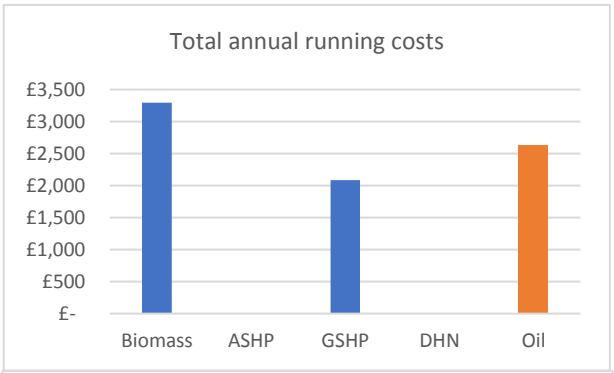
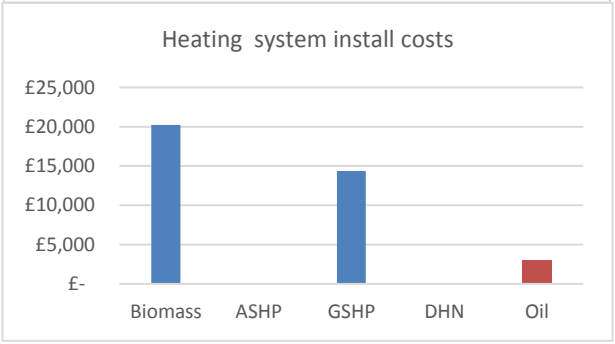
Model 1: Oil heated, Detached/semi, Solid Wall





Building information

- Type: Detached
- Occupants: 4
- Dimensions 8m x 7 m x 5m
- Wall type: Solid (Stone, uninsulated)
- Other insulation: Loft, double glazing
- Total heat demand: 39,485 kWh
- Peak demand: 11.6 kW

This model could very broadly represent a quarter of Scotland's rural off-gas grid housing stock (125,000 oil-heated homes in Scotland are detached or semi-detached with a roughly 50/50 split between those with cavity and solid walls). We have selected a relatively large home whereas in practise this category will contain a wide range. The main difference for smaller homes would be that low-carbon systems would be smaller with slightly lower capital costs.

Heating System Comparison

	Size	Total install cost	Heat bill annual	Service annual	Total annual cost	Annual saving	Lifetime £/kWh	Annual RHI	Kg CO2 annual
Oil		£3,000	£2,430	£200	£2,630	-	0.08		13,840
ASHP	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
GSHP	13 kW	£17,670	£1,840	£250	£2,090	£600	0.10	£4,490	3630
Biomass	15 kW	£20,200	£3,000	£300	£3,300	-	0.14	£2,720	2460

- An ASHP is not recommended as the capacity of the unit would reach the limit of what can be connected to a single-phase domestic electricity supply. Technical solutions can alleviate this constraint, but these will be project specific. A GSHP can still be fitted due to the better year-round performance of these systems.

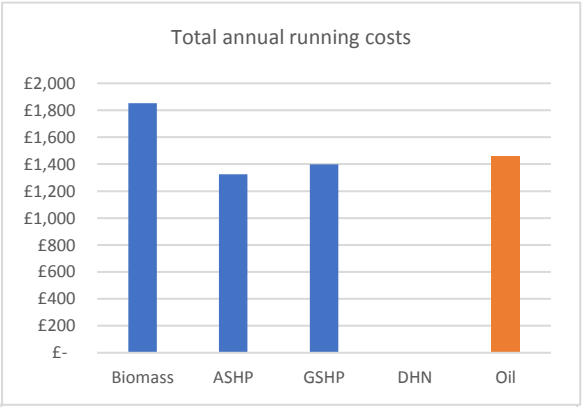
Impact of fitting wall insulation

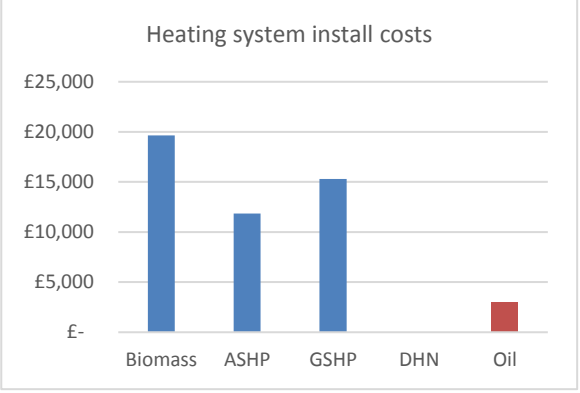
In this scenario we assume that external wall insulation is fitted at an estimated cost of £16,000. In practise it is unlikely that a building owner would want to install external wall insulation in an historic property; moreover this would not be permitted in a listed building or in a conservation area.

	Size	Total install cost	Heat bill annual	Service annual	Total annual cost	Annual saving	Lifetime £/kWh	Annual RHI	Kg CO2 annual
Oil		£3,000	£1,470	£200	£1,670	-	0.08	-	8,350
ASHP	7 kW	£8,560	£1,240	£250	£1,490	£175	0.13	£1,460	1,840
GSHP	6 kW	£12,000	£1,330	£250	£1,580	£90	0.15	£3,254	1,970
Biomass	7 kW	£19,660	£1,810	£300	£2,110	-	0.20	£1,640	2460

- The wall insulation reduces the size of the low-carbon systems required, making ASHP an option and reducing equipment costs.
- We assume that no radiator upgrades are required as a result of the improved building thermal performance, which further reduces the costs of the heat pump options; although likely, this may not always be the case.

Model 1a: Oil heated, Detached/Semi, Cavity wall





Building information

- Type: Detached
- Occupants: 4
- Dimensions 8m x 7 m x 5m
- Wall type: Solid (cavity)
- Other insulation: Loft, double glazing
- Total heat demand: 20,459 kWh
- Peak demand: 4.6 kW

This building is the same as in model 1 except that is has masonry cavity walls as opposed to solid stone. This model could roughly represent a quarter of Scotland's rural off-gas grid housing stock (125,000 oil-heated homes in Scotland are detached or semi-detached with a likely 50/50 split between those with cavity and solid walls). The presence of cavity walls relative to model 1 reduces the heat losses and provides a lower-cost insulation option (cavity wall insulation being lower cost than external wall).

Heating System Comparison

	Size	Total install cost	Heat bill annual	Service annual	Total annual cost	Annual saving	Lifetime £/kWh	Annual RHI	Kg CO2 annual
Oil		£3,000	£1,460	£200	£1,460	-	0.09	-	7,170
ASHP	7 kW	£11,860	£1,080	£250	£1,330	£190	0.12	£1,460	1,590
GSHP	6 kW	£15,300	£1,150	£250	£1,400	£120	0.13	£2,780	1,670
Biomass	7 kW	£19,655	£1,550	£300	£1,850	-	0.19	£1,410	1,490

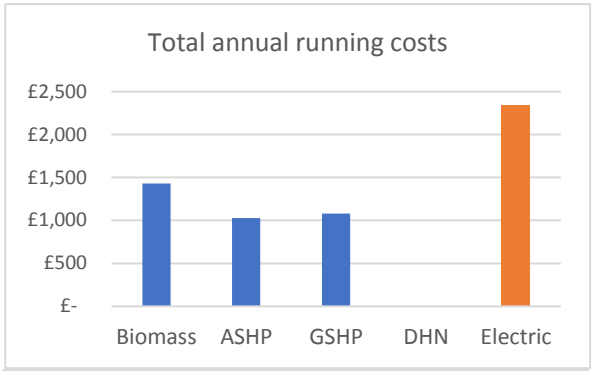
Impact of fitting wall insulation

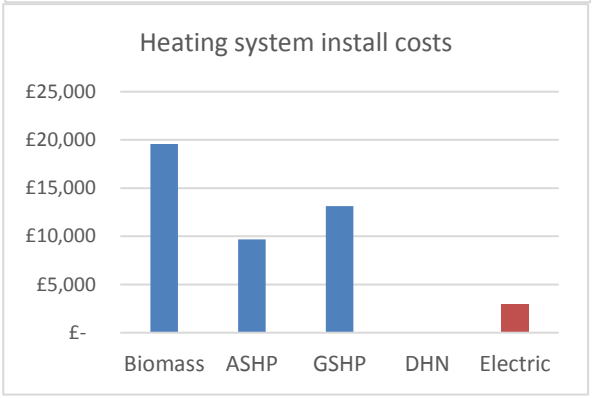
In this scenario we assume that cavity wall insulation is fitted at an estimated cost of £1,500.

	Size	Total install cost	Heat bill annual	Service annual	Total annual cost	Annual saving	Lifetime £/kWh	Annual RHI	Kg CO2 annual
Oil		£3,000	£1,360	£200	£1,160	-	0.07	-	6,620
ASHP	5 kW	£8,220	£1,000	£250	£1,260	£110	0.12	£1,370	1,490
GSHP	6 kW	£11,870	£1,060	£250	£1,310	£50	0.14	£2,580	1,570
Biomass	7 kW	£19,520	£1,430	£300	£1,730	-	0.20	£1,300	1,180

- We assume that no radiator upgrades are required as a result of the improved building thermal performance, which further reduces the costs of the heat pump options; although likely, this may not always be the case.

Model 2: Electric, detached/semi, cavity wall





Building information

- Type: Semi-detached
- Occupants: 2
- Dimensions 7m x 6 m x 5m
- Wall type: Cavity (uninsulated)
- Other insulation: Loft, single glazing
- Total heat demand: 14,890 kWh
- Peak heat demand: 4.7 kW

This model could roughly represent 20% of Scotland's rural off-gas grid housing stock - we estimate that there are 60,000 electrically heated detached and semi-detached homes. SHCS suggests that approximately three-quarters of these have cavity walls and we therefore model only this type of construction. Electrically heated homes do not have wet central heating systems and which is a major consideration – although air to air heat pumps are available, our members tell us that in practise most householders prefer to pay for the central heating upgrade given the cost and comfort benefits that this brings. However, installing a central heating system into a property for the first time will be disruptive as pipework will need to be run between radiators (and under floors etc.).

Heating System Comparison

	Size	Total install cost	Heat bill annual	Service annual	Total annual cost	Annual saving	Lifetime £/kWh	Annual RHI	Kg CO2 annual
Electric		£2,500	£2,350	-	£2,350	-	0.17	-	3,470
ASHP	7 kW	£10,080	£780	£250	£1,030	£1,320	0.12	£1,090	1,150
GSHP	6 kW	£13,130	£830	£250	£1,080	£1,260	0.16	£2,030	1,229
Biomass	7 Kw	£19,580	£1,130	£300	£1,430	£920	0.18	£1,020	930

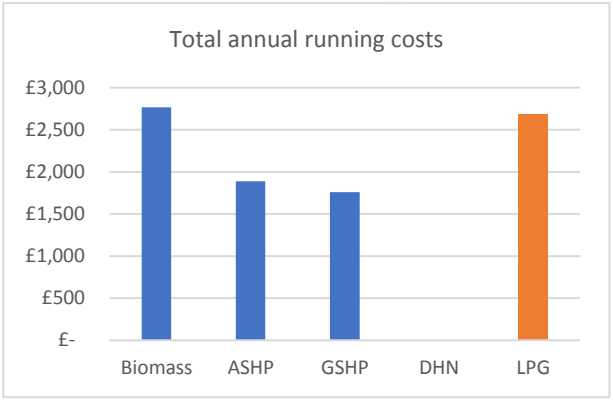
Impact of fitting wall insulation

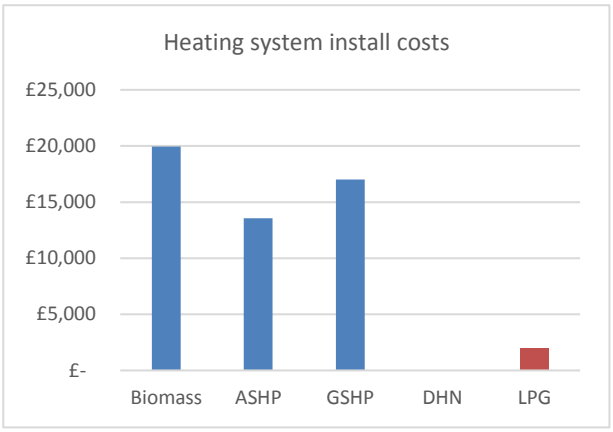
In this scenario we assume that cavity wall insulation is fitted at an estimated cost of £1,100.

	Size	Total install cost	Heat bill annual	Service annual	Total annual cost	Annual saving	Lifetime £/kWh	Annual RHI	Kg CO2 annual
Electric		£2,500	£2,070	-	£2,070	-	0.18	-	3,060
ASHP	5 kW	£9,350	£700	£250	£950	£1,120	0.15	£950	1,030
GSHP	6 kW	£12,990	£740	£250	£990	£1,080	0.18	£1,795	1,090
Biomass	7 Kw	£19,580	£1,130	£300	£1,430	£920	0.18	£1,020	930

- Electrically heated homes are underheated given their very high heating costs. We have factored in some additional 'comfort take' in this scenario.
- Older electrically heated homes with solid walls may often prefer a biomass solution – solid wall insulation may not be an option if the building is listed or in a conservation area, and it may be prohibitively expensive for a very large building.

Model 3: LPG, detached/semi, solid wall





Building information

- Type: Detached
- Occupants: 3
- Dimensions 8m x 5 m x 5m
- Wall type: Solid stone (uninsulated)
- Other insulation: Loft, double glazing
- Total heat demand: 32,500 kWh
- Peak heat demand: 9.8 kW

There are 19,000 LPG heated homes in Scotland accounting for around 8% of Scotland's rural off-gas grid housing stock. The majority are either detached or semi-detached with a likely 50/50 split between those with solid and those with cavity walls. They are more likely to be found in the south of Scotland.

Heating System Comparison

	Size	Total install cost	Heat bill annual	Service annual	Total annual cost	Annual saving	Lifetime £/kWh	Annual RHI	Kg CO2 annual
LPG		£2,000	£2,530	£150	£2,680	-	0.09	-	8,900
ASHP	16 kW	£13,550	£1,640	£250	£1,890	£800	0.10	£1,480	2,420
GSHP	13 kW	£17,000	£1,510	£250	£1,760	£920	0.11	£4,490	2,230
Biomass	11 Kw	£19,950	£2,470	£300	£2,770	-	0.15	£2,240	930

- In the absence of wall insulation, a GSHP would provide the best value long-term option provided there is space on the property to install a ground-collector.

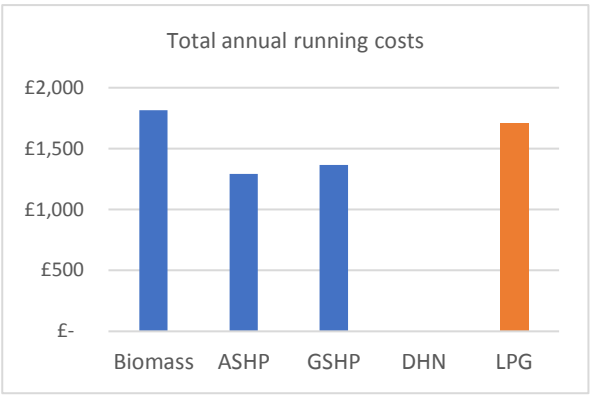
Impact of fitting wall insulation

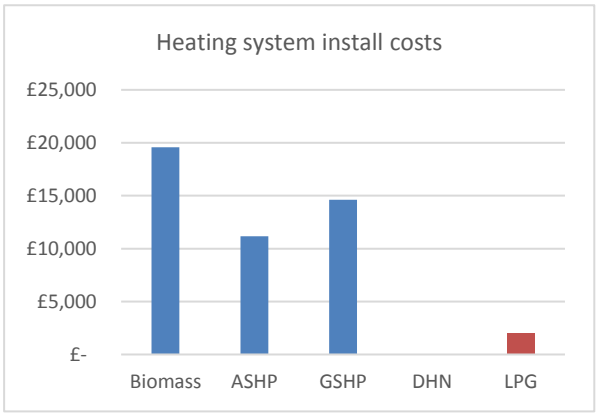
In this scenario we assume that solid wall insulation is fitted at an estimated cost of £13,500. In practise it is unlikely that a building owner would want to install external wall insulation in an historic property; moreover this would not be permitted in a listed building or in a conservation area.

	Size	Total install cost	Heat bill annual	Service annual	Total annual cost	Annual saving	Lifetime £/kWh	Annual RHI	Kg CO2 annual
LPG		£2,000	£1,450	£150	£1,450	-	0.10	-	5,090
ASHP	5 kW	£8,280	£980	£250	£1,230	£370	0.11	£1,350	1,450
GSHP	6 kW	£11,930	£1040	£250	£1,290	£310	0.13	£2,541	1,540
Biomass	7 Kw	£19,580	£1,411	£300	£1,711	-	0.20	£1,280	1,160

- We assume that no radiator upgrades are required as a result of the improved building thermal performance, which further reduces the costs of the heat pump options; although likely, this may not always be the case.

Model 3a: LPG, detached/semi, cavity wall





Building information

- Type: Detached
- Occupants: 3
- Dimensions 8m x 5m x 5m
- Wall type: Brick, cavity (uninsulated)
- Other insulation: Loft, double glazing
- Total heat demand: 19,980 kWh
- Peak heat demand: 5.1 kW

This building is the same as in model 3 except that is has masonry cavity walls as opposed to solid stone. We estimate that the 19,000 LPG-heated homes in Scotland account for approximately 8% of the rural off-gas grid housing stock. Roughly half are detached or semi-detached with a roughly 50/50 split between those with solid and those with cavity walls.

Heating System Comparison

	Size	Total install cost	Heat bill annual	Service annual	Total annual cost	Annual saving	Lifetime £/kWh	Annual RHI	Kg CO2 annual
LPG		£2,000	£1,560	£150	£1,560	-	0.10	-	5,470
ASHP	7 kW	£11,200	£1,040	£250	£1,290	£420	0.12	£1,460	1,540
GSHP	6 kW	£14,630	£1,120	£250	£1,370	£340	0.14	£2,730	1,650
Biomass	7 Kw	£19,580	£1,500	£300	£1,800	-	0.19	£1,374	1,246

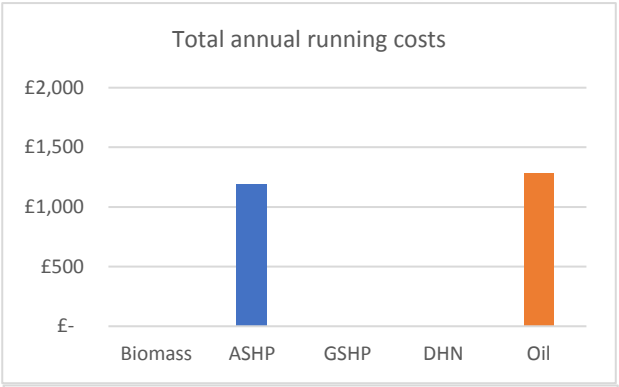
Impact of fitting wall insulation

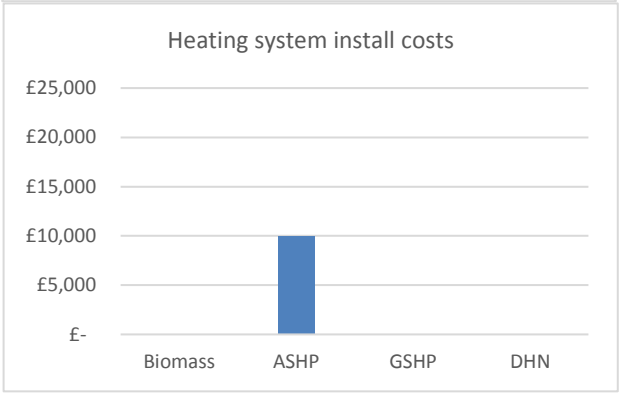
In this scenario we assume that cavity wall insulation is fitted at an estimated cost of £1,500.

	Size	Total install cost	Heat bill annual	Service annual	Total annual cost	Annual saving	Lifetime £/kWh	Annual RHI	Kg CO2 annual
LPG		£2,000	£1,220	£150	£1,370	-	0.10	-	4,300
ASHP	5 kW	£8,140	£840	£250	£1,370	£290	0.12	£1,140	1,240
GSHP	13 kW	£12,890	£880	£250	£1,130	£240	0.15	£2,150	1,300
Biomass	7 Kw	£19,440	£1,190	£300	£1,490	-	0.17	£2,240	930

- We assume that no radiator upgrades are required as a result of the improved building thermal performance, which further reduces the costs of the heat pump options; although likely, this may not always be the case.

Case Study 4: Oil, terrace, solid wall





Building information

- Type: Detached
- Occupants: 4
- Dimensions 7m x 5m x 5m
- Wall type: Brick, no cavity (uninsulated)
- Other insulation: Loft, double glazing
- Total heat demand: 25,830 kWh
- Peak heat demand: 7.5 kW

There are 13,000 oil heated terrace homes in Scotland accounting for around 5% of Scotland's rural off-gas grid housing stock. There is likely to be 50/50 split between those with solid and those with cavity walls.

Heating System Comparison

	Size	Total install cost	Heat bill annual	Service annual	Total annual cost	Annual saving	Lifetime £/kWh	Annual RHI	Kg CO2 annual
Oil		£2,500	£1,560	£200	£1,790	-	0.08	-	9,060
ASHP	12 kW	£10,360	£1,250	£250	£1,500	£290	0.11	£1,520	1,860
GSHP	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Biomass	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

- We have limited options here to ASHP only: most terraced houses are unlikely to have space for either a ground collector array (GSHP) or a biomass boiler and its associated fuel storage.

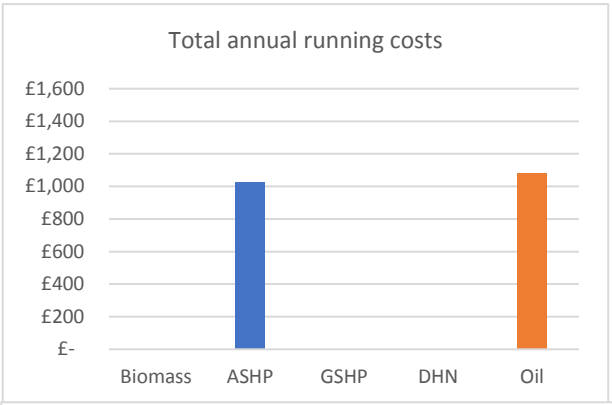
Impact of fitting wall insulation

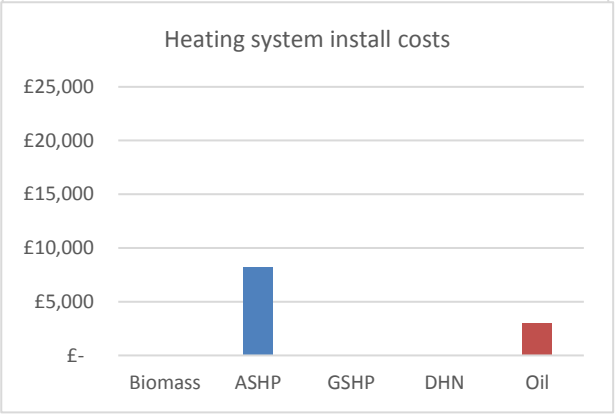
In this scenario we assume that solid wall insulation is fitted at an estimated cost of £5,500. In practise it is unlikely that a building owner would want to install external wall insulation in an historic property; moreover this would not be permitted in a listed building or in a conservation area.

	Size	Total install cost	Heat bill annual	Service annual	Total annual cost	Annual saving	Lifetime £/kWh	Annual RHI	Kg CO2 annual
Oil		£2,500	£1,080	£150	1,280	-	0.09	-	6,150
ASHP	5 kW	£8,220	£940	£250	£1,190	£90	0.12	£1,270	1,390
GSHP	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Biomass	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

- We assume that no radiator upgrades are required as a result of the improved building thermal performance, which further reduces the costs of the heat pump options; although likely, this may not always be the case.
- The smaller size of this house means that the money saved on avoided radiator upgrades covers nearly half the cost of the wall insulation, making it a more attractive option than on larger homes.

Case Study 4a: Oil, terrace, cavity wall





Building information

- Type: Detached
- Occupants: 4
- Dimensions 7m x 5m x 5m
- Wall type: Brick, cavity (uninsulated)
- Other insulation: Loft, double glazing
- Total heat demand: 18,283 kWh
- Peak heat demand: 4.7 kW

This building is the same as in model 4 except that is has masonry cavity walls as opposed to solid stone. There are 13,000 oil heated terrace homes in Scotland accounting for around 5% of Scotland's rural off-gas grid housing stock. There is likely to be 50/50 split between those with solid and those with cavity walls.

Heating System Comparison

	Size	Total install cost	Heat bill annual	Service annual	Total annual cost	Annual saving	Lifetime £/kWh	Annual RHI	Kg CO2 annual
Oil		£2,500	£1,130	£200	£1,330	-	0.09	-	6,400
ASHP	7 kW	£10,360	£970	£250	£1,210	£110	0.13	£1,340	1,860
GSHP	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Biomass	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

- We have limited options here to ASHP only: most terraced houses are unlikely to have space for either a ground collector array (GSHP) or a biomass boiler and its associated fuel storage.

Impact of fitting wall insulation

In this scenario we assume that solid wall insulation is fitted at an estimated cost of £800.

	Size	Total install cost	Heat bill annual	Service annual	Total annual cost	Annual saving	Lifetime £/kWh	Annual RHI	Kg CO2 annual
Oil		£2,500	£890	£150	1,080	-	0.10	-	5,020
ASHP	5 kW	£8,220	£780	£250	£1,030	£60	0.13	£1,040	1,150
GSHP	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Biomass	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

- We assume that no radiator upgrades are required as a result of the improved building thermal performance, which further reduces the costs of the heat pump options. The money saved thanks to the cavity wall insulation is more than paid for by the avoided radiator upgrades.

Overview

We provide the following modelled case studies to demonstrate the costs of low-carbon heat and energy efficiency upgrade options for rural, off-gas grid homes, to answer in more detail the questions posed in the call for evidence regarding cost. We have included wall insulation (cavity and external) in our models to highlight the important connections between fabric efficiency and low-carbon heat, which we believe should be considered together as part of the Energy Efficient Scotland programme.

These are based on a simplified energy and costs model created for Scottish Renewables that uses the MCS heat loss model, itself based on the CIBSE admittance method. The case studies were chosen as per the method outlined below to try and represent, very broadly, the most common types of home in rural off gas grid Scotland. The assumptions used are set out at the end of the paper.

Key findings

- **Biomass:** is relatively high-cost option (although we have likely over-estimated costs here for smaller homes) but provides a key option in larger and older homes with solid walls where wall insulation may not be desirable or permitted (e.g. listed, conservation area).
- **Air source heat pumps:** will tend to be the most cost-effective solution where a building has relatively good thermal performance and is likely to be the only option for terraced or small semi-detached homes that do not have space for a ground source heat pump or biomass.
- **Ground source heat pumps:** as with biomass, they may be an important option for larger and harder to insulate homes; the higher capital cost of these systems reflects the need for groundworks and a collector array relative to an air source heat pump, but larger systems will operate more efficiently throughout the year. It is important to note that the ground collector will last up to 50 years, meaning that subsequent heat pump system replacement costs will be lower. This justifies some form of public subsidy to help ground source compete on cost with air source, as there will be buildings where this is the best or only option.
- **External wall insulation** is needed in very large, solid-walled properties to make them suitable for heat pumps. Although the costs are significant, insulation will reduce the costs of heat pump installations (lower equipment costs and potentially avoiding radiator upgrades) with annual running cost savings of up to a thousand pounds per year. However, this will not allow the low-carbon heating and energy efficiency costs to be recouped within the 10 years of the formers operational life and demonstrates the need to help households see the long-term value of energy efficiency improvements.
- **Cavity wall insulation:** may highly cost-effective in conjunction with air source heat pump installations as this will reduce the need for radiator upgrades reducing energy use and the cost of a heat pump installation.
- **Further research:** better information on the number of listed and conservation area homes, as well as the design and capacity of existing radiators installed in homes in Scotland would allow a more detailed and accurate estimate of the potential to install heat pumps and other low-carbon heating systems.

Case study selection

We have used the Scottish House Condition Survey (2017) to select the most representative high-level case studies. The case studies should be applicable to approximately 85% of rural off-gas grid homes, although we caution that there are myriad real-world variations that will cause results to differ within these very broad generalisations.

Case Study	Number of homes[1]	Percentage of rural off-gas grid stock
Oil heated, detached & semi-detached	125,000	48%

[1] Source: Scottish House Condition Survey 2017

Electric, detached & semi-detached	66,500[2]	7%
LPG, detached & semi-detached	19,000	7%
Oil, terrace	13,000	5%

*Source: SCHS 2017

In most cases we provide information on solid and cavity wall variants as this will have a large bearing on the equipment selection.

Analysis of SCHS data

We used the following method to estimate the rural off-gas grid housing stock. Our starting point is the Scottish House Condition Survey (SHCS) finding that 65% of off-gas grid buildings are in rural areas (defined as settlements with less than 3,000 residents). This provides the overall figure of 260,000 rural off-gas grid households:

- 420,000: homes off the gas grid in Scotland (17% of all homes in Scotland)
    - 260,000 in rural areas (settlements of less than 3000 people): 65%
    - 148,000 in urban areas (Settlements of more than 3000 people): 35%

- 260,000 are in rural areas: this will be a slight underestimate as there may be several larger towns in off-gas grid areas. We assume that all oil, LPG and solid fuelled homes are off the gas grid (using SCHS 2017 figures for these fuels) and assume that the remainder are electrically heated giving the following picture of fuel use in these homes:

Breakdown of fuel and housing type, off-gas grid homes (SCHS 2017)

	Detached	Semi-detached	Terrace	Tenement	Flat	Total
Oil	108,000	17,000	13,000	0	2,000	140,000
Electric[12]	30,000	30,000	10,000	0	4,000	74,000
Solid	9,000	10,000	4,000	2,000	1,000	26,000
LPG	13,000	6,000	1,000	0	0	21,000
						261,000

Model assumptions

The key assumptions and simplifications made in the models above are explained below.

Building characteristics

- **Detached/semi:** we have provided a single model to cover these types of home. In reality, a semi-detached house will have slightly lower energy demand and heat losses due to the presence of a shared wall.
- **Total heat demand:** is for both space and hot water heating, the latter being a function of the number of occupants.
- **Climate:** all homes are modelled using average weather data for Perth.

Technology and installation costs

[2] Estimated: The SCHS does not provide a breakdown of the % of electrically heated homes in rural areas, so we have assumed that electricity heats the remaining 74,000 rural off-gas grid homes that are not on oil, solid fuel or LPG. We also assume that 15% are terraced (in line with the general off-gas grid trend), 5% are in flats and distribute the remaining homes equally between detached and semi-detached homes.

- **Lifetime cost (£/kWh):** this provides a metric that analysis both capital and running costs to provide an overall comparator of cost effectiveness between systems. All calculations are made over 10 years (a conservative estimate for operational life) and exclude RHI revenue or energy efficiency installation costs.
- **Renewable Heat Incentive:** the annual payments that would be received for the low-carbon heating systems are included in the tables, but do not feature in any of the running cost and other calculations given the uncertainty regarding the future of the scheme.
- **Installation costs:** we have assumed installation costs for both low-carbon heating and energy efficiency measures for a one-off job. Installation costs would be lower or both where several buildings are being improved at the same time (for example, under a 'street by street' approach).

Energy efficiency assumptions

- **Insulation:** we assume that all homes have double glazing and full loft insulation – the latter is a minimum requirement to qualify for RHI payments. In some listed buildings and those in conservation areas, it may not be possible to install double glazing.
- **Comfort taking:** we add an extra 10% heat demand to solid wall homes that are insulated to take account of 'comfort take' - when a building is easier to heat its occupants will often heat more than before.

Other heating technologies

- **Resistive electric:** we do not account for cheaper overnight electricity tariffs that electric storage heaters will use, although we adjust consumption down by 15% in model 2 to account for this and the fact that electrically heated homes are often under-heated.

Heat pump assumptions

- **Ground source:** smaller GSHP in the model perform worse than their equivalent ASHP which reflects the assumption in the model rather than real-world performance. In most real-world scenarios, ground source would be expected to run more efficiently than air source and therefore have slightly lower running costs.
- **Space requirements:** we have assumed that detached, semi-detached and terraced have space for all types of heat pump. Only detached and semi-detached are able to accommodate a GSHP due to the requirement for a ground loop collector or boreholes.
- **Heating emitter replacements:** we assume that all radiators in a property will need replacing unless otherwise specified, at an assumed cost of £300 per radiator. The number of radiators is determined by the size of the property.
- **Ground source collectors:** we have assumed that all systems use ground loop collectors rather than boreholes. These are significantly cheaper but require a greater surface area, and in a domestic property would involve disruption to the garden.
- **SPF:** The Seasonal Performance Factors (SPF) have been taken using manufacturers data calculated at flow temperatures of 50oC. For ASHP units, we have used -2oC outdoor temperatures. These SPFs have been taken using the SPF3 SEPEMO system boundary definition[3], as classified on the MCS database. For DHW production, an SPF of 2.5 has been assumed.

Biomass

- **Biomass auto-feeder:** It has been assumed that all biomass pellet boilers have been fitted with a fuel feed system and separate fuel store, at an approximate cost of £3,500. This mechanism enables bulk deliveries and reduces the requirement for manual fuel feeding into a pellet stove hopper, making the system more convenient where it is heating a fully occupied home. This option may not be chosen by consumers where the home will have relatively low-occupancy (e.g. only used during holidays).

Assumed fuel costs

[3] http://sepemo.ehpa.org/uploads/media/D6_9_7_Zottl_HPC4_7.pdf

	Price per unit	Notes
Oil	5.24p/kWh	Assumes 28sec heating oil. Average based on EST figures
LPG	6.86p/kWh	Assumes bulk LPG Storage. Average based on EST figures
Electricity	15.75p/kWh	Average based on EST figures. Note that we do not account for cheaper overnight tariffs for use with electric storage heaters – this would reduce the 'electric' running costs in the models.
Biomass	6.45p/kWh	Assumes bulk pellet delivery (small batch). Average based on EST figures

Carbon intensity figures for all fuels are from SAP 10.