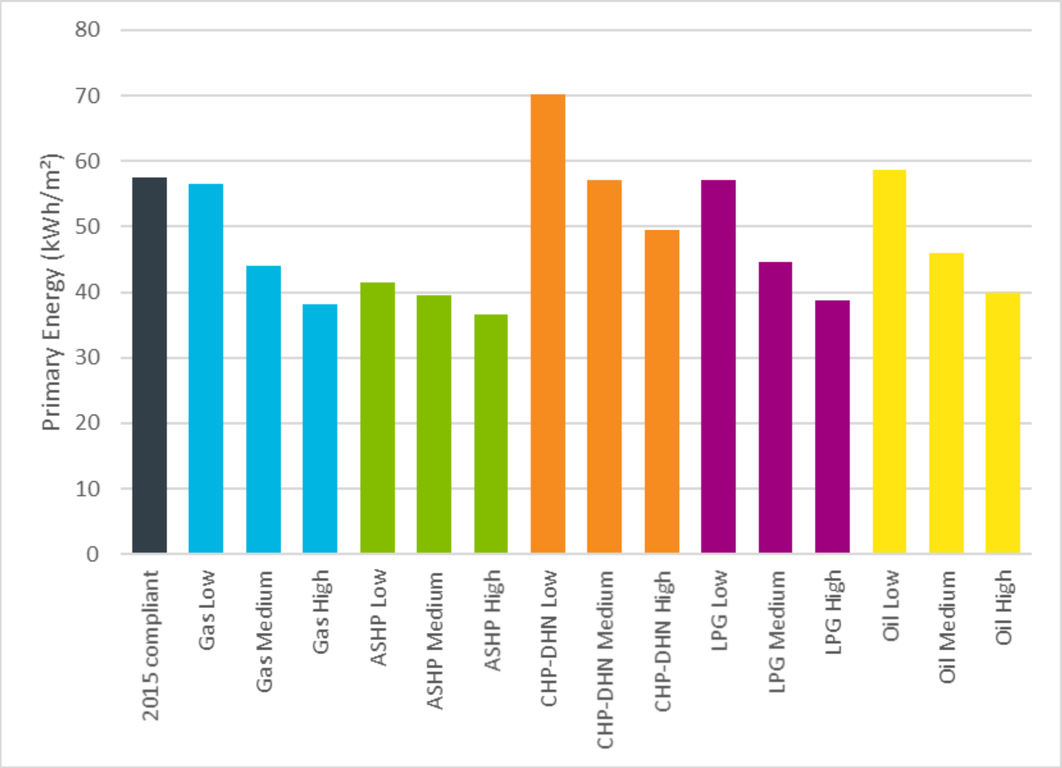

**Figure 25: Comparison of primary energy results for core modelling and sensitivity tests**

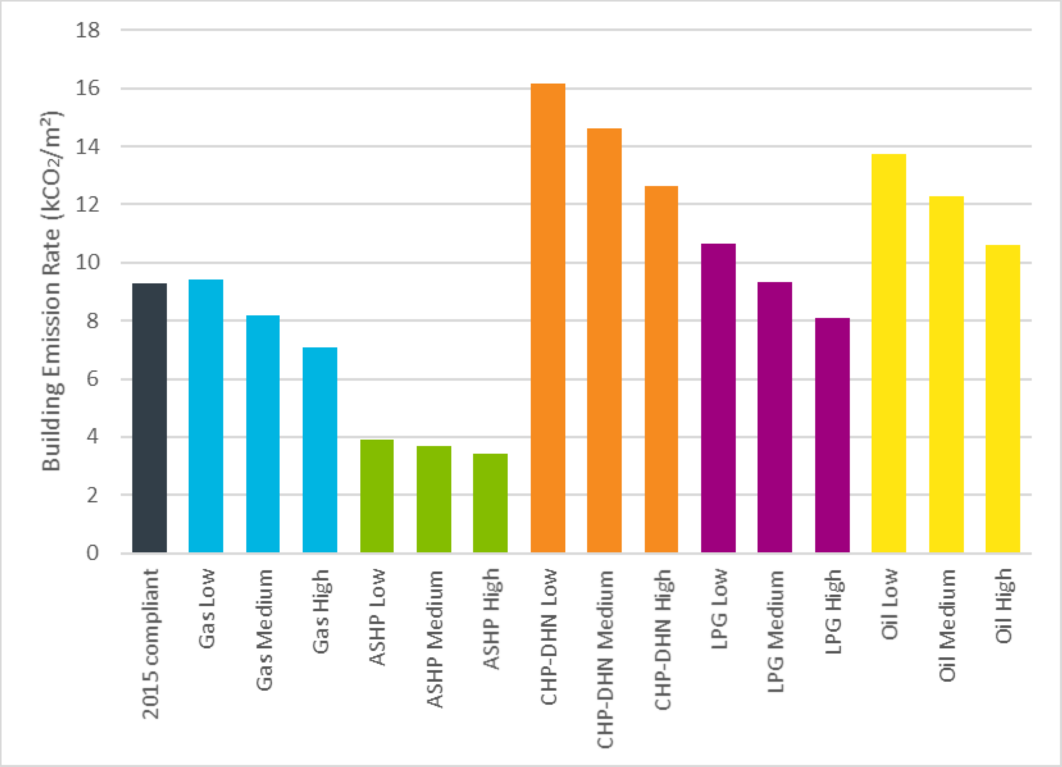

**Figure 26: Comparison of $CO_2$ results for core modelling and sensitivity tests**

187. The building could be further improved beyond the levels of energy efficiency and PV generation considered in the core modelling. The area of PV considered is limited to the lesser of either 6.5% or 13% of GIA (depending on the Low, Medium or High option is adopted) and 50% of the roof area. In the case of the primary school the lesser value is the percentage of the GIA in both cases. Therefore it is reasonable to postulate that in a specific example this could be increased to 50% of the roof area; the effect of increasing PV in this way is shown in Table 87, Figure 27 and Figure 28.

**Table 87: Comparison of core modelling and sensitivity test results assuming PV area is 50% of roof when DHN, LPG or Oil is used**

| Model Name | Primary Energy | | $CO_2$ | | Model category |
|---|---|---|---|---|---|
| | BPE | Margin on 2015 | BER | Margin on 2015 | |
| 2015 compliant | 57.5 | 0% | 9.28 | 0% | Core modelling |
| Gas+PV Low | 56.5 | 2% | 9.44 | -2% | |
| Gas+PV Medium | 44.0 | 23% | 8.16 | 12% | |
| Gas+PV High | 38.2 | 34% | 7.07 | 24% | |
| ASHP Low | 41.5 | 28% | 3.90 | 58% | |
| ASHP Medium | 39.5 | 31% | 3.70 | 60% | |
| ASHP High | 36.5 | 37% | 3.41 | 63% | |
| CHP-DHN+50%PV Low | 35.5 | 38% | 13.12 | -41% | Sensitivity test |
| CHP-DHN+50%PV Medium | 33.3 | 42% | 12.52 | -35% | |
| CHP-DHN+50%PV High | 25.6 | 55% | 10.55 | -14% | |
| LPG+50%PV Low | 22.3 | 61% | 7.60 | 18% | |
| LPG+50%PV Medium | 20.6 | 64% | 7.23 | 22% | |
| LPG+50%PV High | 14.7 | 74% | 5.98 | 36% | |
| Oil+50%PV Low | 23.9 | 58% | 10.67 | -15% | |
| Oil+50%PV Medium | 22.1 | 62% | 10.17 | -10% | |
| Oil+50%PV High | 16.0 | 72% | 8.52 | 8% | |

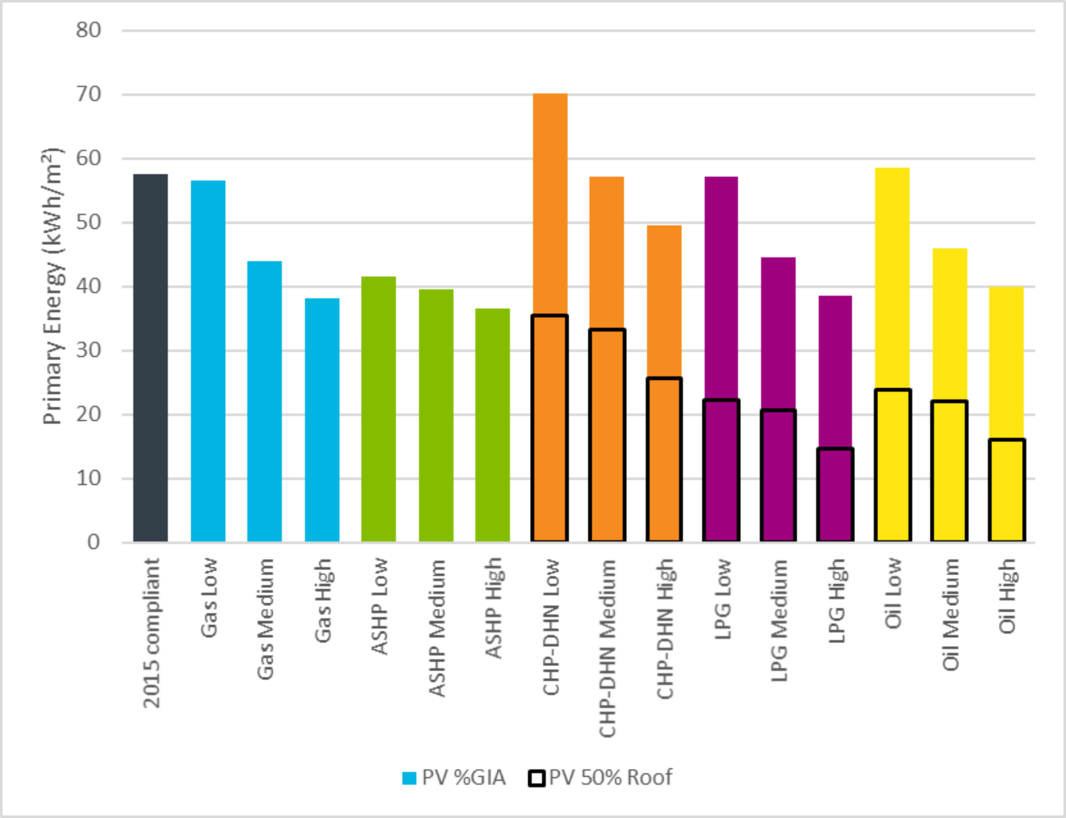

Figure 27: Comparison of primary energy results for core modelling and sensitivity tests showing effect of PV area = 50% of roof

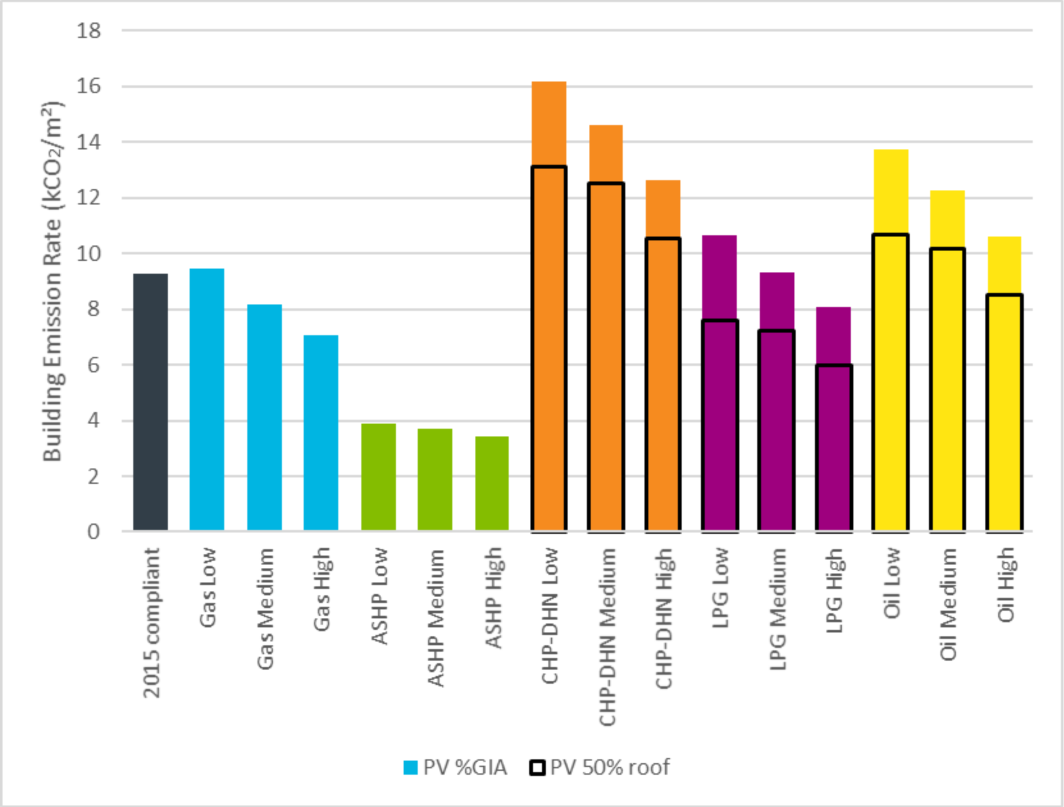

Figure 28: Comparison of $CO_2$ results for core modelling and sensitivity tests showing effect of PV area = 50% of roof

188. This further analysis shows that with increased PV area (where the building form allows) the range of routes to compliance using these alternative heat sources is increased:

- LPG can achieve compliance for both primary energy and $CO_2$ if the standard is based on any of the three Gas+PV options.
- Oil can achieve compliance for both primary energy and $CO_2$ if the standard is based on the Gas+PV Low option.
- Gas CHP can achieve compliance with or primary energy only if the standard is based on any of the three Gas+PV.
- All three heat sources can achieve compliance for primary energy only if the standard is based on any of the three Gas+PV or ASHP options.

189. It is important to note that this analysis has been undertaken on one building type. The primary school was chosen as it is the dominant building sub-type heated with each of these three sources and hence a reasonable case for sensitivity analysis. It is expected generally that all building types will find it harder to comply for LPG, oil and gas CHP district heating compared to a gas or ASHP notional building, but level of challenge will differ to some degree.

### 1.16 Review of the need for a carbon metric

190. 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.

191. Primary energy and carbon dioxide emissions targets can have different impacts depending on the fuel type. For example, 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. If the notional building was based on an ASHP, including a carbon target would result in a greater challenge for gas-heated buildings than a primary energy target alone.

192. The proposed preferred approach is to set a notional building differentiated by fuel type (gas / ASHP). As a result, the addition of a carbon metric would not be expected to have the impact of making it more difficult for gas-heated buildings to comply.

193. 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. As shown in the sensitivity analysis described in section 1.15, a carbon target is much more onerous than a primary energy target. 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.

194. As shown in section 1.15, it would be very challenging for buildings with gas CHP district heating to comply with a carbon target. This needs to be considered against policy aims to, for example, continue to connect to existing gas CHP-based heat networks which may change to low carbon heating sources in the future. If necessary, the target could be relaxed for district heating (e.g. introduce technology factors as per

proposals for Part L 2020 in England or through a separate specific notional building targets for heat networks) or implement a solution outside of Building Standards. 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 buildings to connect. In practice it may be challenging to define a water-tight distinction between a new district heat network and a large increase in size/capacity of an existing network. The approach for 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.

195. 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 non-domestic buildings in Scotland have been discussed above. Further sensitivity analysis covering a wider range of fuel/building types or specifications could also be undertaken, and other views could be sought.

# Task 4: Full Cost Benefit Analysis

196. Based on the build/fuel mix, capital and lifetime costs, benefits and transition period defined in Section 0, the national costs and benefits for the low, medium and high 'with fossil fuel' cases compared with continuation of the existing 2015 standards are shown in Table 88. The analysis is based on the HM Treasury Green Book standards and the accompanying supplementary guidance on the valuation of energy use[21]. 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-year building life from the year of construction resulting in a total model period of 70 years.

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

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

**Table 88: Summary of results from cost benefit analysis: total over the appraisal period**

| **Element reported on** | **Option 1: Section 6 2021 ‘Low standard’, no change in heating fuel** | **Option 2: Section 6 2021 ‘Medium standard’, no change in heating fuel** | **Option 3: Section 6 2021 ‘High standard’, no change in heating fuel** |
|---|---|---|---|
| Energy savings (£M) | 150 | 245 | 264 |
| Incremental costs (£M) | (230) | (366) | (497) |
| Total financial benefit/(cost) (£M) | **(80)** | **(121)** | **(234)** |
| Carbon savings - non-traded (£M) | (11) | (4) | 22 |
| Carbon savings - traded (£M) | 16 | 24 | 24 |
| Total carbon savings (£m) | 5 | 20 | 46 |
| Air quality savings (£m) | 69 | 78 | 80 |
| Net benefit/(cost) (£m) | **(6)** | **(23)** | **(107)** |
| Amount of gas saved (GWh) | (1,005) | (467) | 1,492 |
| Amount of electricity saved (GWh) | 4,125 | 6,684 | 6,746 |
| Amount of $CO_2$ saved - non-traded ($MtCO_2$) | (0) | (0) | 0 |
| Amount of $CO_2$ saved - traded ($MtCO_2$) | 0 | 0 | 0 |
| Cost effectiveness – non-traded (£/$tCO_2$) | 36 | (335) | 424 |
| Cost effectiveness – traded (£/$tCO_2$) | 89 | 129 | 356 |

197. The results show that none of the options have a net benefit even after the value of carbon and air quality benefits are considered although the cost associated with Option 1 is relatively small relative to the overall costs and benefits associated with the policy.

198. The value of air quality benefits is significantly larger than the value of reduced carbon emissions and is primarily due to the avoided use of biomass in one of the primary school archetypes. Given the introduction of a primary energy metric, there is significantly less benefit of adopting biomass compared to gas heating. For the purpose of this analysis, it is therefore assumed that the primary school will now adopt gas heating. Table 88 shows the value of air quality improvements varying between £69m and £80m across the three options. In all cases the value of the improvements from reduced use of biomass is calculated to be around £50m (the reminder is associated with reduced gas and electricity use). Therefore, if biomass use continued at a rate similar to that indicated in the EPC database then the net cost of all options would be increased by around £50m.

199. Table 88 shows an increase in gas consumption over the counterfactual for options 1 and 2. As explained in Paragraph 146, this is primarily driven by large increase in lighting efficacy which reduces the internal heat gains and thus increases the space heating demands. This increase in gas uses is more than countered by a corresponding reduction in electricity use.

200. The financial benefit / cost of each option is relatively consistent with the level of additional incremental cost involved although the ratio of costs to benefits does increase with increasing levels of energy efficiency i.e. from 1.5 times between options 1 and 2 to 1.9 times between options 2 and 3. This would be expected as a result of reduced incremental savings from additional investment where there is no major change in technology. However, the net benefit / cost after carbon and air quality savings are considered is substantially larger. This is because of the very large air quality benefit associated with all options from the avoidance of biomass which is only included in the counterfactual scenario. The scale of the benefit from avoiding biomass does not vary much between Options 1 and 3 meaning that the total net cost of Options 2 and 3 are proportionately larger than their incremental financial cost would suggest (i.e. the financial cost of Option 3 is around three times that of Option 1 whereas its total net cost is around 19 times higher).

# Conclusions

201. 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 non-domestic buildings.

202. Improvements to the current notional 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 and feasibility. Based on this, three new alternative standards (low, medium and high) were proposed and their benefits and costs were assessed at an individual building and national level.

203. The fabric standard of the low option is aligned to the better of the two fabric standards used under the current Section 6 2015 standard. Further fabric improvements are included in the medium and high options. All three options include improvements in the efficiency of most elements of building services over the 2015 standards, some of these remain constant across all three options (e.g. boiler and lighting efficiencies) whilst cooling and ASHP efficiencies improve from one option to the next. The size of PV array under the 2015 standard is limited to the lesser of 4.5% of the GIA and 50% of the roof area; the three improved options adopt a similar approach but raise the percentage of GIA whilst keeping the 50% of roof area limit.

204. 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 all options, it is proposed that the notional building is based on gas heating + PV, with 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.

205. 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 buildings. 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.

206. The low, medium and high options are estimated to reduce carbon emissions by 8%, 16% and 25% respectively across the build mix. This was evaluated using SBEM v5.6a

and the proposed new carbon emission factors, across 12 buildings selected to represent common non-domestic 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 37% on 2015 standards. Hence none of these options would meet this recommendation. A move away from the use of mains gas would be needed to achieve this.

207. It is estimated that the capital cost of adopting a gas heating + PV compliant solution is typically between 1% and 3% higher than the current standard depending on the building type and the optional improved standard (for some building types the capital cost is slightly lower than the counterfactual). Adopting an ASHP compliant solution is estimated to always be more expensive than the equivalent gas heating + PV solution, with the capital cost ranging between 1% and 7% above the current standard. In some cases, the difference in capital cost between Gas+PV and ASHP is very small.

208. The national cost benefit analysis shows that the low, medium and high options result in a net cost of £6m, £23m and £107m respectively.

209. 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 LPG, oil and gas CHP district heating, (all 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.

- The sensitivity analysis was undertaken on a naturally ventilated primary school as it was identified as best representative of the building types to most commonly use these alternative heat sources. It was modelled with LPG, Oil and CHP-lead district heating.

- If the new standard was to be based on the medium Gas+PV option then LPG could achieve compliance if combined with PV and adopting the specifications of the high standard. Oil may be able to comply if adopting the specifications of the high standard and an increased area of PV. District heating with gas-CHP is only able to comply with the primary energy metric when combined with the specifications of the high standard and increased PV areas, and did not comply with the $CO_2$ metric in any of the scenarios considered in the report.

- In all cases, the carbon target was the most stringent of the two targets and dictated the compliant solution.

The Scottish Government does need to consider the results for gas CHP within its broader strategic goal to encourage district heating.

210. 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. Our view is that to introduce an incentive for built form

would be complicated to implement successfully and would be likely to have unintended consequences. Significant further research would be necessary to assess and develop such an approach in a robust and fair way across a wide range of non-domestic building types and avoiding unintended consequences or loop-holes.

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# Appendix A: Cost Breakdown

211. 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.

212. The cost analysis is intended to reflect typical national costs from Q1 2020 that might be incurred by a public or private developer with reasonably efficient supply chain, design development and construction processes. However, costs incurred by individual organisations will vary according to their design, 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 project. These variations design, location and delivery method could result in a cost range of +/- c.30% or more (see Section 0). Notwithstanding these variations, the proportional uplifts associated with moving from one specification to another are likely to be relatively similar across different market segments[22].

213. To provide context to the cost variations assessed in the study an indicative overall build cost (£ per m2) 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 building 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.

214. 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.

215. Table 89 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.

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[22] Costs increases may be outside the described range for highly bespoke designs; however, these buildings are typically more expensive to construct and so the relative impact on build costs may be similar or potentially smaller than for more typical buildings.

## Table 89: 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 – steel framed construction with mineral wool | 0.23 W/m².K | m² | £365 | £0 | 60 |
| | 0.20 W/m².K | m² | £371 | £0 | 60 |
| | 0.18 W/m².K | m² | £375 | £0 | 60 |
| | 0.15 W/m².K | m² | £382 | £0 | 60 |
| External Wall – masonry construction with mineral wool | 0.23 W/m².K | m² | £235 | £0 | 60 |
| | 0.20 W/m².K | m² | £238 | £0 | 60 |
| | 0.18 W/m².K | m² | £240 | £0 | 60 |
| | 0.15 W/m².K | m² | £244 | £0 | 60 |
| Ground / Exposed Floor (concrete slab, rigid insulation and screed) | 0.22 W/m².K | m² | £61-70 | £0 | 60 |
| | 0.20 W/m².K | m² | £63-71 | £0 | 60 |
| | 0.15 W/m².K | m² | £66-76 | £0 | 60 |
| | 0.13 W/m².K | m² | £68-78 | £0 | 60 |
| Raised exposed Floor (concrete deck, rigid insulation and screed) | 0.20 W/m².K | m² | £42 | £0 | 60 |
| | 0.15 W/m².K | m² | £46 | £0 | 60 |
| | 0.13 W/m².K | m² | £48 | £0 | 60 |
| Flat roof – warm deck | 0.18 W/m².K | m² | £214 | £0 | 60 |
| | 0.16 W/m².K | m² | £215 | £0 | 60 |
| | 0.15 W/m².K | m² | £216 | £0 | 60 |
| | 0.11 W/m².K | m² | £220 | £0 | 60 |
| Warehouse roof | 0.18 W/m².K | m² | £53 | £0 | 60 |
| | 0.16 W/m².K | m² | £65 | £0 | 60 |
| | 0.15 W/m².K | m² | £71 | £0 | 60 |
| | 0.11 W/m².K | m² | £85 | £0 | 60 |
| Windows uPVC | 1.8 W/m².K | m² | £570 | £0 | 30 |
| | 1.6 W/m².K | m² | £570 | £0 | 30 |
| | 1.4 W/m².K | m² | £600 | £0 | 30 |
| | 0.8 W/m².K | m² | £660 | £0 | 30 |
| Gas boiler (incl flue, pump and controls) | 91% | kW | £40 | £0.5 | 15 |
| | 93% | kW | £45 | £0.5 | 15 |
| ASHP | 1.75 | kW | £447 | £0.5 | 15 |
| | 3.55 | kW | £469 | £0.5 | 15 |
| | 4.5 | kW | £493 | £0.5 | 15 |
| | 5.12 | kW | £517 | £0.5 | 15 |

| Element | Specification | Unit | New cost (£ per unit) | Annual maintenance costs (£ per unit)* | Average life expectancy |
|---|---|---|---|---|---|
| Biomass boiler | incl flue and fuel store | kW | £598 | £0.6 | 15 |
| Buffer tank | 10 l per kW | Ltr | £1 | £0 | 15 |
| Radiant gas panels |  | m² GIFA | £22 | £0 | 20 |
| Radiators | Low temp | m² GIFA | £27 | £0 | 20 |
| Airtightness | 5 | m³m²hr @50Pa | £0 | £0 | 60 |
|  | 4 |  | £2.5 | £0 | 60 |
|  | 3 |  | £5 | £0 | 60 |
| Lighting - office | 60 Lln/W | m² GIFA | £59 | £0 | 15 |
|  | 65 Lln/W |  | £61 | £0 | 15 |
|  | 75-80 Lln/W |  | £61 | £0 | 15 |
|  | 95 Lln/W |  | £67 | £0 | 15 |
|  | 125 Lln/W |  | £83 | £0 | 15 |
| Lighting - warehouse | 60 Lln/W | m² GIFA | £53 | £0 | 15 |
|  | 65 Lln/W |  | £53 | £0 | 15 |
|  | 75-80 Lln/W |  | £55 | £0 | 15 |
|  | 95 Lln/W |  | £60 | £0 | 15 |
|  | 125 Lln/W |  | £65 | £0 | 15 |
| Lighting - display | 22 Lln/W | m² lit area | £45 | £0 | 15 |
|  | 60 Lln/W |  | £50 | £0 | 15 |
|  | 65 Lln/W |  | £60 | £0 | 15 |
|  | 125 Lln/W |  | £67 | £0 | 15 |
| Display light controls | Time switch | m² lit area | £2.5 | £0 | 20 |
| Roof mounted - photovoltaic panels | Variable costs for systems >4kWp | Per kWp installed | £1,100 | £12 | 25 |
| Chiller | 4.5 | kW | £180 | £0.19 | 25 |
|  | 5.5 | kW | £200 | £0.19 | 25 |
|  | 6.4 | kW | £230 | £0.19 | 25 |
|  | 7.1 | kW | £256 | £0.19 | 25 |
| AHU Heat recovery unit | 70% efficient | m³/s | £7000 | £0.70 | 25 |
|  | 76% efficient | m³/s | £8000 | £0.80 | 25 |

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