Technical Feasibility of Low Carbon Heating in Domestic Buildings

Technical feasibility appendix to the Report for Scottish Government's Directorate for Energy & Climate Change

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1 Suitability of Scotland's housing stock for individual low-carbon heating technologies

1.1 Introduction

The suitability of Scotland's housing stock for the considered low-carbon heating technologies was further investigated. For each technology, the characteristics of suitable and unsuitable homes were analysed and compared. Additionally, the number of homes that are affected by different suitability constraints was assessed.

The following sections report our findings on the stock suitability for each technology in 2017. For those technologies where the fuse limit constraint or the peak specific heat demand constraint are relevant, separate sets of outputs were produced for a range of threshold values: 60A, 80A and 100A for fuse limit and 100, 120 and 150 W/m^2 for specific heat loss.

A figure summarising our results was therefore produced for each technology and threshold sensitivity. Each figure reports on the left a summary of the composition of the suitable and unsuitable portions of the stock, showing a breakdown of homes according to their age, property type, property size, wall insulation, roof insulation and existing heating system. On the right, the number of homes affected by each suitability constraint is reported (blue), together with the total number of constrained homes (red). Note that the total number of constrained homes is generally smaller than the sum of homes affected by each constraint, as the same home may be affected by more than one constraint at a time.

No results are reported in this section for GSHP and high-temperature GSHP, as the analysis of their suitability was performed on the basis of only two characteristics of the stock: the dwelling type and the location in an urban or rural area.

1.1.1 Characteristics of the housing stock

The choice of dwelling characteristics considered in the archetype definition was predominantly based on characteristics influencing the suitability of low-carbon heating in Scottish homes. An overview of the dwelling characteristics reported in the plots in the next sections is shown in Table 1.

Table 1: Relevant dwelling attributes

Attributes	Values	Notes
Age	• Pre-1919 • 1919-1991 • Post-1991	The age group 1919-1991 was not further disaggregated, as associated potential restrictions on renovation and materials are expected to be similar among this group.
Property type	• Detached • Semi-detached • Terraced • Flat (block) • Flat (other)	'Semi-detached' includes both semi-detached houses and end-terraced houses, as these are expected to have similar heat demand per unit floor area, having the same number of external walls. 'Terraced' only includes mid-terraced houses.

Attributes	Values	Notes
		'Flat (block)' includes homes in large blocks of flats, composed of >15 residential dwellings located within a single building. 'Flat (other)' includes homes in smaller blocks of flats, composed of up to 15 residential dwellings located within a single building.
Size	• Small (< 66 m^2) • Medium (66 – 108 m^2) • Large (> 108 m^2)	Total dwelling floor area
Wall insulation	• SWI - Solid wall insulated • SWU - Solid wall uninsulated • CWI - Cavity wall insulated • CWU - Cavity wall uninsulated with low exposure to wind and rain • CWU exposed - Cavity wall uninsulated with high exposure to wind and rain	'High exposure to wind and rain' corresponds to 'very severe' or 'severe' exposure. Similarly, 'low exposure to wind and rain' corresponds to 'sheltered' or 'moderate' exposure.
Roof insulation	• <100 mm • 100-250 mm • >250 mm • Room in roof • No loft	Homes with non-habitable space in the loft were assigned a value according to the thickness of their roof insulation ('<100 mm', '100-250 mm' or '>250 mm'). Homes with habitable space in the loft were assigned the value 'Room in roof' for insulation of less than 200 mm, or the value '>250 mm' for insulation of more than 200 mm. Homes with no access to the loft (e.g. flats) were assigned the value 'no loft'.
Existing heating system	• Gas boiler • Oil boiler • Electric • Other	'Oil boiler' heating systems include both oil and LPG boilers. 'Electric' heating systems include electric storage and direct electric. 'Other' heating systems include: biomass boilers, solid fuel boilers, communal heating and homes with no heating system.

Attributes	Values	Notes
		The type of pre-existent heat distribution system was not considered a barrier to suitability of heating technologies.

1.1.2 Suitability constraints

The suitability constraints considered in this study and reported in our plots are peak heating demand, heat density, gas network, space constraint, installation disruption and solar orientation.

Peak heating demand

Peak heating demand includes both fuse limit and peak specific heat demand constraints.

The fuse limit constraint is relevant for heating technologies that rely on electricity, as a large peak heat demand may result in a peak consumption of electrical power that can be incompatible with the fuse rating of a home. Therefore, this constraint may affect the implementation of all types of electric heating and conventional or high-temperature heat pumps.

Peak specific heat demand is intended as total heat demand of a dwelling divided by the total floor area of the habitable rooms. A large peak specific heat demand may be an obstacle for the implementation of air-source and ground-source heat pumps, as the required low-temperature radiators may be insufficient to ensure thermal comfort during all seasons.

Heat density

A heat density constraint was considered to test the suitability of homes for district heating.

A map of Scotland's domestic heating demand was analysed and homes located in areas with local heat demand density above a threshold of 40kWh/m^2 were considered compatible with district heating. This heat demand density test was performed both on each Scottish datazone and on each square of a grid with 1 km^2 resolution, with either of the two tests being sufficient for suitability. The assessment on the 1 km^2 resolution grid was performed in order to identify rural areas with local high heat density that would otherwise not have emerged from the datazone analysis, as rural datazones have very large areas.

80% of homes that resulted compatible with district heating were assumed to be suitable for district heating, based on the likely cost-effectiveness of DH deployment.

Gas network

The gas network constraint was applied to all homes that are not located on the gas grid. This constraint impacts the installation of heating technologies that rely on low-carbon gas, such as hydrogen boilers, natural gas boilers with biomethane grid injection and hybrid heat pumps with natural gas.

Space constraint

Homes with total dwelling floor area per habitable room smaller than 18m^2 are considered space constrained. This constraint is expected to affect the installation of conventional, high-temperature and hybrid heat pumps, due to their additional requirement of a large hot water cylinder for the production of hot water.

Installation disruption

A high level of disruption is expected for the implementation of all heat pump technologies and solid biomass boilers, due to the extensive work required for the installation of large equipment and new radiators, and to the allocation of storage for solid biomass. A higher hassle factor is expected to be associated with older homes and homes which may require planning consent to perform minor construction work. Therefore, it was assumed that 50% of old homes (built before 1919), listed homes and homes in conservation areas are constrained by installation disruption.

Solar orientation

The solar orientation constraint affects the suitability for heating technologies in combination with solar thermal. Only homes with roofs facing south, south east or south west were considered suitable for solar thermal.

1.2 ASHP

Figure 1: Stock suitability for ASHP, considering fuse limit of 100A and peak specific heating demand of 150 W/m² in 2017

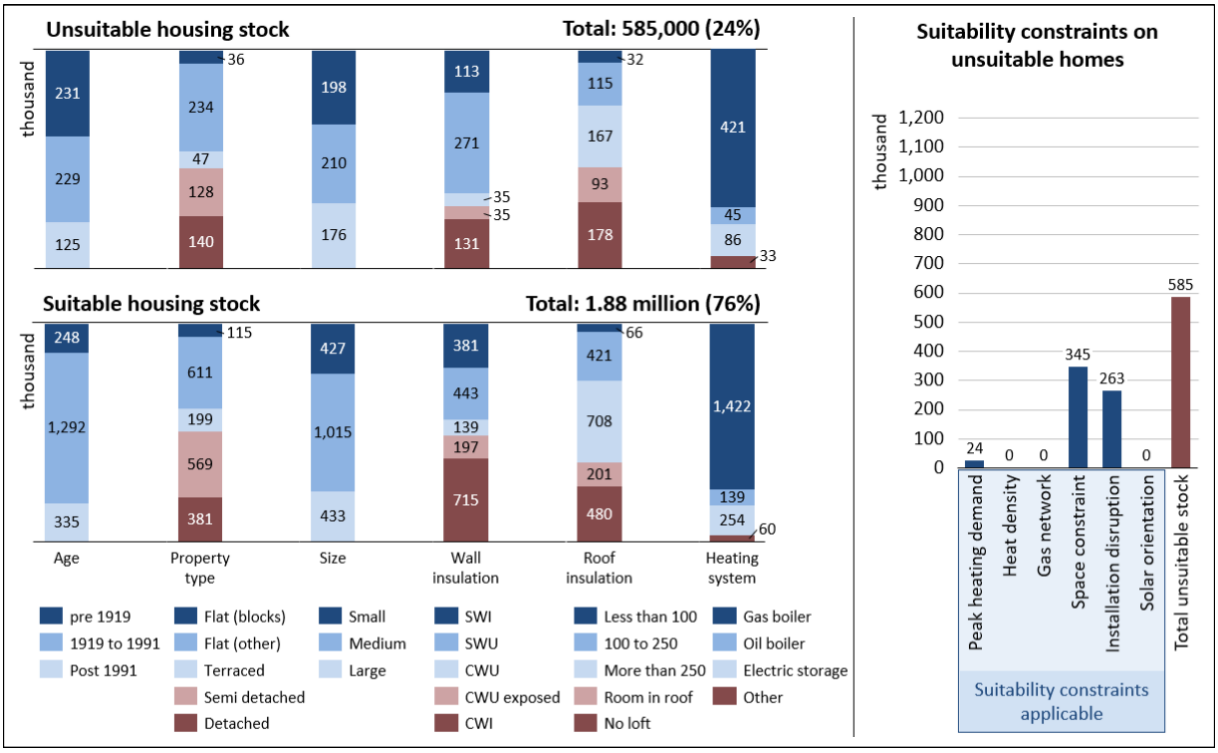


Figure 2: Stock suitability for ASHP, considering fuse limit of 80A and peak specific heating demand of 120 W/m² in 2017

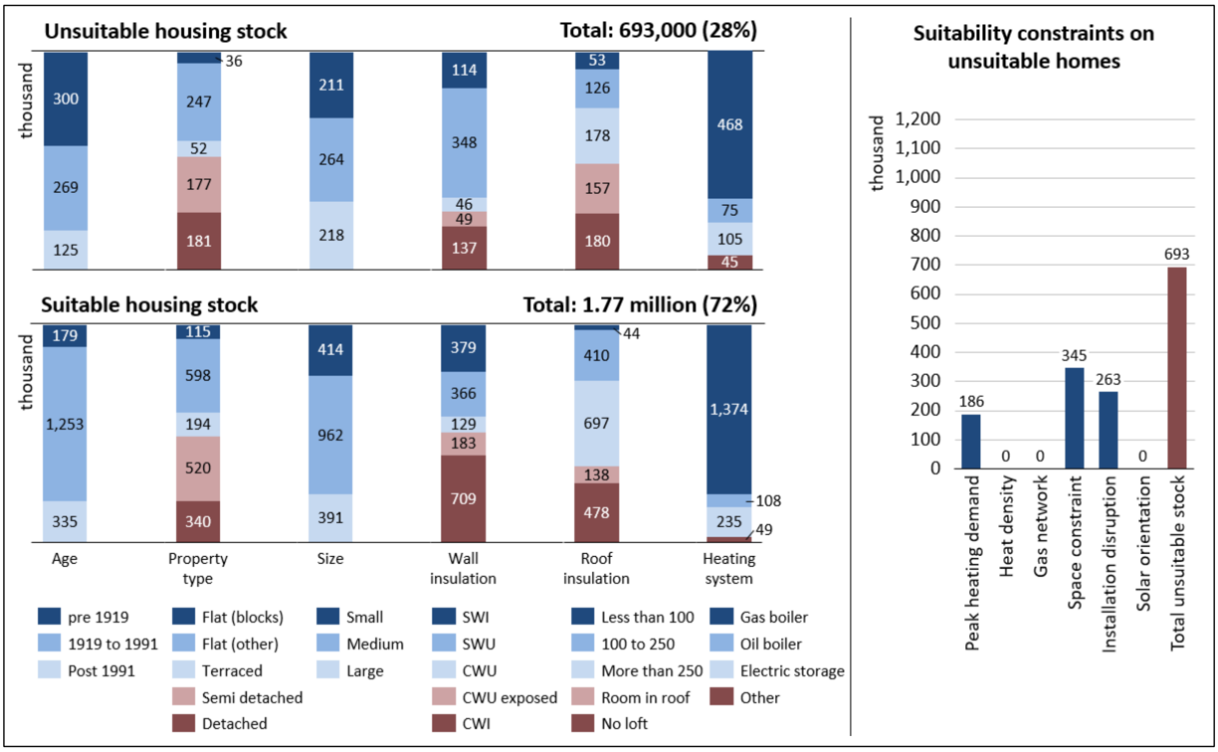
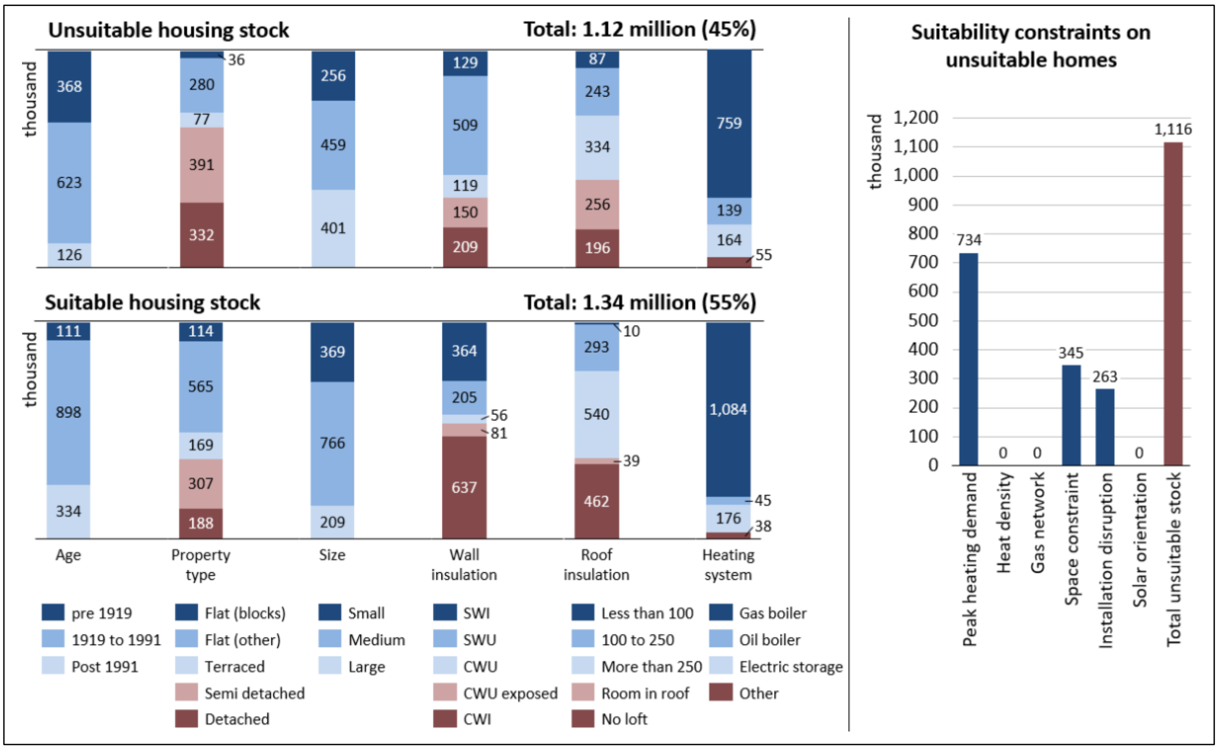


Figure 3: Stock suitability for ASHP, considering fuse limit of 60A and peak specific heating demand of 100 W/m^2 in 2017



1.3 High-temperature ASHP

Figure 4: Stock suitability for high-temperature ASHP, considering fuse limit of 100A and peak specific heating demand of 150 W/m^2 in 2017

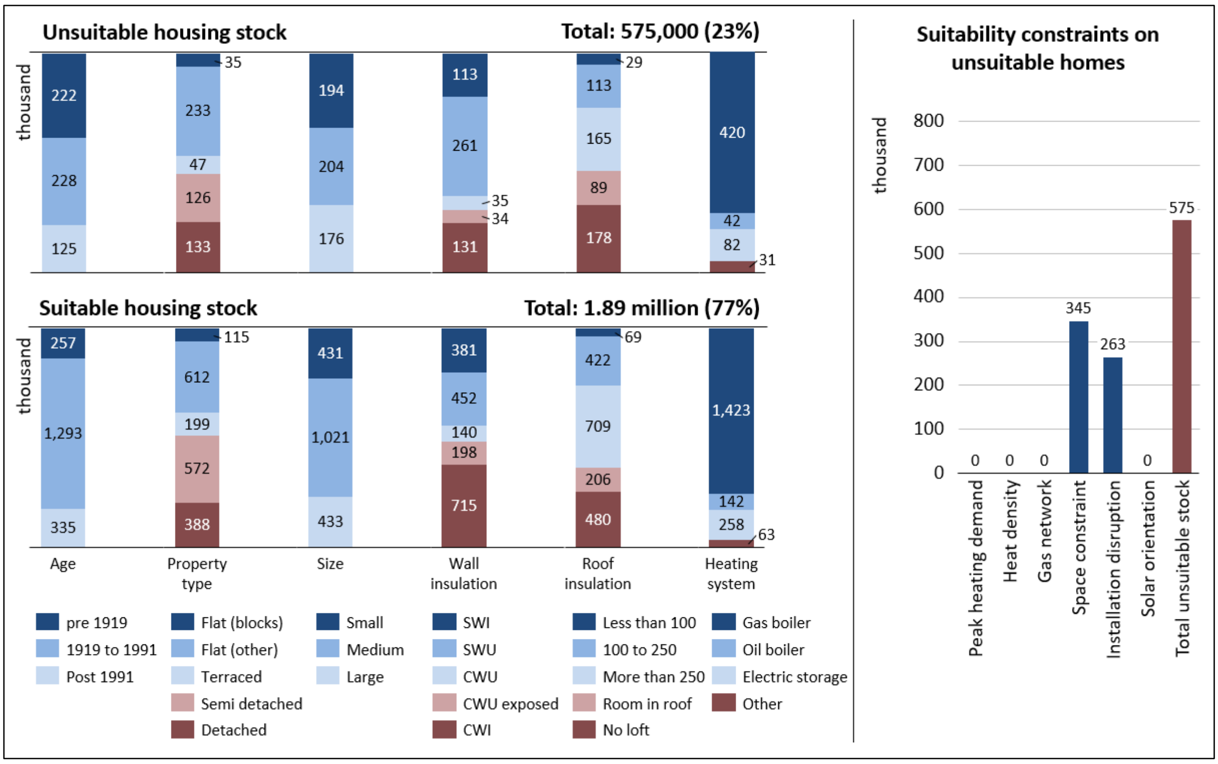


Figure 5: Stock suitability for high-temperature ASHP, considering fuse limit of 80A and peak specific heating demand of 120 W/m^2 in 2017

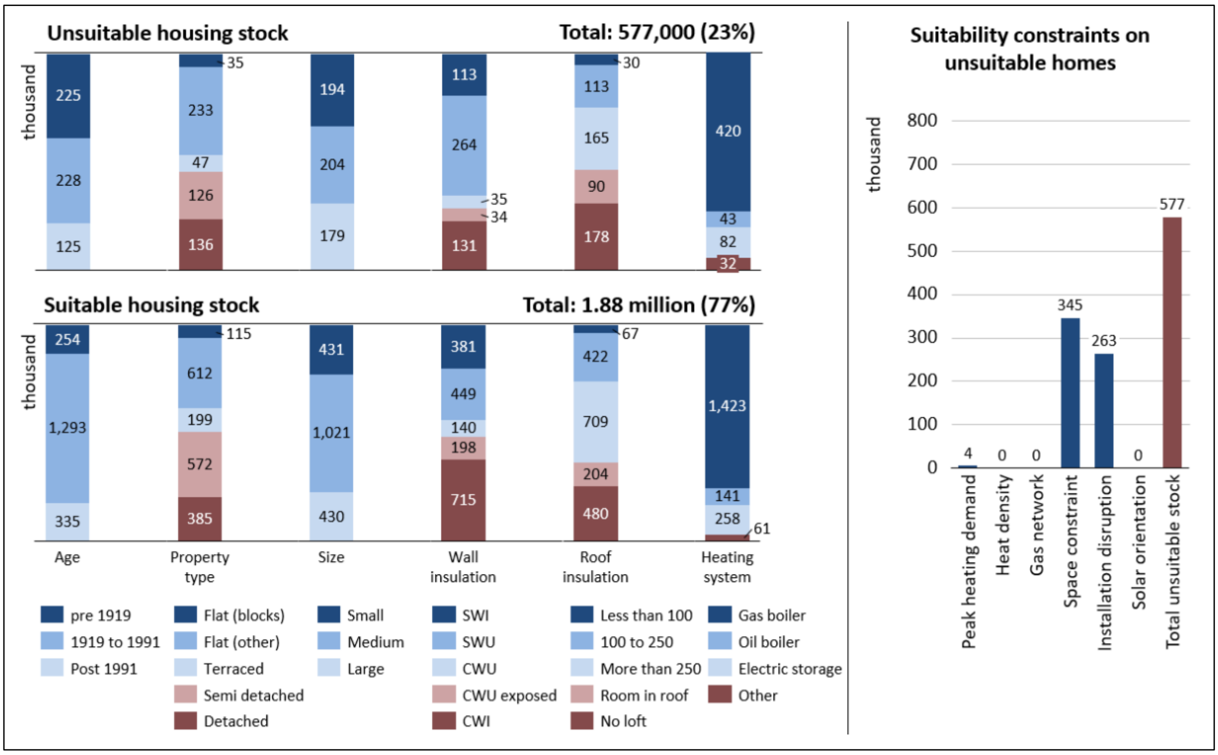
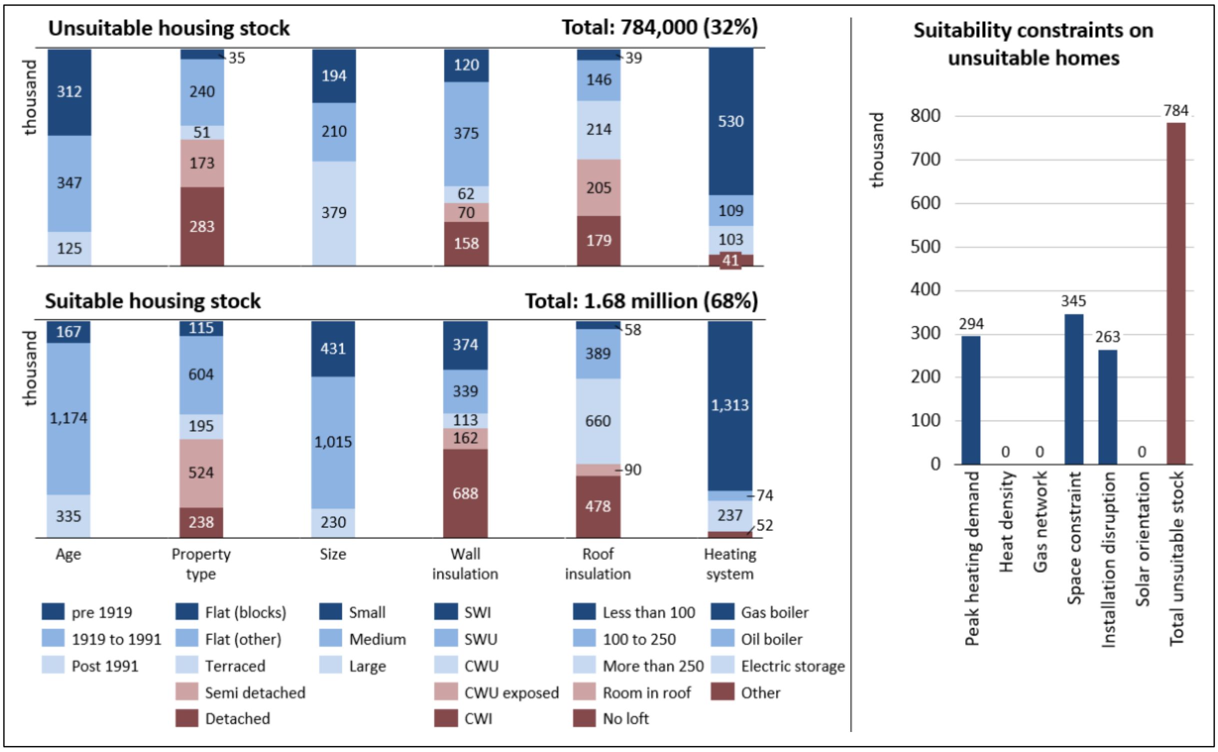


Figure 6: Stock suitability for high-temperature ASHP, considering fuse limit of 60A and peak specific heating demand of 100 W/m^2 in 2017



1.4 Communal ASHP

Figure 7: Stock suitability for communal ASHP, considering fuse limit of 100A and peak specific heating demand of 150 W/m^2 in 2017

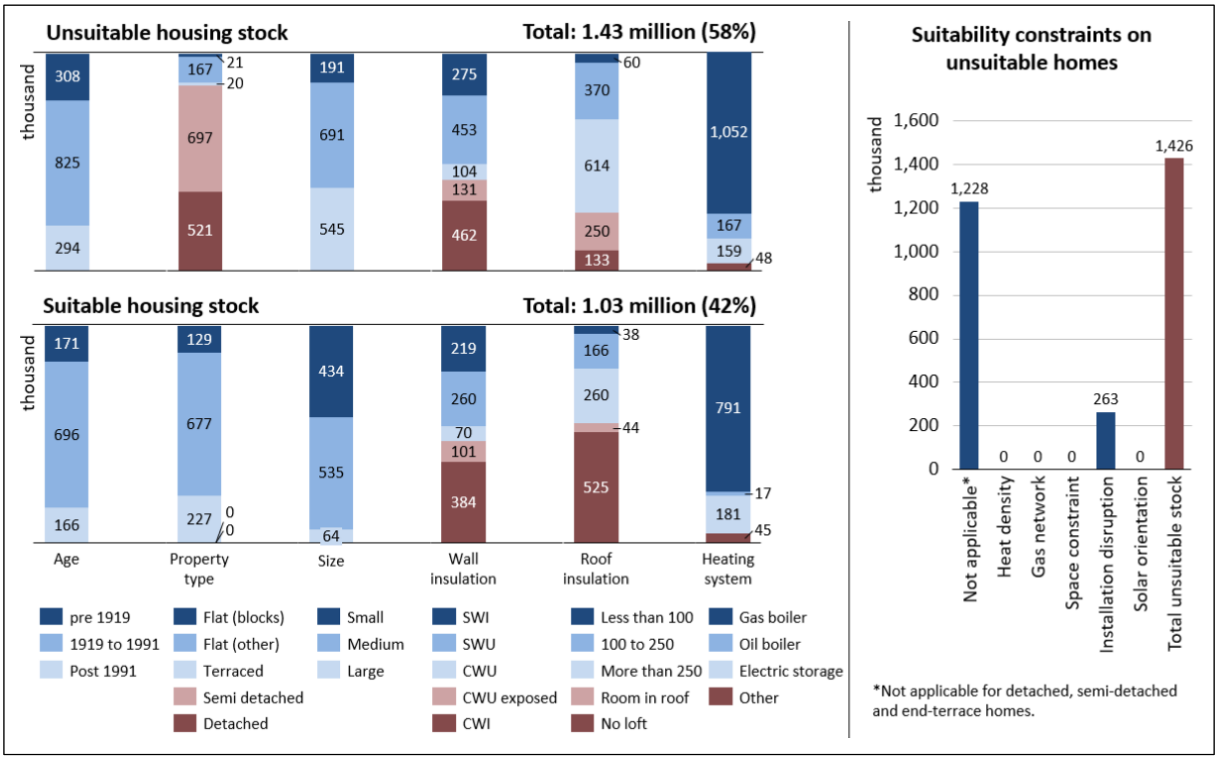


Figure 8: Stock suitability for communal ASHP, considering fuse limit of 80A and peak specific heating demand of 120 W/m^2 in 2017

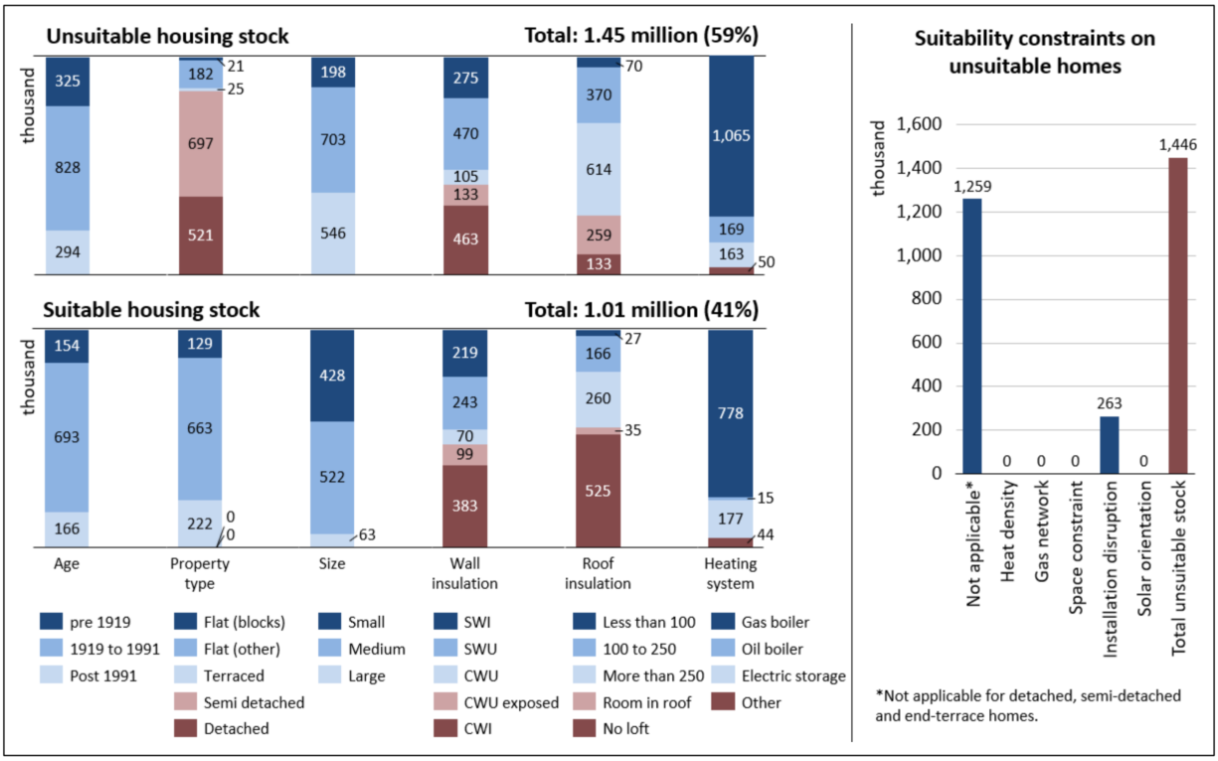
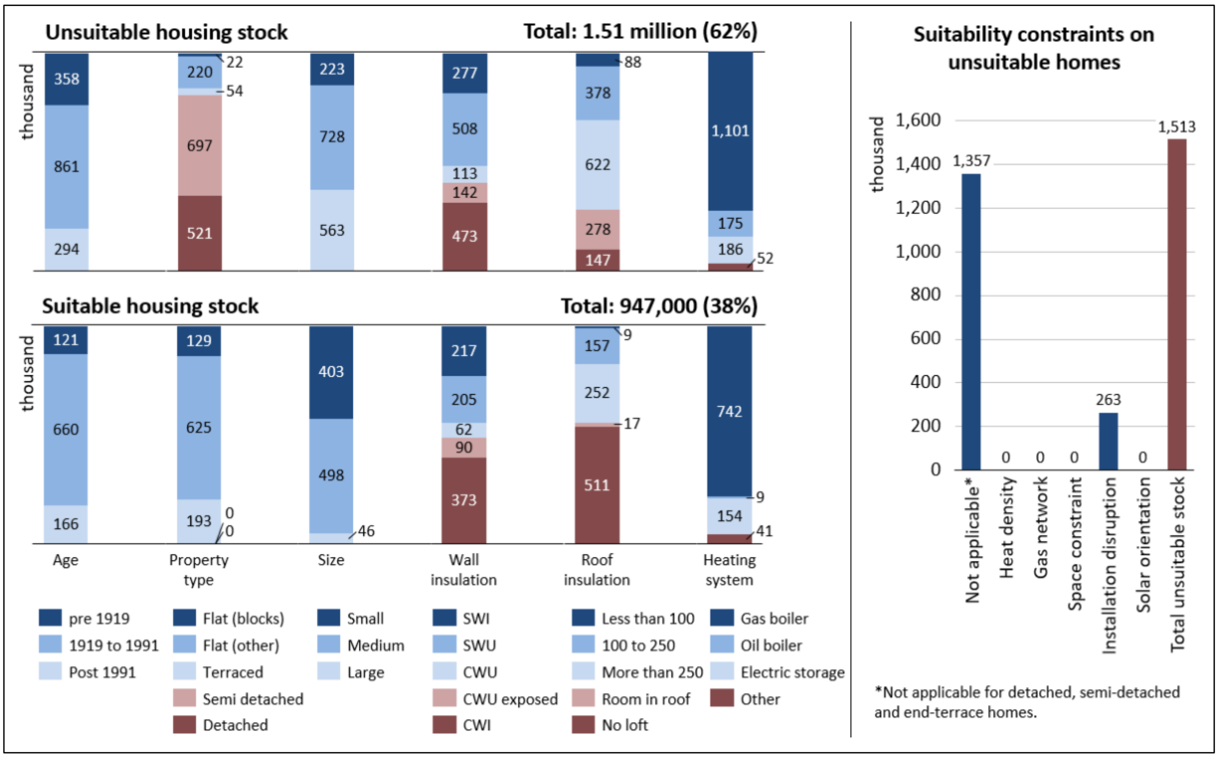


Figure 9: Stock suitability for communal ASHP, considering fuse limit of 60A and peak specific heating demand of 100 W/m^2 in 2017



1.5 Electric storage heating

Figure 10: Stock suitability for electric storage heating, considering fuse limit of 100A in 2017

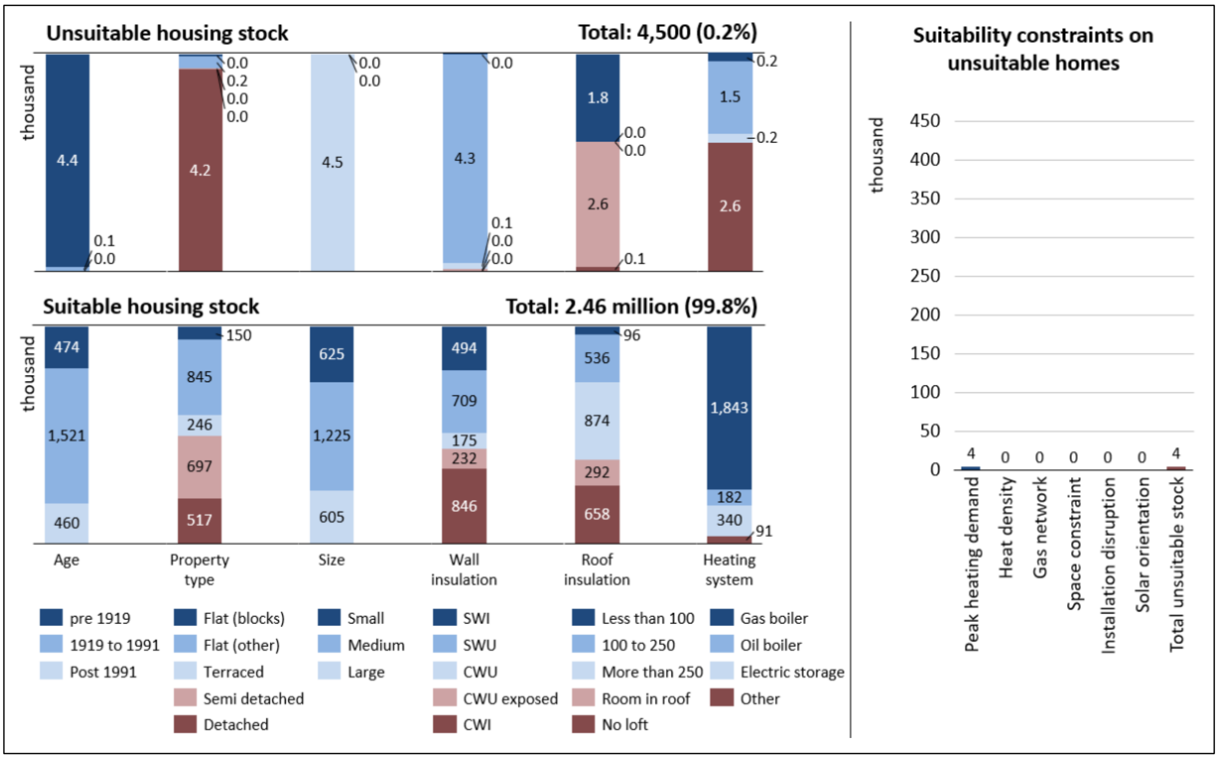


Figure 11: Stock suitability for electric storage heating, considering fuse limit of 80A in 2017

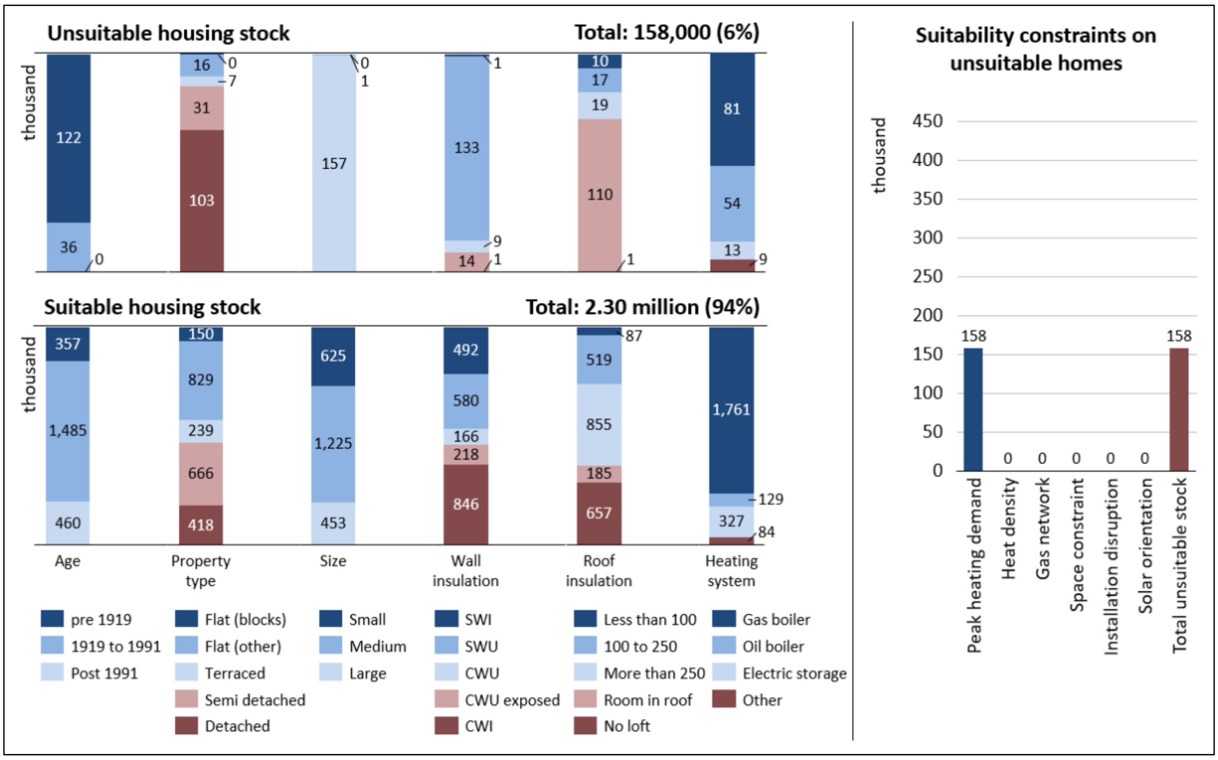
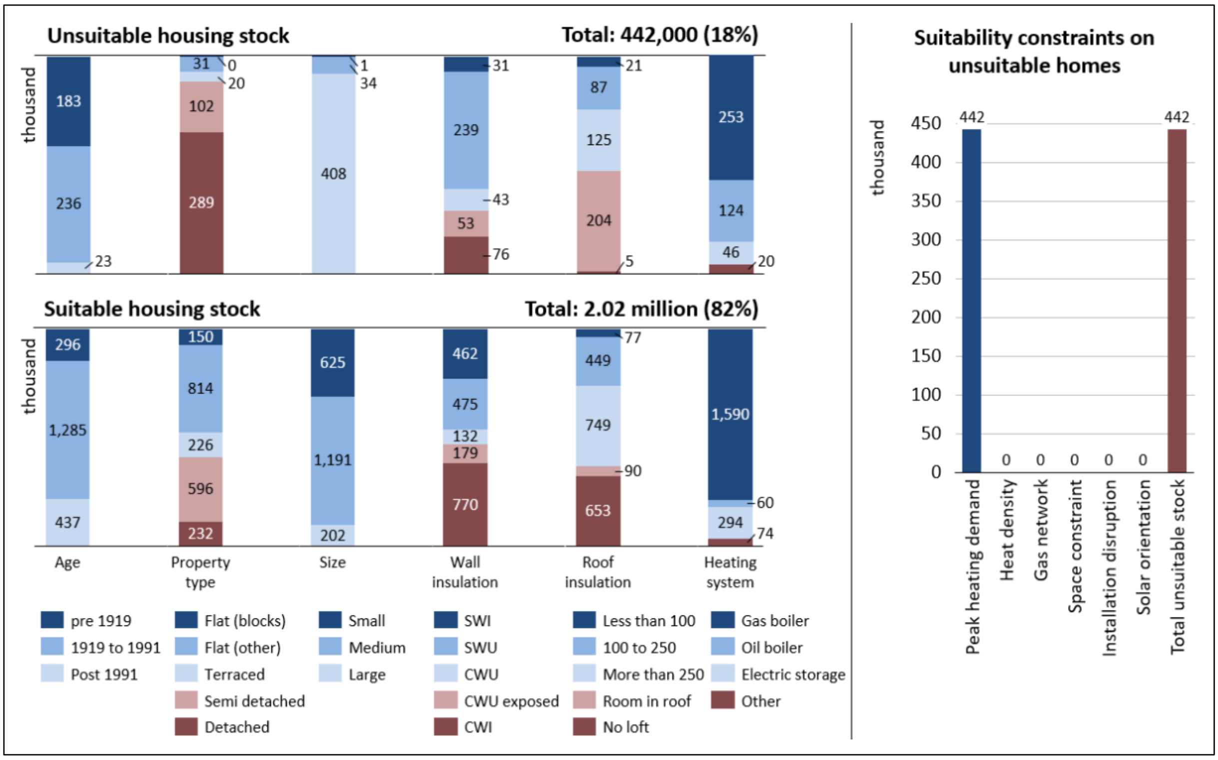


Figure 12: Stock suitability for electric storage heating, considering fuse limit of 60A in 2017



1.6 Direct electric heating

Figure 13: Stock suitability for direct electric heating, considering fuse limit of 100A in 2017

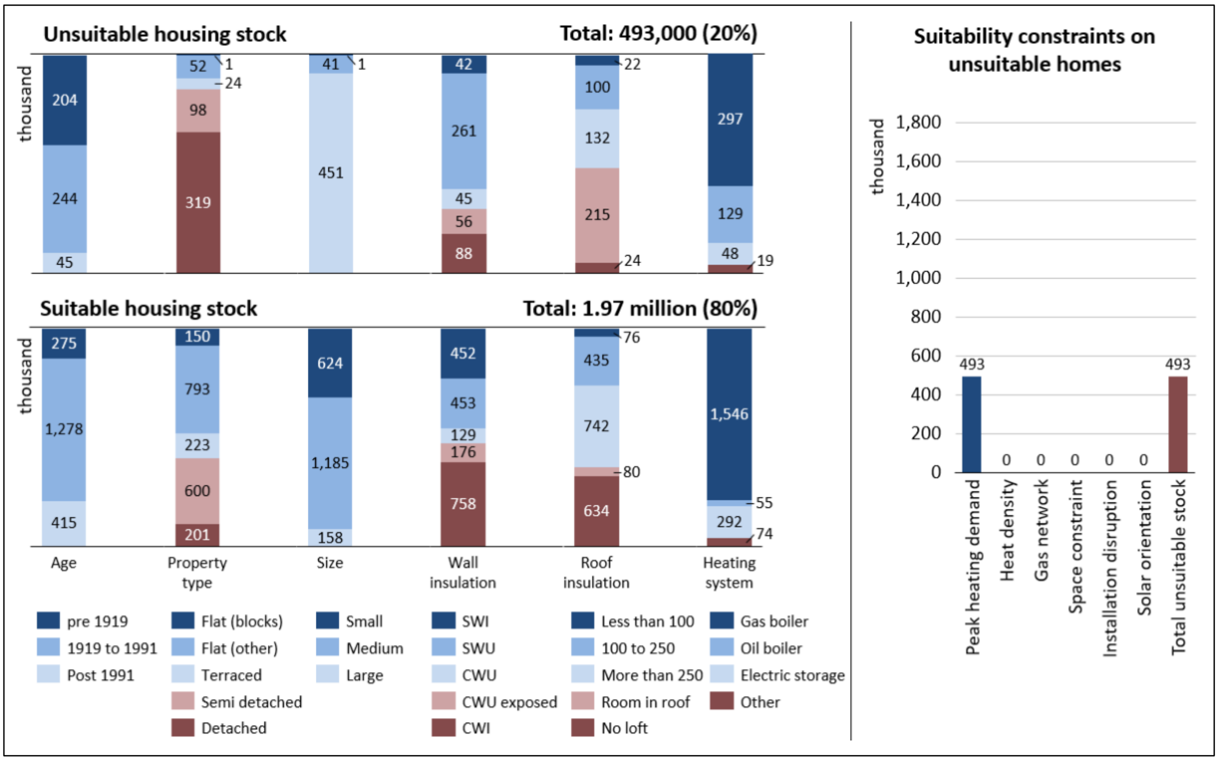


Figure 14: Stock suitability for direct electric heating, considering fuse limit of 80A in 2017

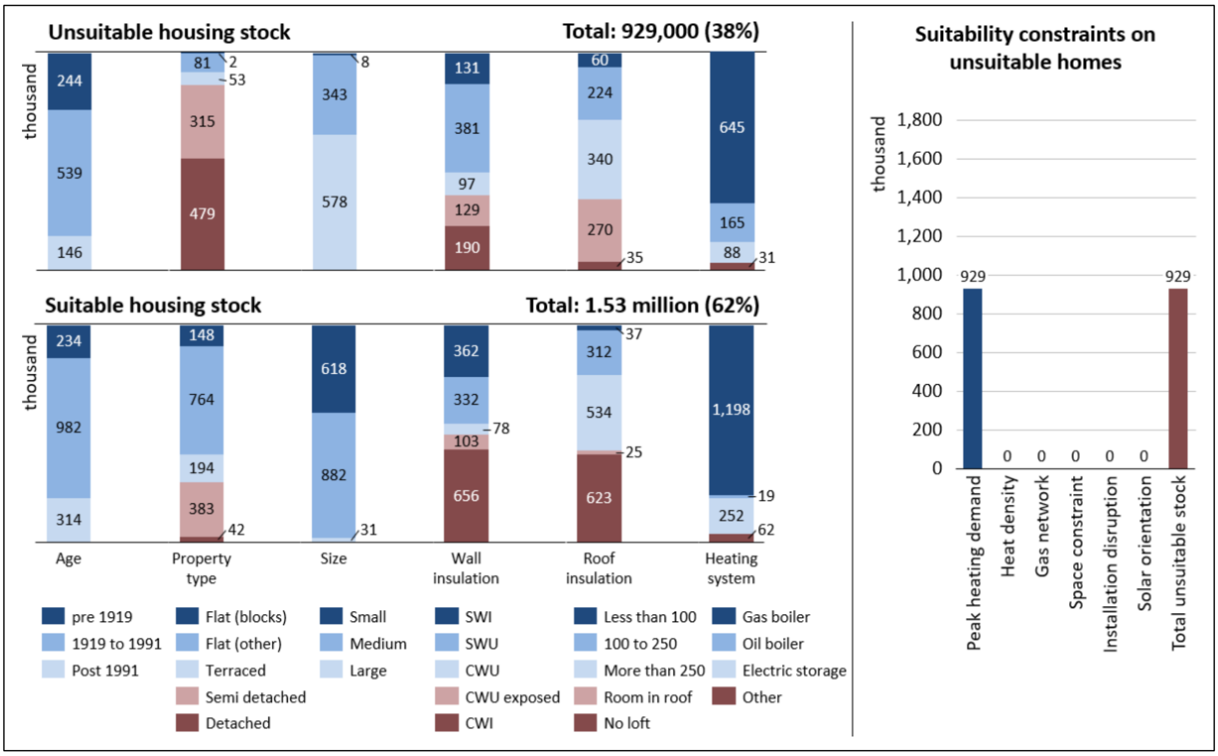
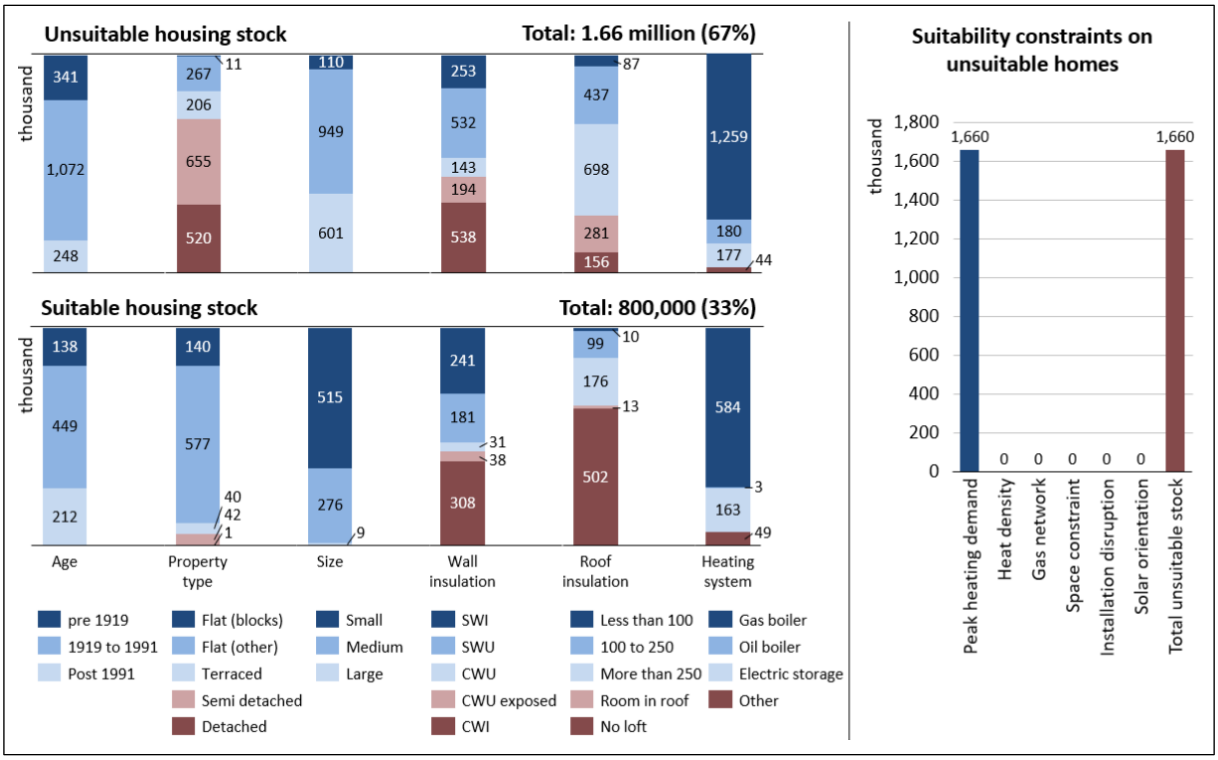


Figure 15: Stock suitability for direct electric heating, considering fuse limit of 60A in 2017



1.7 Electric boilers

Figure 16: Stock suitability for electric boilers, considering fuse limit of 100A in 2017

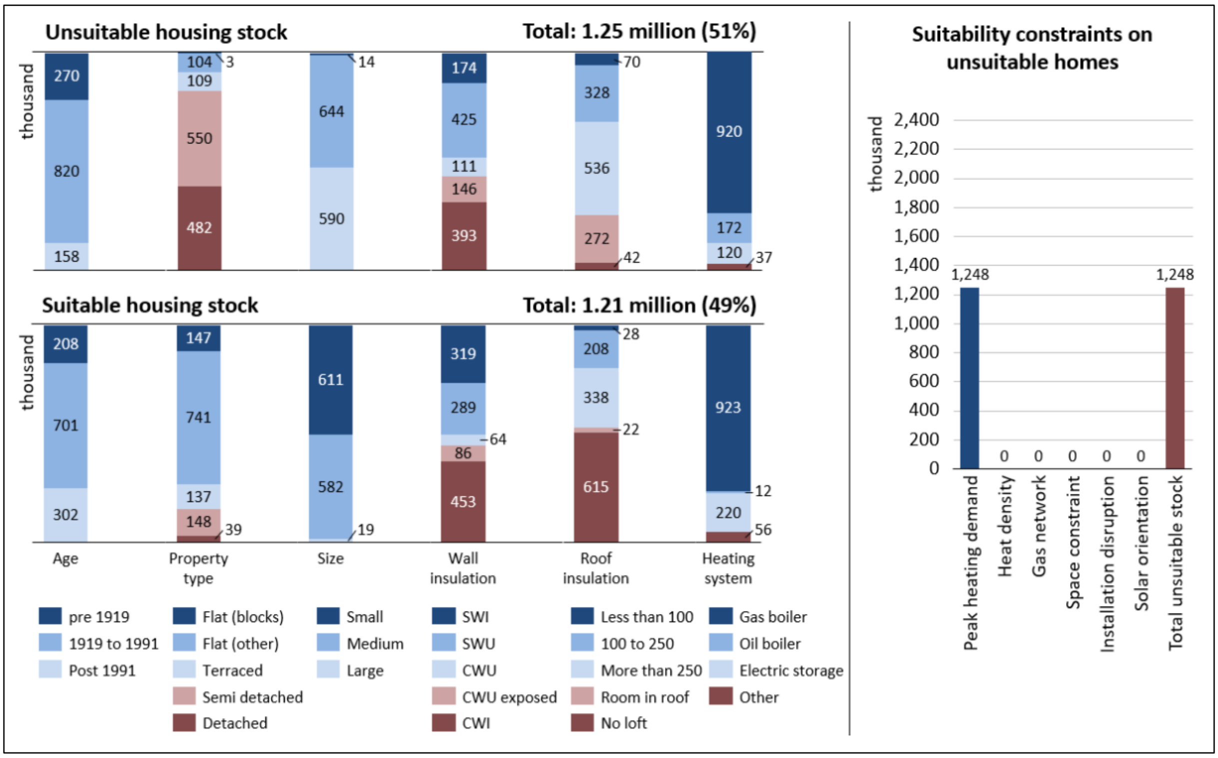


Figure 17: Stock suitability for electric boilers, considering fuse limit of 80A in 2017

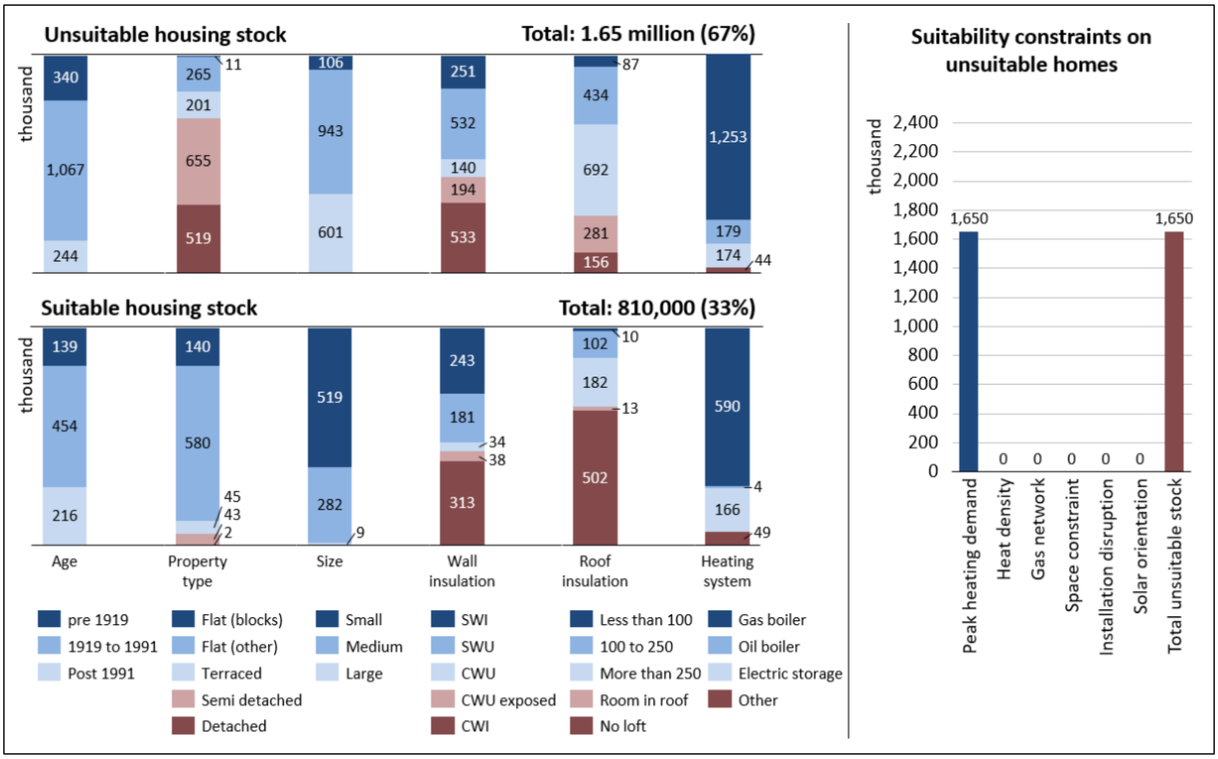
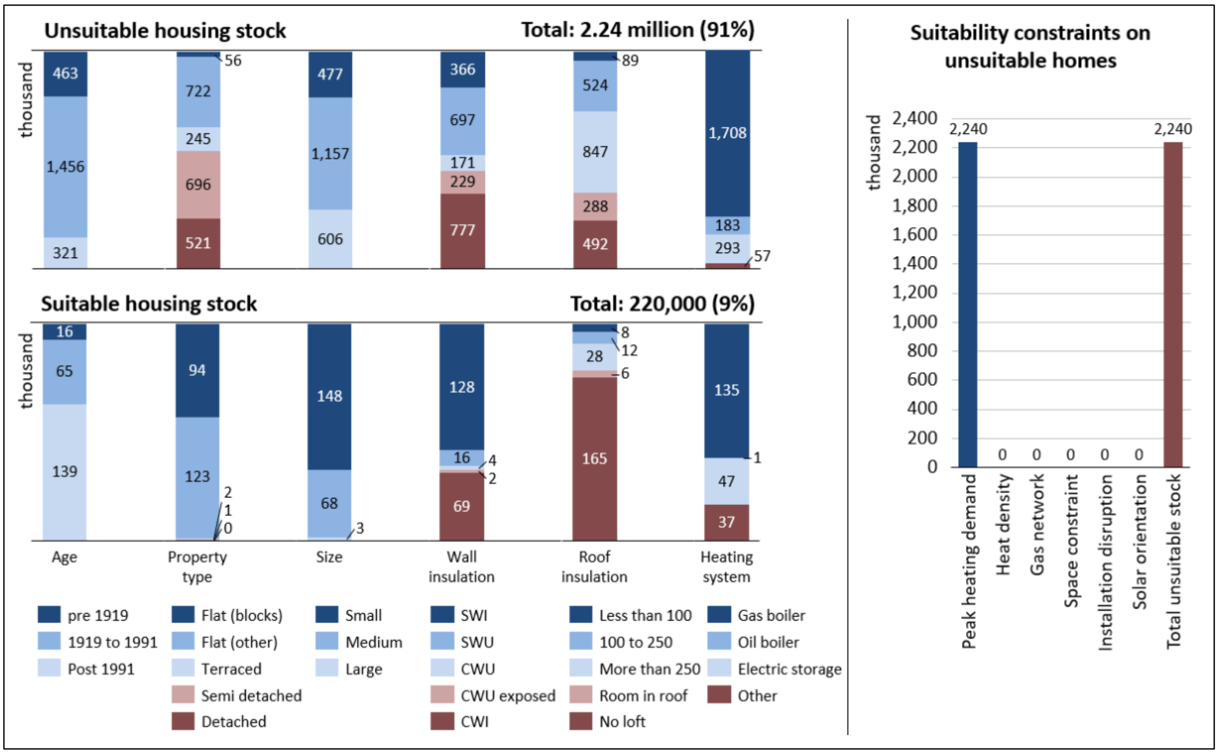
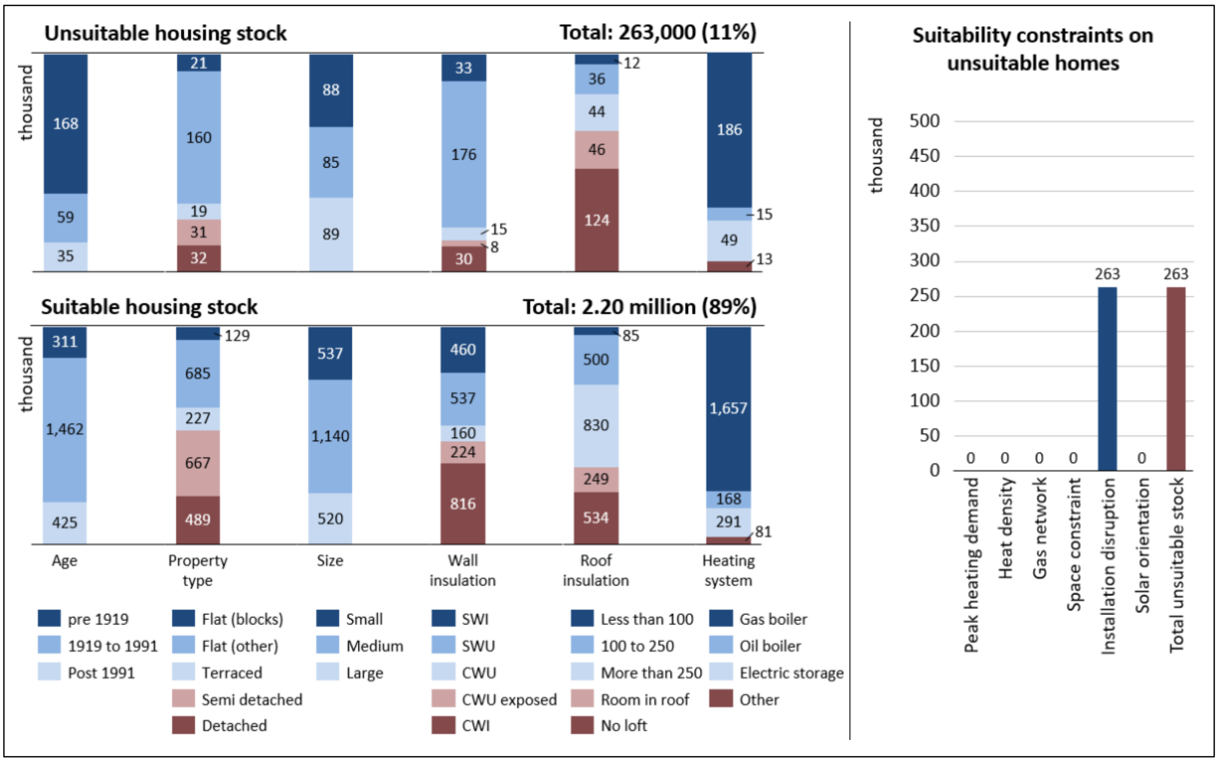


Figure 18: Stock suitability for electric boilers, considering fuse limit of 60A in 2017



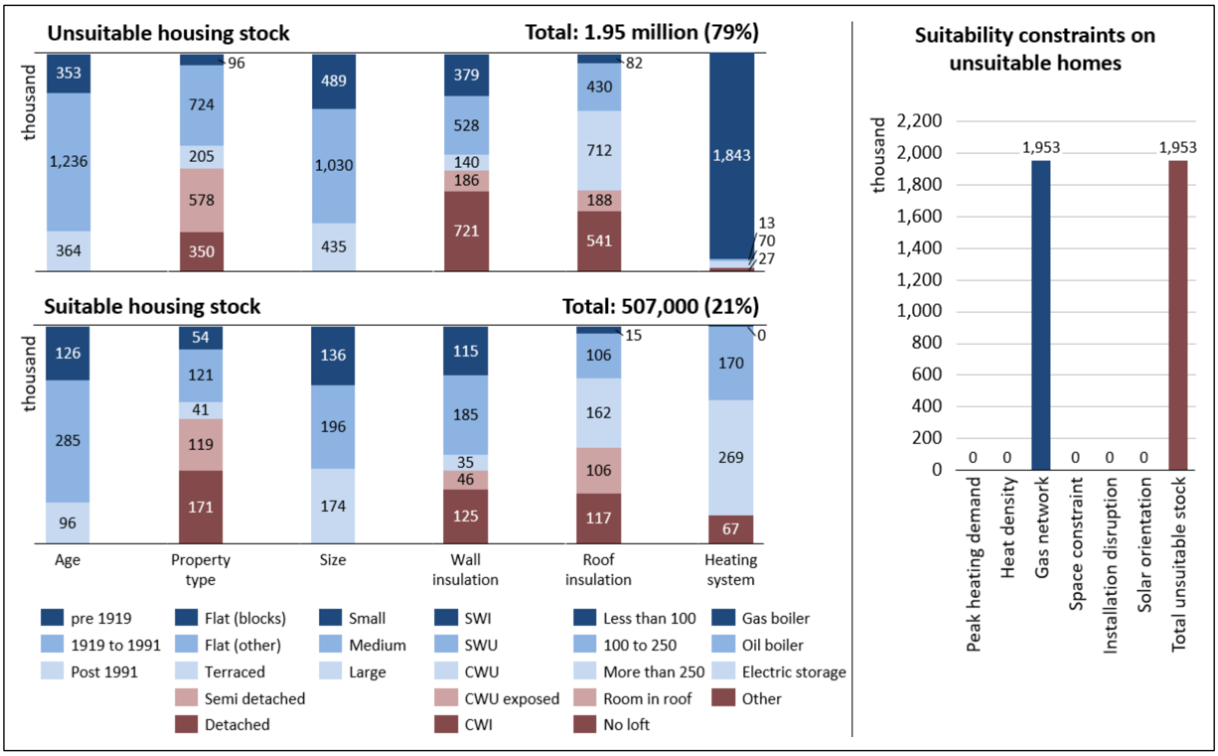
1.8 Solid biomass boilers

Figure 19: Stock suitability for solid biomass boilers in 2017



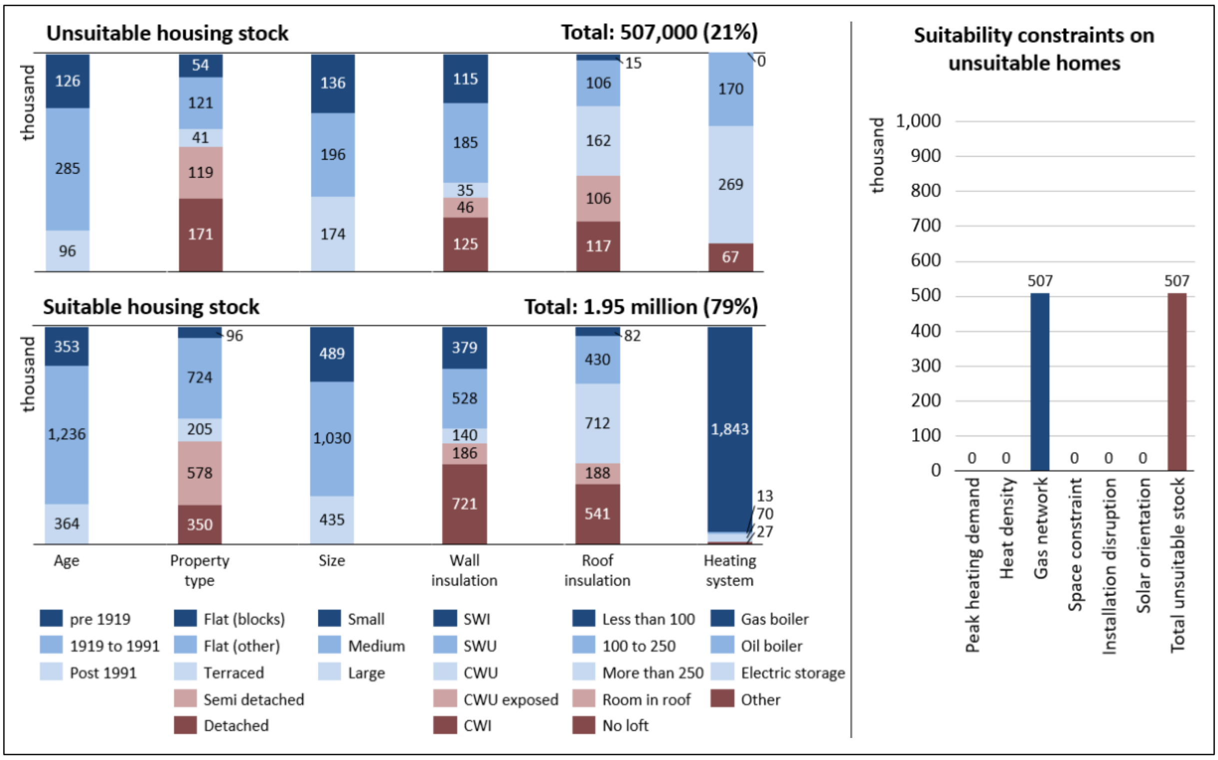
1.9 BioLPG boilers and bioliquid boilers

Figure 20: Stock suitability for bioLPG boilers and bioliquid boilers in 2017



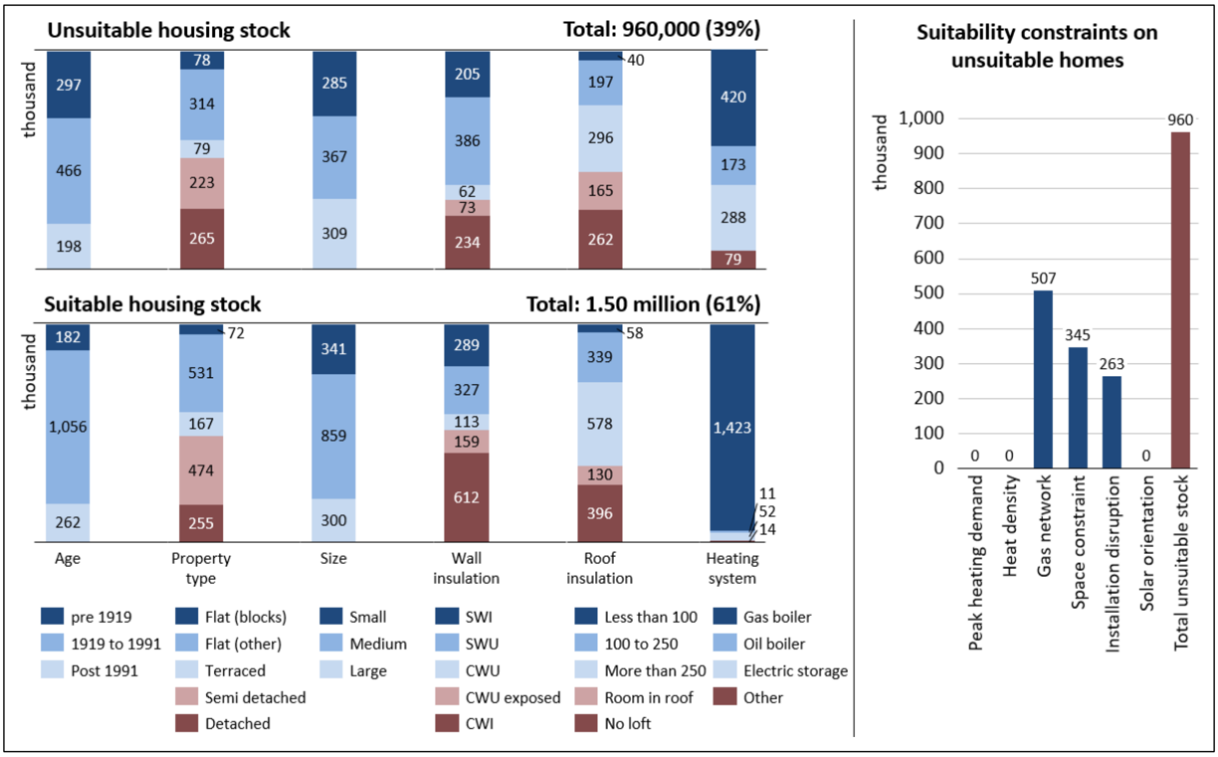
1.10 Hydrogen boilers and biomethane grid injection

Figure 21: Stock suitability for hydrogen boilers and biomethane grid injection in 2017



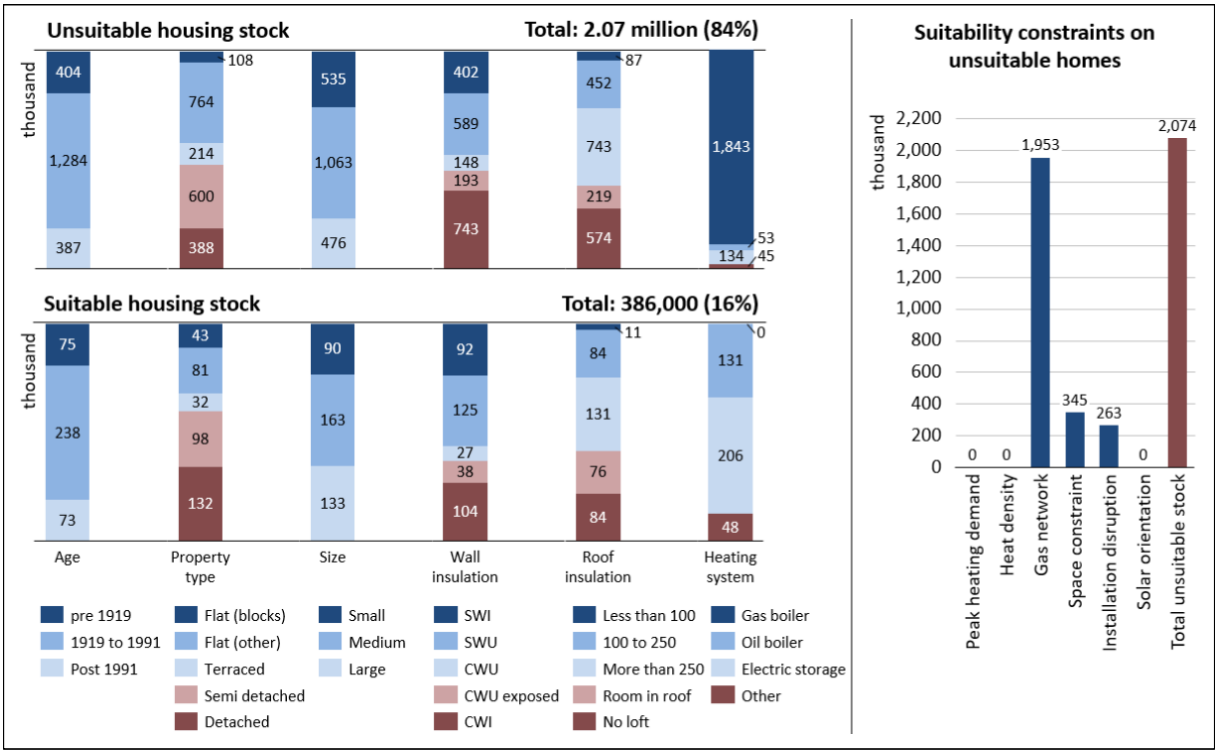
1.11 Hybrid heat pumps with gas boilers or hydrogen boilers

Figure 22: Stock suitability for hybrid heat pumps with gas boilers or hydrogen boilers in 2017



1.12 Hybrid heat pumps with bioliquid

Figure 23: Stock suitability for hybrid heat pumps with bioliquid boilers in 2017



1.13 Hybrid heat pumps with direct electric heating

Figure 24: Stock suitability for hybrid heat pumps with direct electric heating, considering fuse limit of 100A in 2017

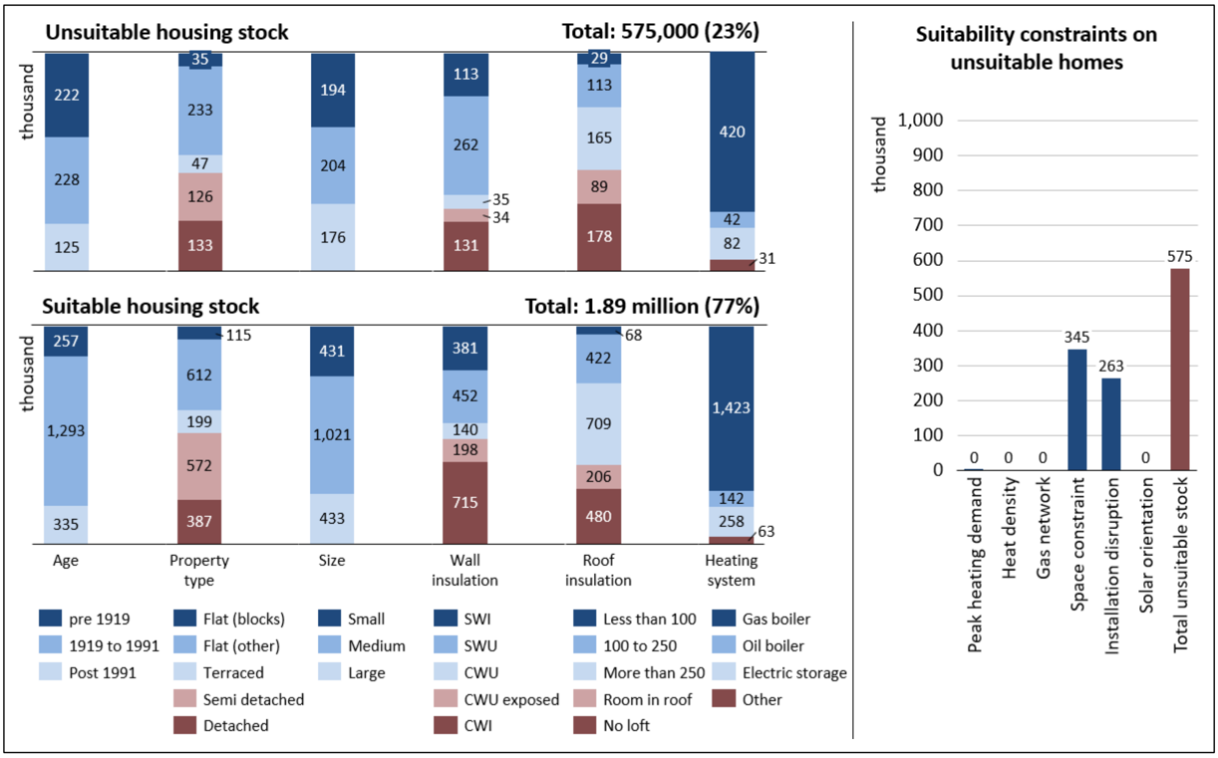


Figure 25: Stock suitability for hybrid heat pumps with direct electric heating, considering fuse limit of 80A in 2017

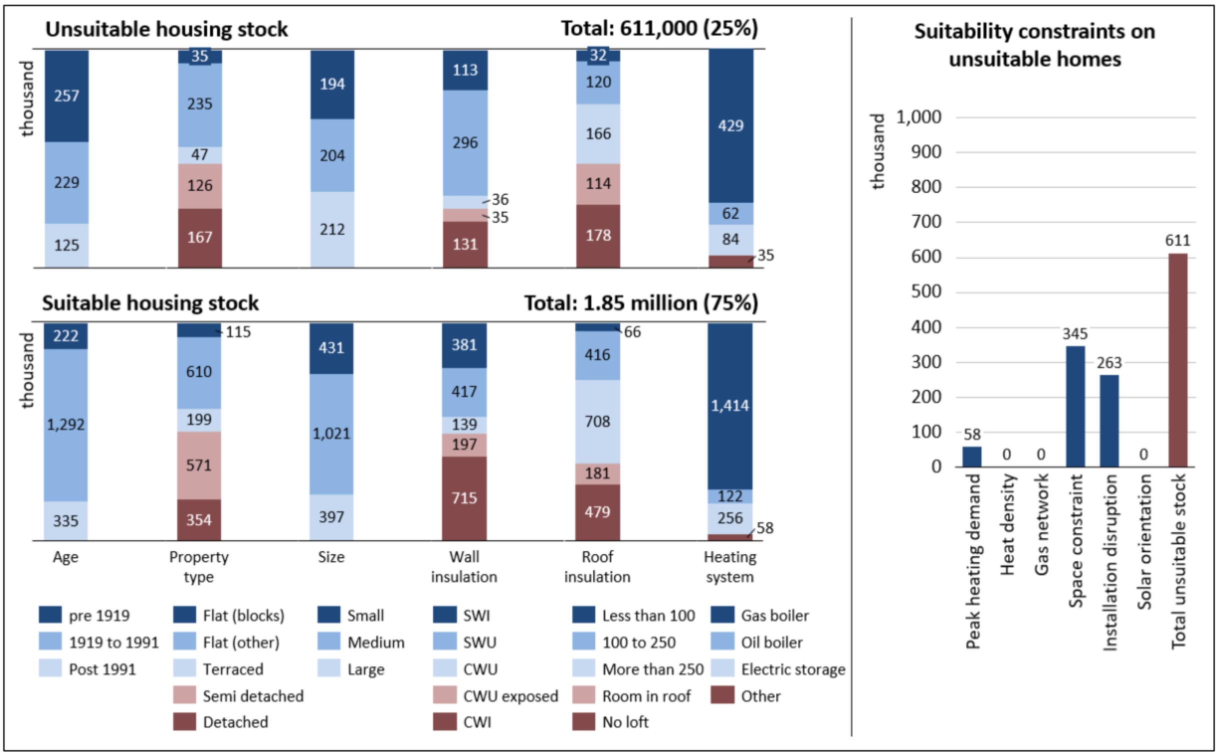
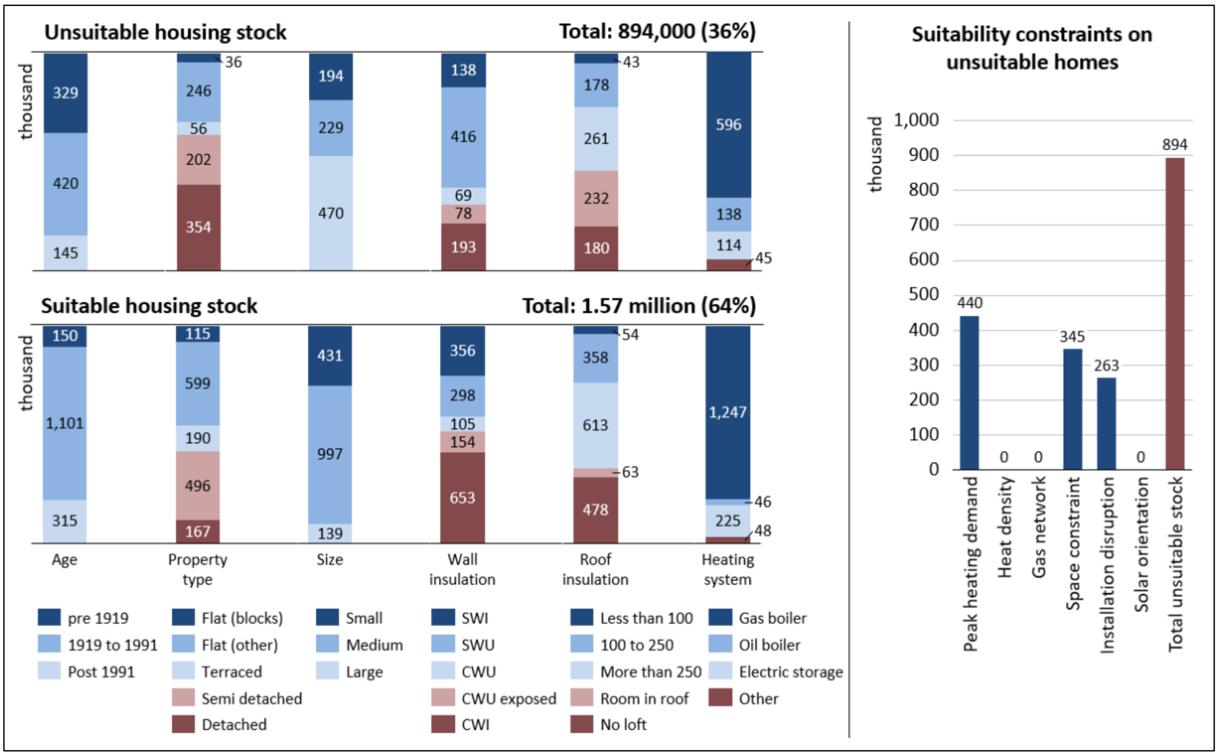
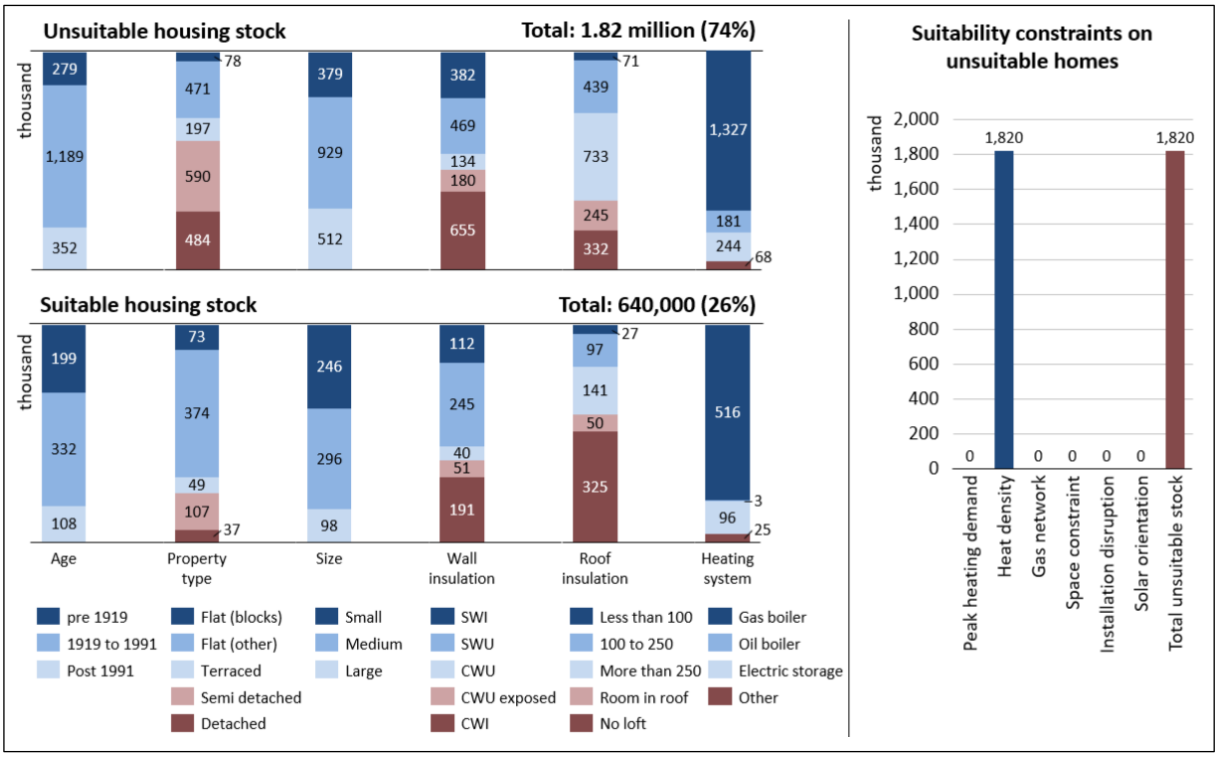


Figure 26: Stock suitability for hybrid heat pumps with direct electric heating, considering fuse limit of 60A in 2017



1.14 District heating

Figure 27: Stock suitability for district heating in 2017



1.15 ASHP with solar thermal

Figure 28: Stock suitability for ASHP with solar thermal, considering fuse limit of 100A and peak specific heating demand of 150 W/m^2 in 2017

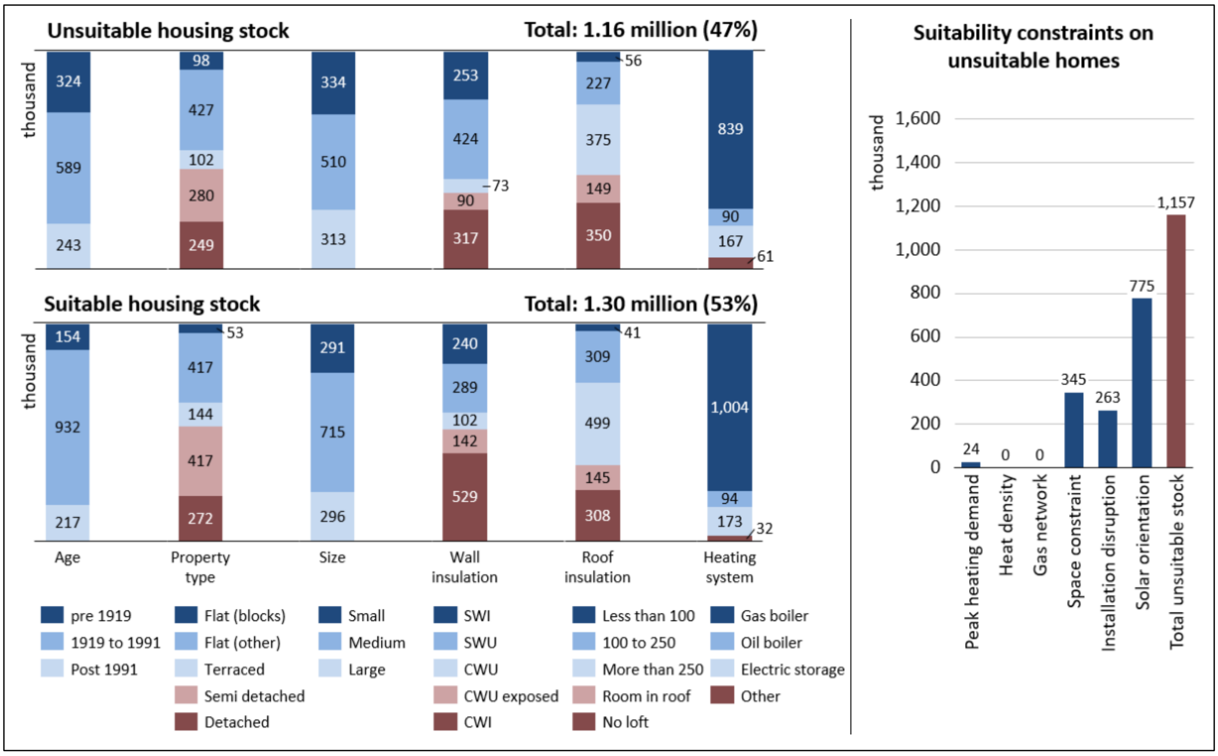


Figure 29: Stock suitability for ASHP with solar thermal, considering fuse limit of 80A and peak specific heating demand of 120 W/m² in 2017

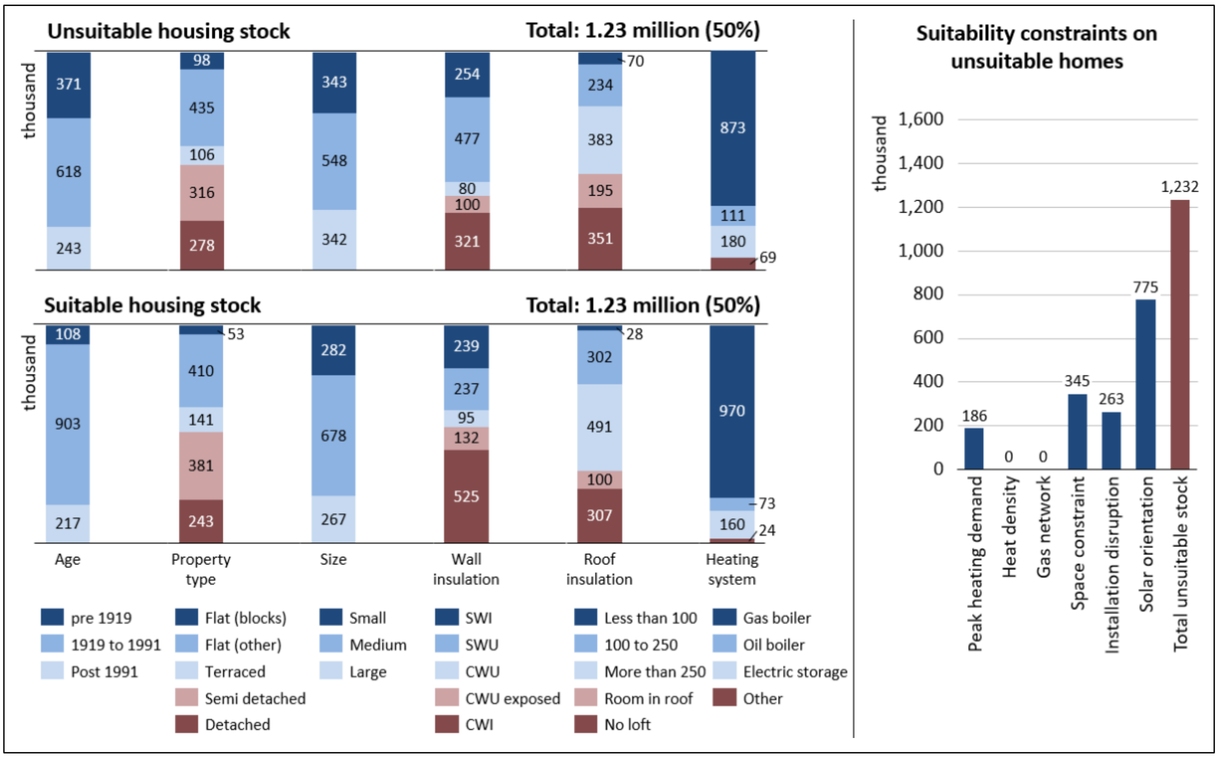
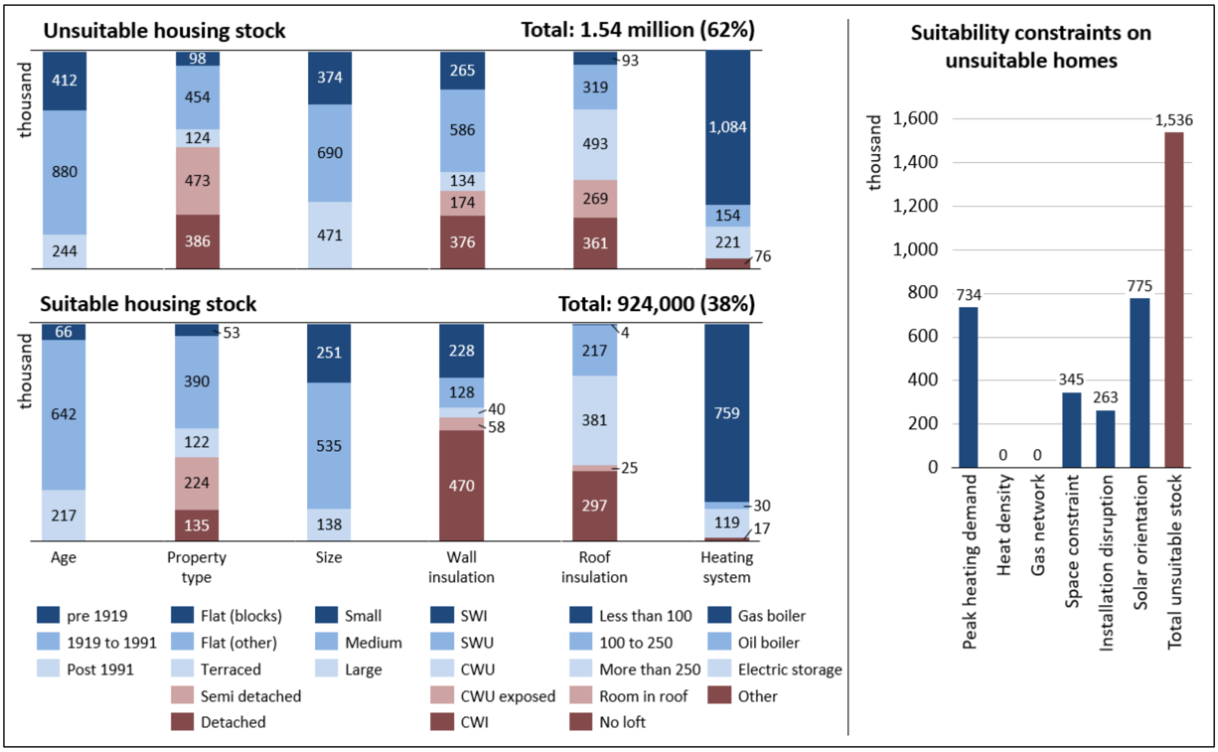


Figure 30: Stock suitability for ASHP with solar thermal, considering fuse limit of 60A and peak specific heating demand of 100 W/m² in 2017



1.16 Electric storage heating with solar thermal

Figure 31: Stock suitability for electric storage heating with solar thermal, considering fuse limit of 100A in 2017

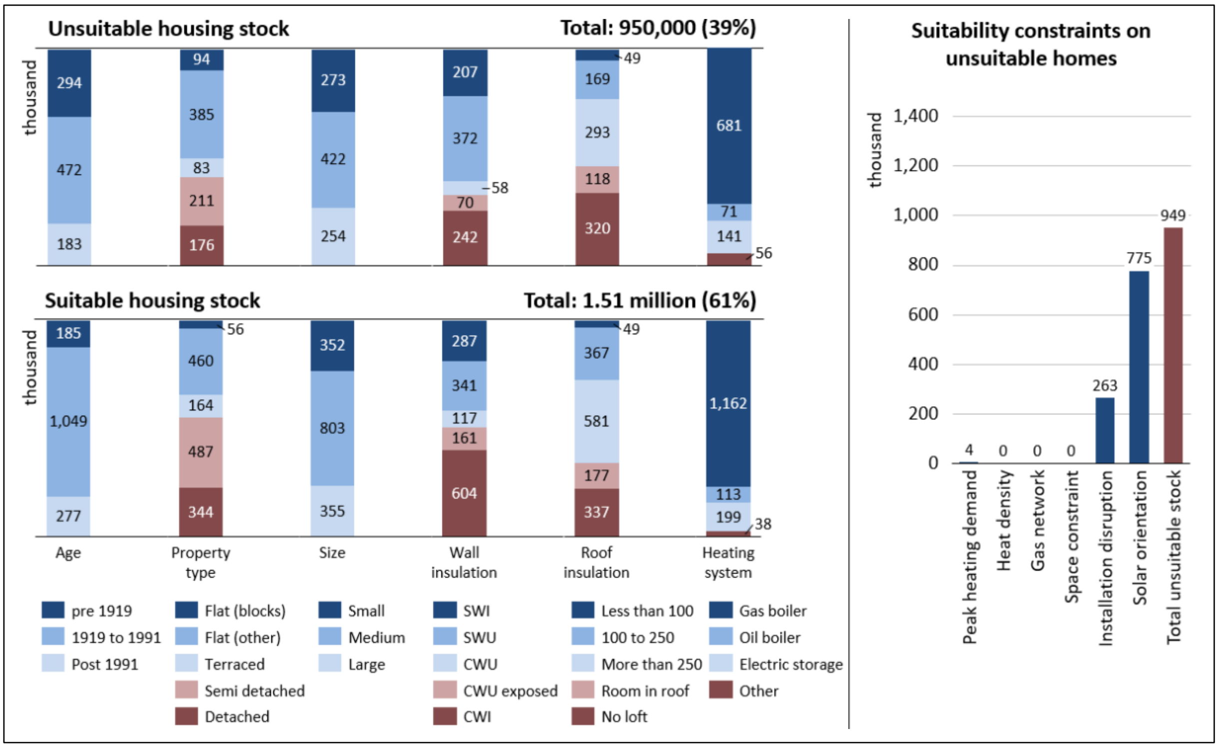


Figure 32: Stock suitability for electric storage heating with solar thermal, considering fuse limit of 80A in 2017

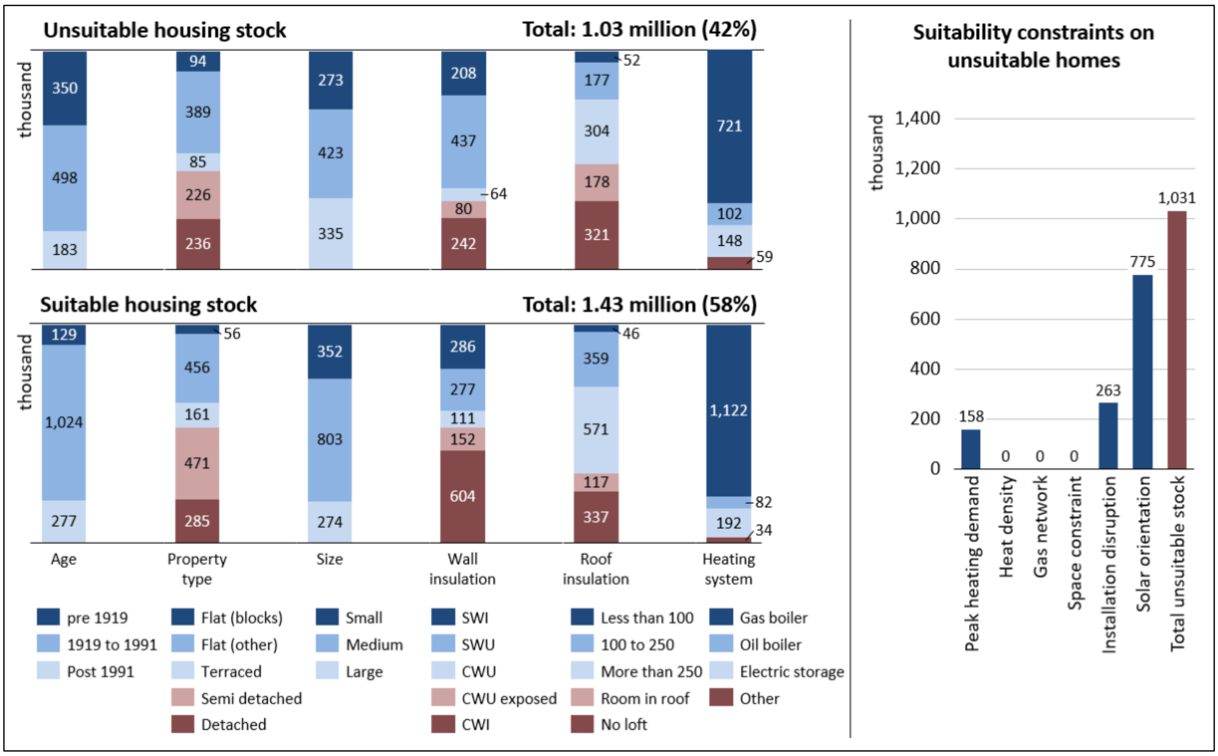
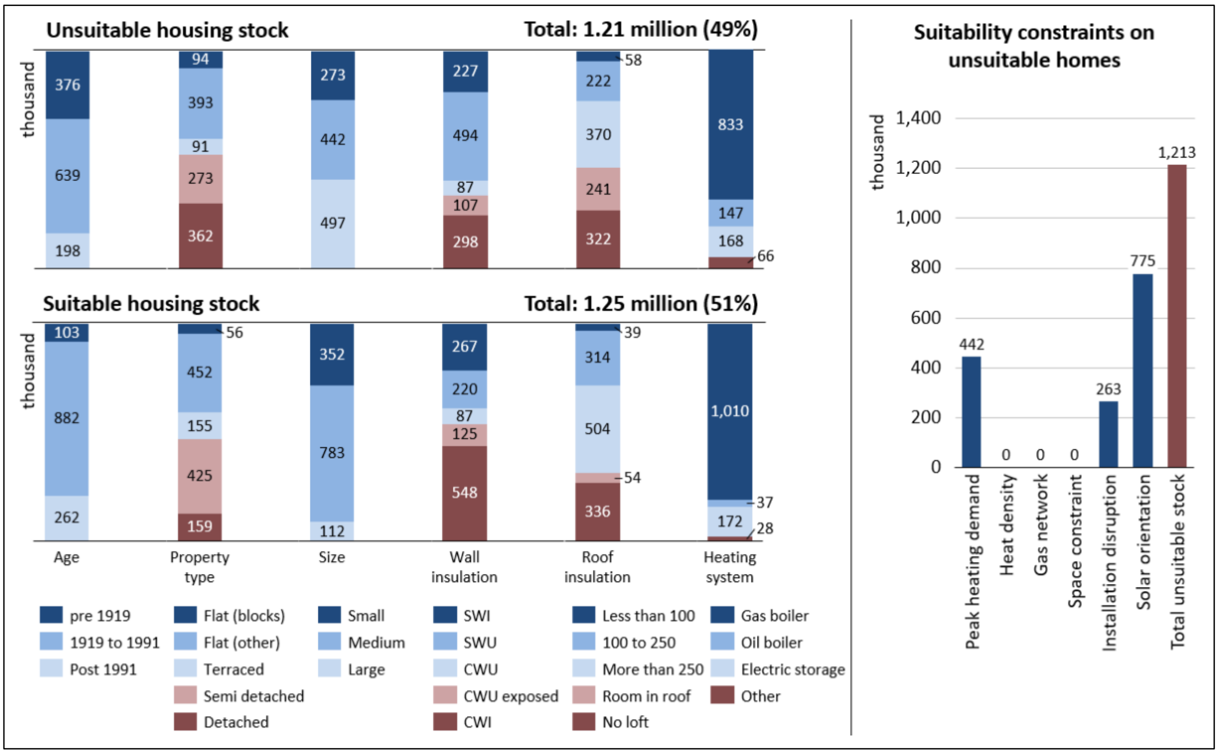


Figure 33: Stock suitability for electric storage heating with solar thermal, considering fuse limit of 60A in 2017



1.17 Direct electric heating with solar thermal

Figure 34: Stock suitability for direct electric heating with solar thermal, considering fuse limit of 100A in 2017

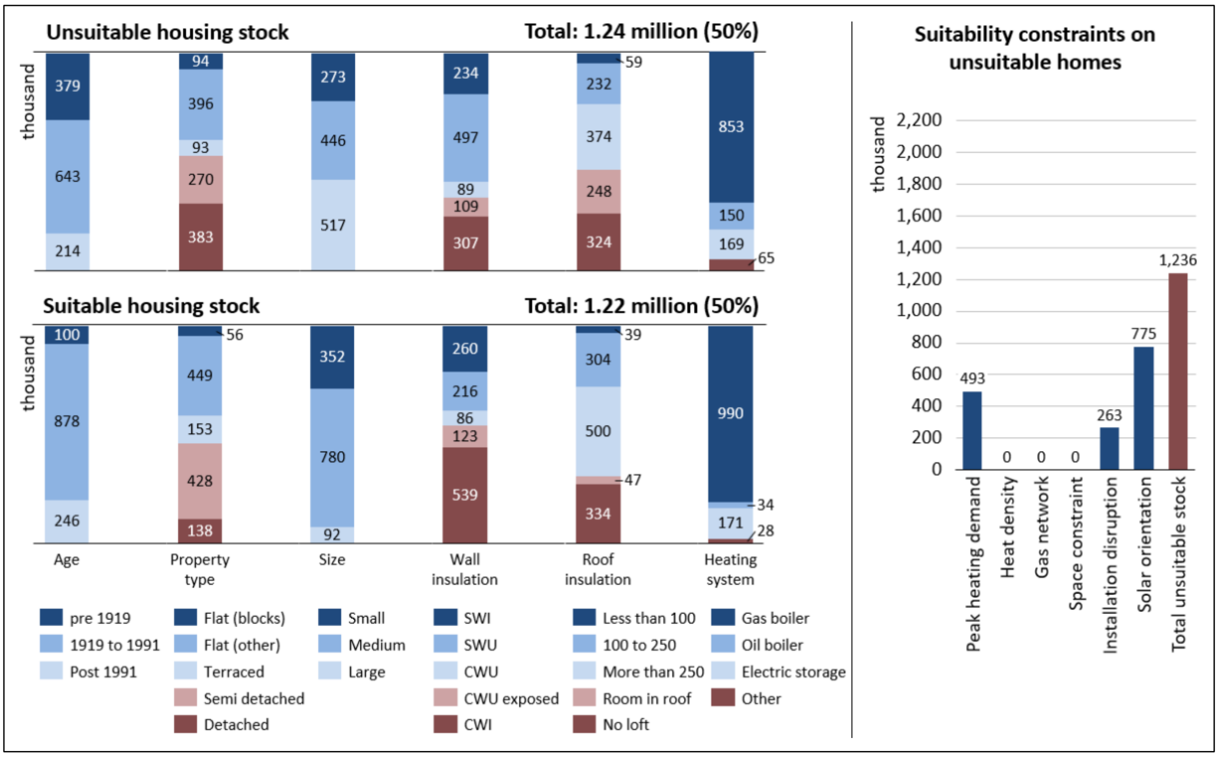


Figure 35: Stock suitability for direct electric heating with solar thermal, considering fuse limit of 80A in 2017

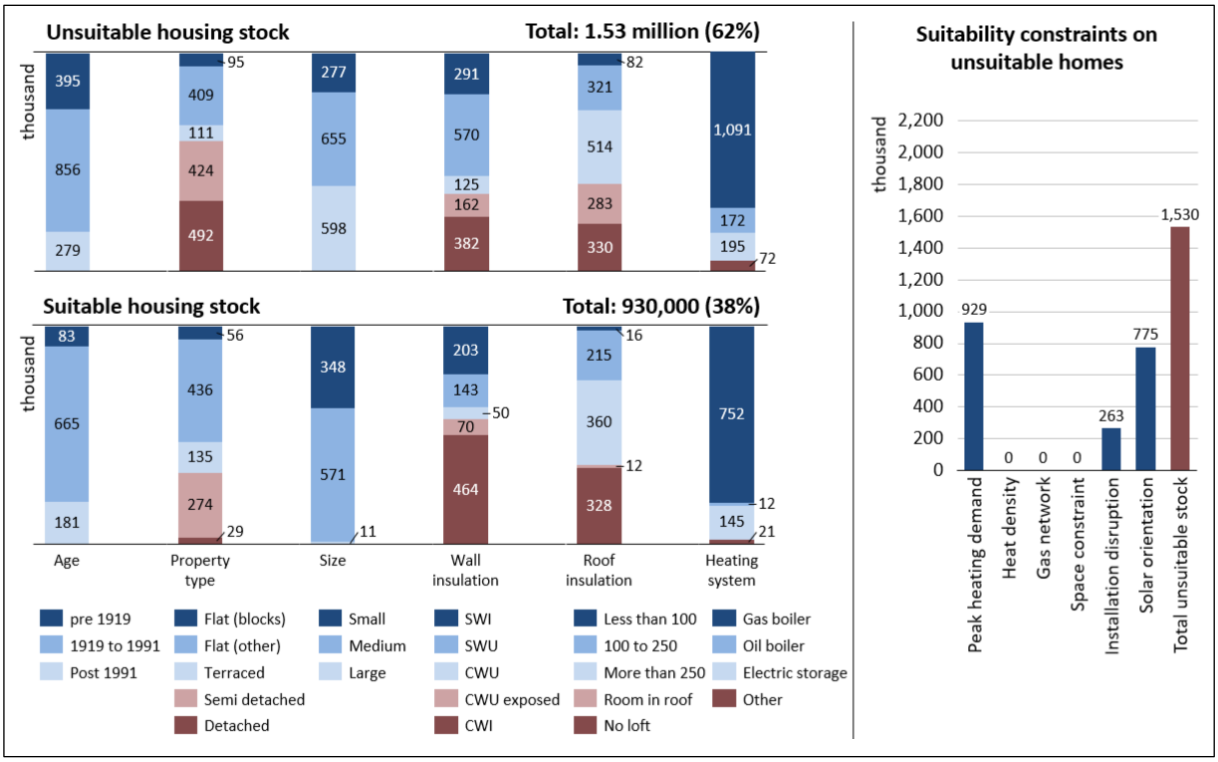
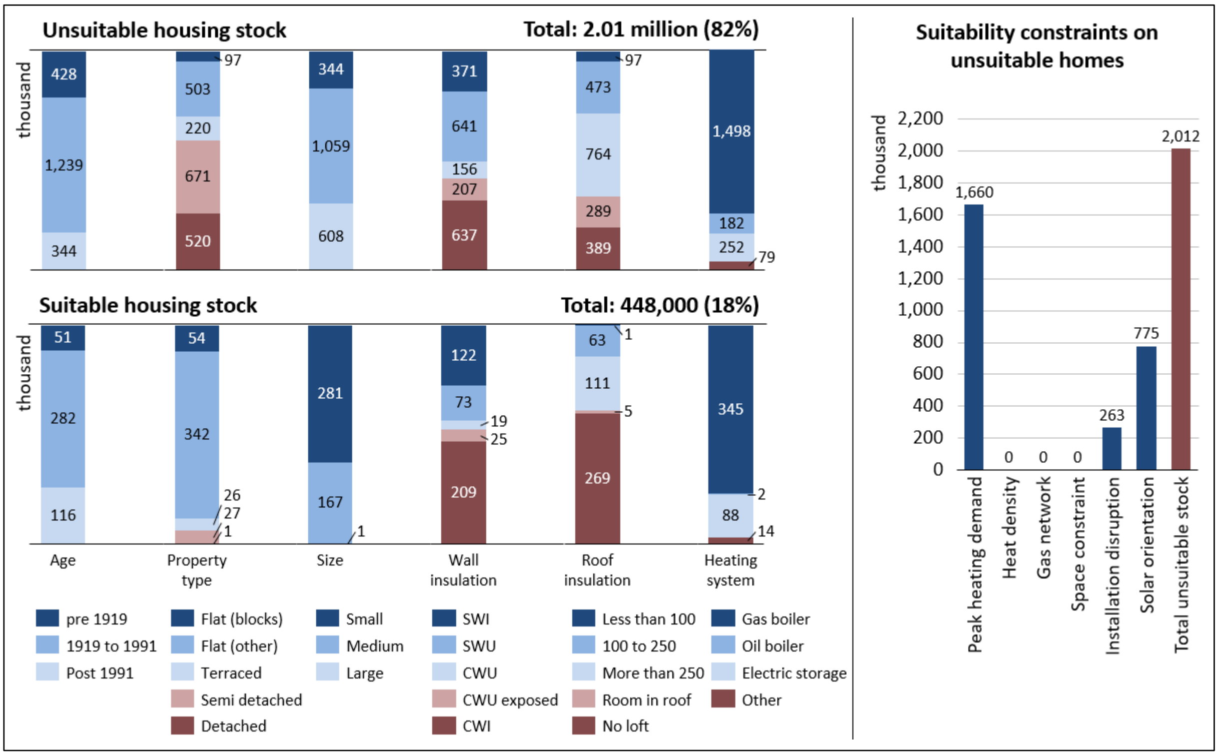


Figure 36: Stock suitability for direct electric heating with solar thermal, considering fuse limit of 60A in 2017



1.18 Electric boilers with solar thermal

Figure 37: Stock suitability for electric boilers with solar thermal, considering fuse limit of 100A in 2017

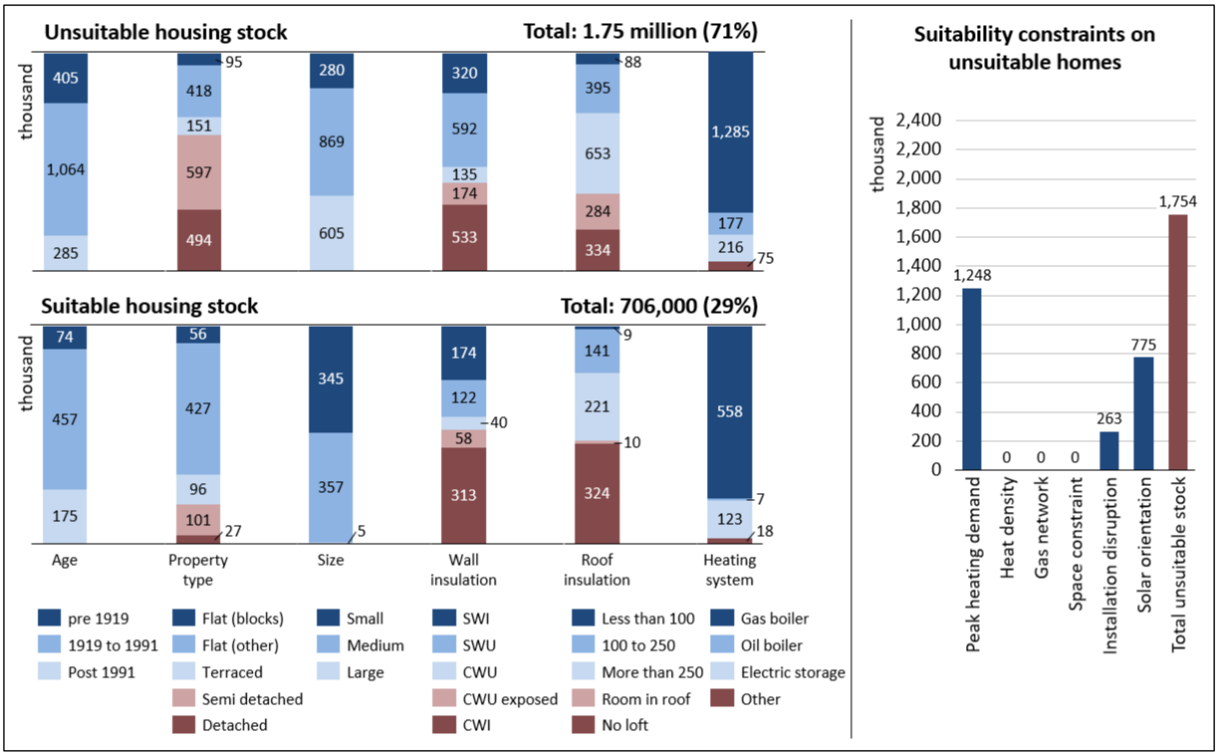


Figure 38: Stock suitability for electric boilers with solar thermal, considering fuse limit of 80A in 2017

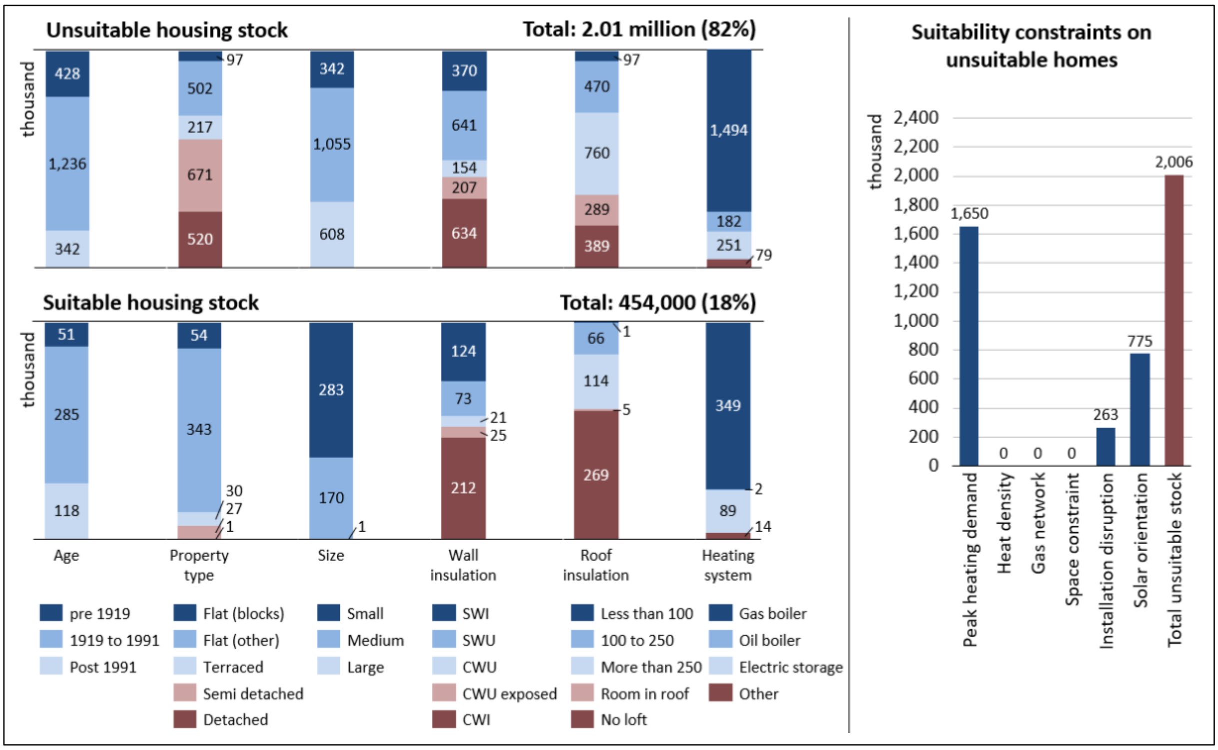
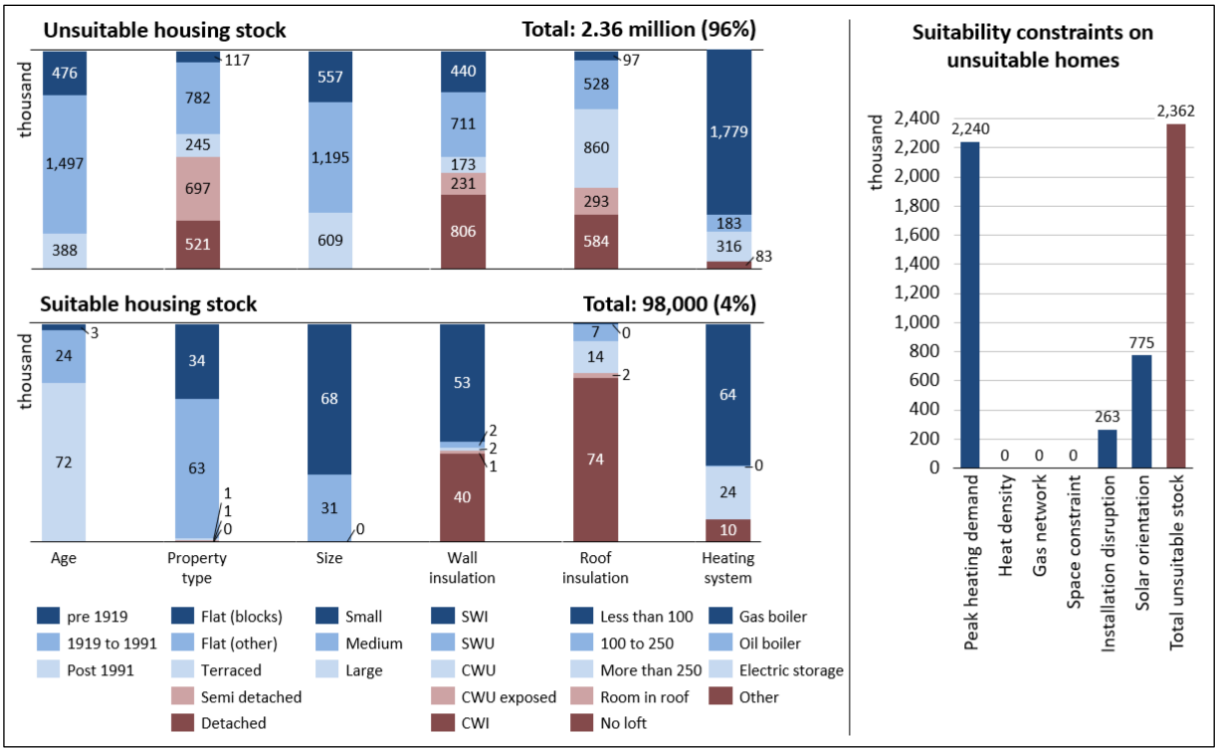


Figure 39: Stock suitability for electric boilers with solar thermal, considering fuse limit of 60A in 2017



2 Suitability of the most common dwelling archetypes for low-carbon heating technologies

The suitability of 20 of the most common dwelling archetypes for the considered low-carbon heating technologies was also investigated individually.

The selected archetypes include the 19 most populated archetypes, ranking highest in terms of the portion of the stock they represent. Additionally, the 22nd archetype was also considered, as this is the most populated archetype for which the counterfactual heating technology is electric heating.

The characteristics of the 20 selected archetypes are summarised in Table 2. These archetypes are relatively diversified in terms of dwelling type, size, age and insulation characteristics, but their counterfactual heating technology is gas boiler for the majority of them. All archetypes represent together ~700 thousand homes, capturing ~29% of Scotland's housing stock.

The suitability of selected common archetypes for the considered low-carbon heating technologies is summarised in Figure 40 and Figure 41 for 2017 and in Figure 42 and Figure 43 for 2040.

GSHP and high-temperature GSHP are not reported among the outputs, as the analysis of their suitability was performed on the basis of only two characteristics of the stock: the dwelling type and the location in an urban or rural area. While this approximation is sufficiently accurate to depict the suitability of the whole stock for these technologies, it might be inappropriate to accurately assess the suitability of single archetypes.

Table 2: Characteristics of the selected most common archetypes

Archetype ranking	Property Type	Size	Age	Wall Insulation	Loft Insulation (mm)	Counterfactual	Space heating demand in 2020 (kWh/yr)	Space heating demand in 2040 (kWh/yr)	Hot water demand in 2020 and 2040 (kWh/yr)	Stock
1	Semi detached	Medium	1919 to 1991	CWI	More than 250	Gas boiler	10,144	8,383	2,251	**111,180**
2	Flat (other)	Small	Pre 1919	SWU	None	Gas boiler	6,345	3,272	1,426	**64,389**
3	Flat (other)	Medium	1919 to 1991	CWI	None	Gas boiler	7,134	5,522	1,901	**55,533**
4	Semi detached	Medium	1919 to 1991	CWI	100 to 250	Gas boiler	10,358	8,779	2,298	**55,427**
5	Flat (other)	Small	1919 to 1991	CWI	None	Gas boiler	5,640	4,272	1,646	**47,361**
6	Flat (other)	Medium	Pre 1919	SWU	None	Gas boiler	9,608	5,747	1,854	**45,069**
7	Detached	Large	Post 1991	SWI	More than 250	Gas boiler	11,571	10,756	1,671	**40,928**
8	Terraced	Medium	1919 to 1991	CWI	More than 250	Gas boiler	9,089	7,028	2,150	**37,325**
9	Flat (other)	Medium	1919 to 1991	CWI	More than 250	Gas boiler	6,741	5,896	1,796	**26,463**
10	Semi detached	Medium	1919 to 1991	SWU	More than 250	Gas boiler	12,227	7,658	1,943	**24,933**
11	Semi detached	Medium	Post 1991	SWI	More than 250	Gas boiler	7,041	6,232	1,498	**23,031**
12	Semi detached	Medium	1919 to 1991	CWU exposed	More than 250	Gas boiler	12,453	8,876	2,258	**21,892**
13	Detached	Large	Pre 1919	SWU	Room in roof	Oil boiler	26,130	16,148	2,956	**20,288**
14	Semi detached	Medium	1919 to 1991	CWU exposed	100 to 250	Gas boiler	12,512	8,451	2,269	**18,976**
15	Flat (other)	Small	1919 to 1991	CWI	More than 250	Gas boiler	5,189	4,411	1,514	**18,914**

Archetype ranking	Property Type	Size	Age	Wall Insulation	Loft Insulation (mm)	Counterfactual	Space heating demand in 2020 (kWh/yr)	Space heating demand in 2040 (kWh/yr)	Hot water demand in 2020 and 2040 (kWh/yr)	Stock
16	Terraced	Medium	1919 to 1991	CWI	100 to 250	Gas boiler	9,274	7,134	2,194	**18,564**
17	Detached	Large	1919 to 1991	CWI	More than 250	Gas boiler	16,207	13,679	2,369	**18,485**
18	Flat (other)	Medium	Post 1991	SWI	None	Gas boiler	4,245	3,949	1,110	**18,241**
19	Flat (other)	Medium	1919 to 1991	CWU exposed	None	Gas boiler	9,128	6,594	1,983	**17,935**
22	Flat (other)	Small	Pre 1919	SWU	None	Electric storage	6,321	4,312	1,420	**17,245**

Figure 40: Suitability of the most common dwelling archetypes for the selected low-carbon heating technologies, considering fuse limit of 80A and peak specific heating demand of 120 W/m² in 2017 (1/2)

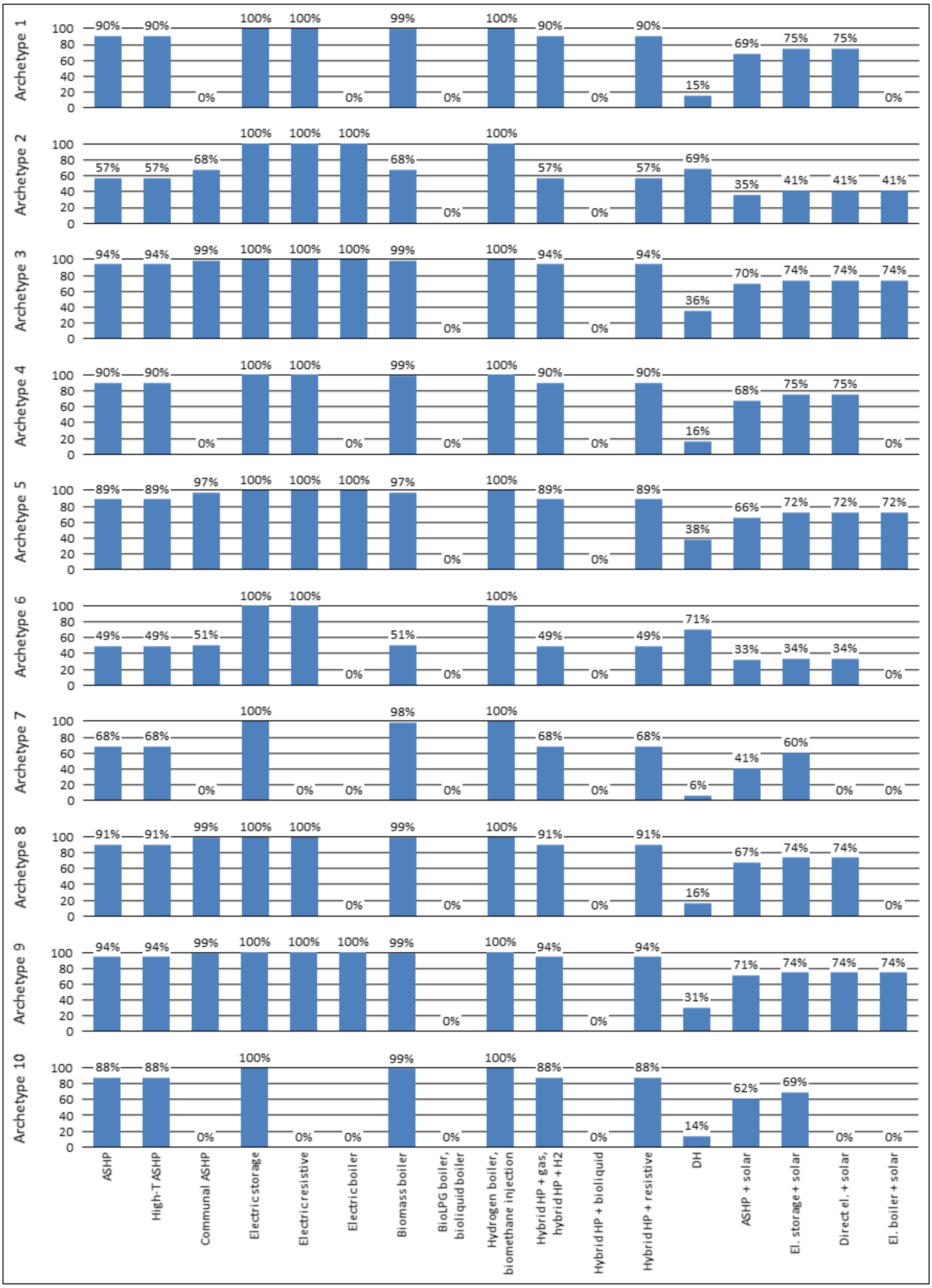


Figure 41: Suitability of the most common dwelling archetypes for the selected low-carbon heating technologies, considering fuse limit of 80A and peak specific heating demand of 120 W/m² in 2017 (2/2)

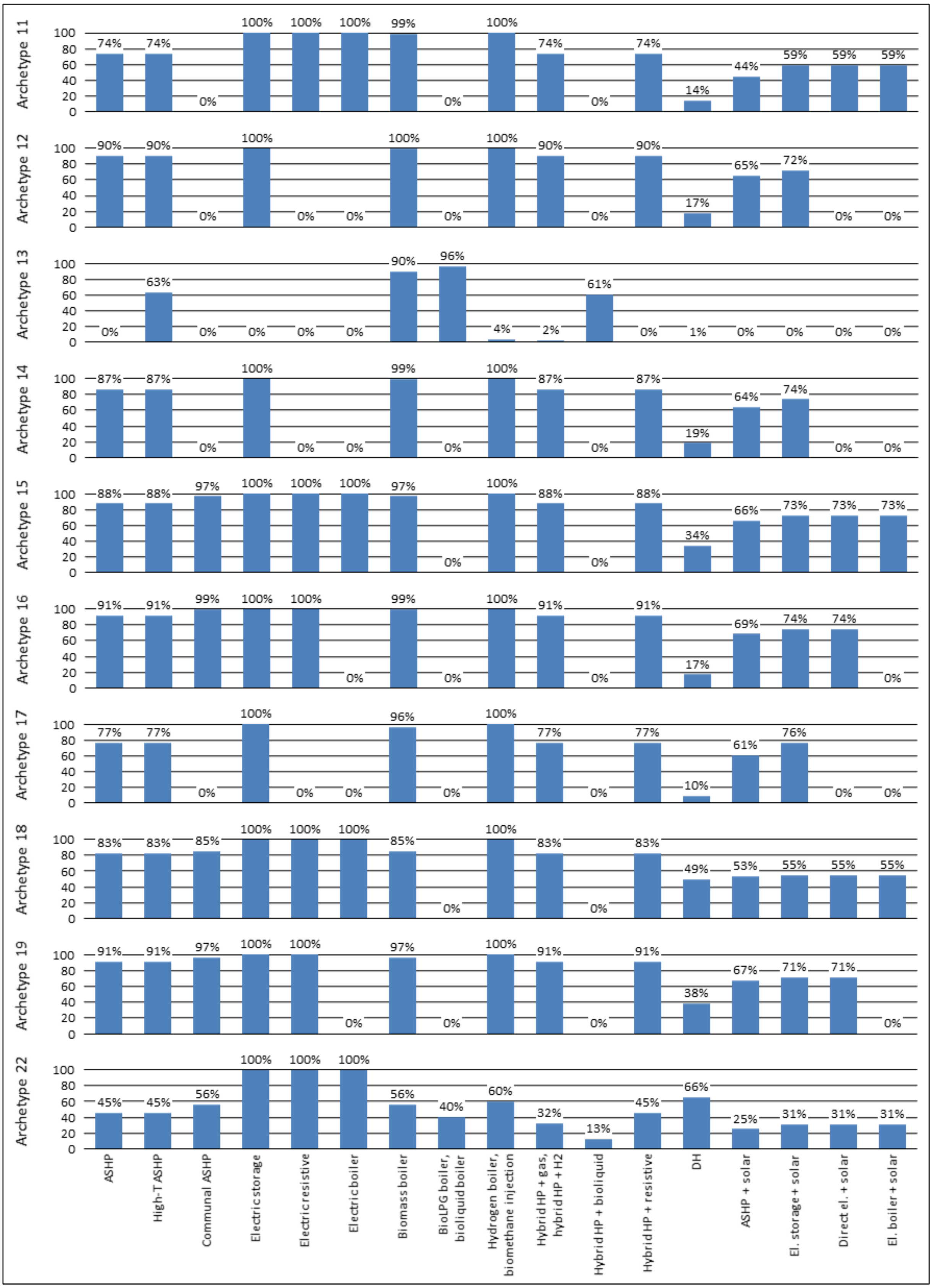


Figure 42: Suitability of the most common dwelling archetypes for the selected low-carbon heating technologies, considering fuse limit of 80A and peak specific heating demand of 120 W/m² in 2040 (1/2)

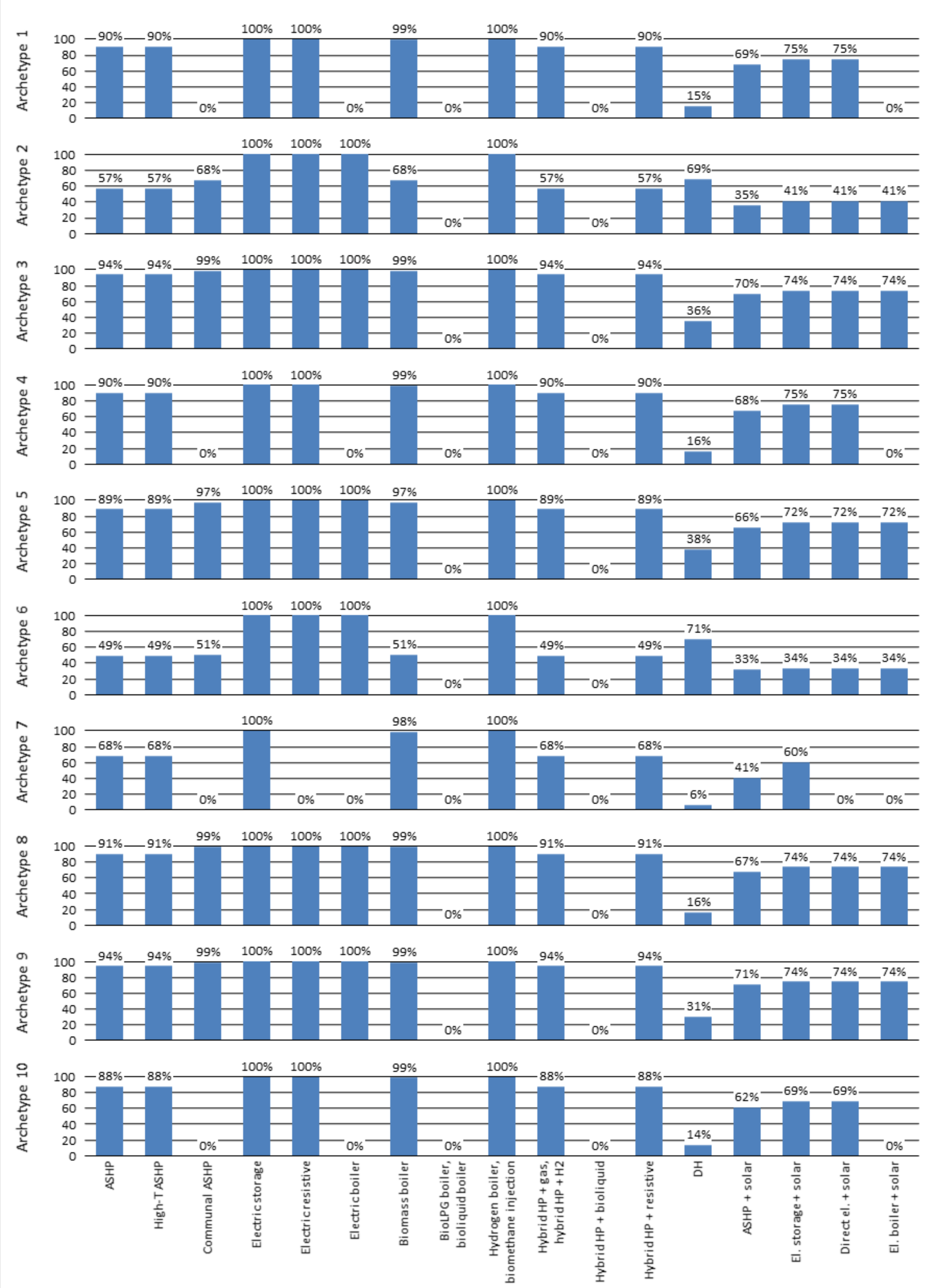
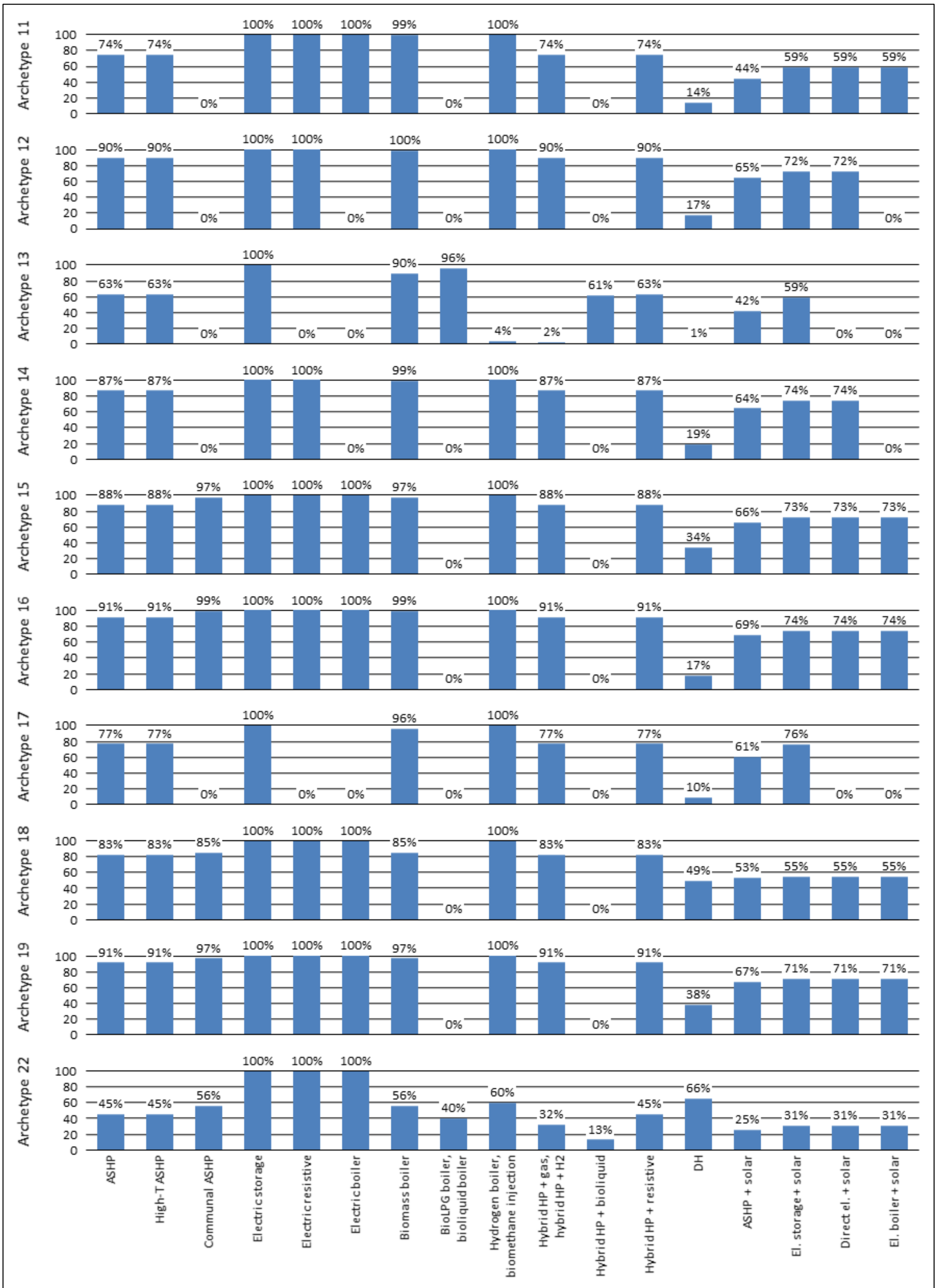


Figure 43: Suitability of the most common dwelling archetypes for the selected low-carbon heating technologies, considering fuse limit of 80A and peak specific heating demand of 120 W/m² in 2040 (2/2)



3 Suitability of heating technologies in off-gas grid homes

Homes located in areas off the gas grid amount to 507,000 units or ~20.6% of the total stock. The suitability of off-gas grid homes for the considered low-carbon heating technologies is reported in Figure 44 and Figure 45 for the year 2017 and 2040 respectively.

The assessment was performed for three combinations of peak specific heat demand and fuse limit. The results obtained applying the most stringent threshold combination (100W/m^2 and 60A) refer to the stock which is in any case likely to be suitable for a specific technology. The additional portion of the stock that results from the analysis with the medium threshold combination (120W/m^2 and 80A) describes the portion of the stock the suitability of which is not ruled out but may carry some risk. The additional portion of suitable stock assessed using the high threshold combination (150W/m^2 and 100A) quantifies the stock which is likely suitable but with high risk of its suitability.

Figure 44: Percentage of off-gas grid homes compatible with each technology in 2017; the sensitivity of suitability was tested against three combinations of peak specific heat demand and fuse rating

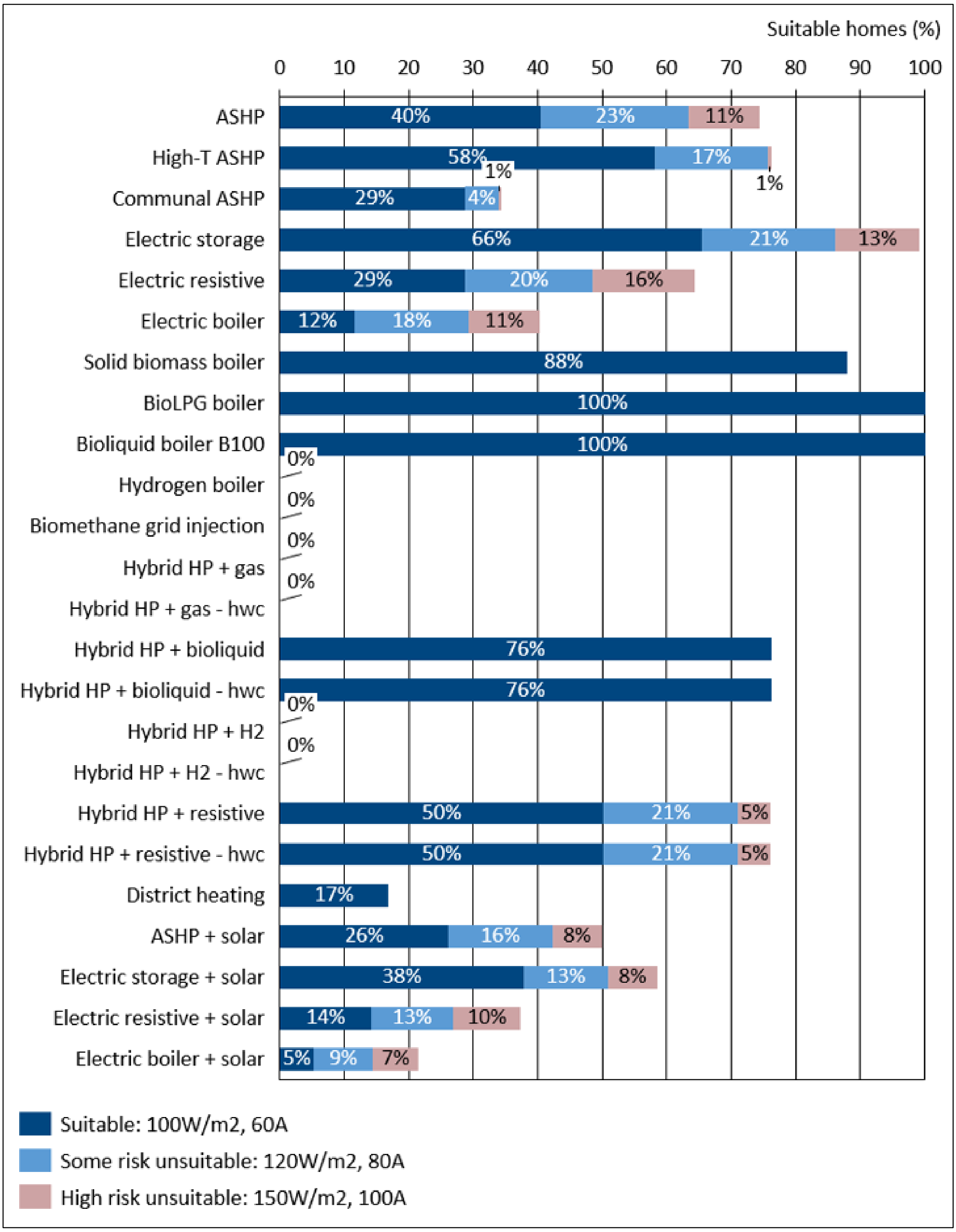
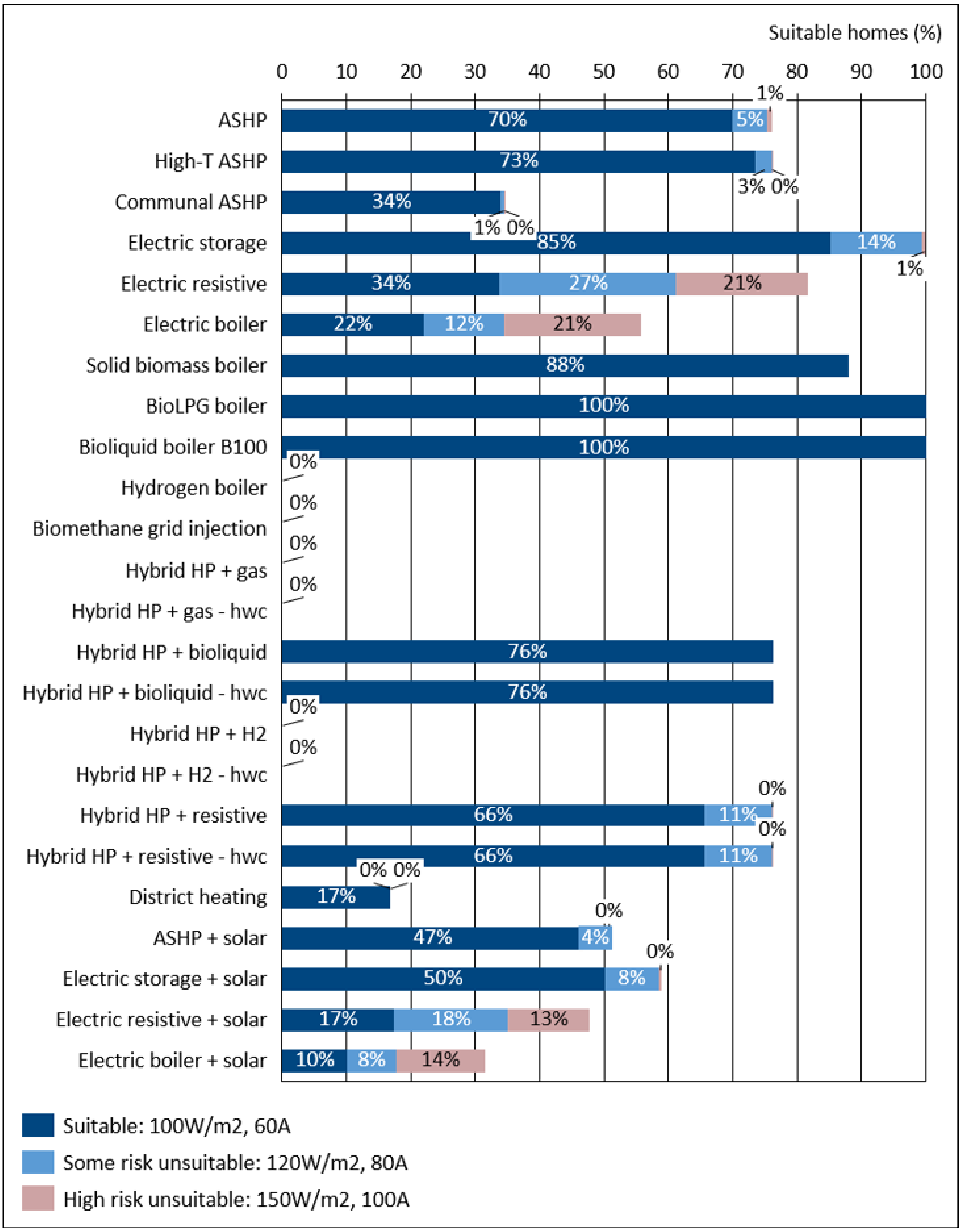


Figure 45: Percentage of off-gas grid homes compatible with each technology in 2040; the sensitivity of suitability was tested against three combinations of peak specific heat demand and fuse rating



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