Energy Efficiency **Partnership** for Homes

Domestic heating systems ranked by carbon emissions (version 2)

Prepared for the Energy Saving Trust by Bruce Young and John Henderson (BRE)

January 2008

Executive Summary

In the drive towards zero-carbon homes, minimisation of carbon emissions from heating and hot water systems will be the greatest challenge. Although conventional central heating systems (those with a gas or oil boiler and radiators) are installed in about 83% of British homes, there are many less popular alternatives. They include community heating, CHP, biomass boilers, heat pumps, and electric resistance heating. There are numerous options and configurations, using different fuels and distribution systems.

In this short study a number of alternative heating and hot water systems have been examined to evaluate their environmental impact in terms of CO2 emissions, using the government's Standard Assessment Procedure (SAP). Two new-build properties have been analysed – a semi-detached house and a flat, of typical size and build quality that would comply with Building Regulations Part L1 (2006) if fitted with gas central heating. Indicative costs have been estimated, and the potential contribution from local generation in the form of photovoltaic (PV) panels and wind turbines included.

Results have been ranked in order of carbon emissions, and showed a 12:1 range for the same level of heating and hot water provision. As would be expected, they generally follow the carbon intensities of the main heating fuel, although different technologies and system types perturb the expected pattern. In the middle of the range, where results are close, the ranking is sensitive to relative changes in the carbon factors for the various fuels. As the purpose of the study was to examine environmental impact rather than regulatory compliance, carbon factors for the year 2006 based on data from 2005 have been adopted and the results are shown in Table 3. At the request of the Heating Strategy Group of the Energy Efficiency Partnership for Homes, the calculations were later repeated with the carbon factors used for regulatory compliance (i.e. for Part L1 of the Building Regulations), and in this (version 2) of the report Table 5 in the Addendum has been inserted to show those results too.

The two properties are well insulated to the latest regulations and so the demand for space heating is relatively small. In older, less well insulated, housing the ratio of space heating to water heating demand would be considerably higher and different results would have been obtained. Other choices for dimensioning and configuration of particular systems would also affect performance in each case. While recognising the scope for such variation, it is concluded that the alternative heating systems with the greatest carbon saving potential are:

- Community heating and CHP, fuelled wholly or mainly by biomass
- Wood burning boilers
- Ground source heat pumps with low temperature emitters (e.g. underfloor heating)
- Thermal solar panels in conjunction with boiler systems.

Contents

1. Introduction

Many types of heating systems are available to provide space and water heating service in dwellings, with a large choice of fuels. They embrace a number of different technologies and have widely different technical characteristics. Some types are simple and have no moving parts; some have many interacting components and complex behaviour; some are suitable for installation only in severely restricted circumstances. The large and bewildering choice makes it hard for consumers to select an optimal solution on technical, economic, or environmental grounds, and it is difficult to obtain a balanced view of their relative merits.

The environmental performance of a wide range of domestic heating systems has now been assessed to help identify those with the greatest potential to reduce future carbon emissions. The contribution of renewable energy options in the form of thermal solar collectors, heat pumps, photovoltaic panels, and wind turbines has been included. Micro-CHP has been excluded, as performance depends strongly on technology type and specific product design, and there is insufficient data for an evaluation at present. The context has been confined to single-family dwellings with either independent or shared heating plant, augmented in some cases by additional equipment suitable for installation on a domestic scale.

The design and configuration of every type of heating system affects performance. This is recognised in the Standard Assessment Procedure (SAP), and so there is a range of possible results for every case. The approach taken here has been to choose the most favourable configuration, subject to reasonable practical limits, of each technology option. Many other options could be added to those presented here, and the relative positions in Tables 3 and 5 should not be considered as definitive in all circumstances.

2. Method

Two characteristic dwellings have been chosen for the study. They are a semi-detached house and a flat, with details in Table 1 below. New properties were selected because many of the heating options under consideration are unsuitable, or excessively costly, to retro-fit to existing housing. Both are newly built to a specification that would just meet Part L1A of the Building Regulations for England & Wales (2006) if gas central heating were installed. However, the build specification is the same for each of the heating options examined, and consequently the dwellings will not necessarily comply with the Building Regulations when other types of heating are installed.

Table 1 : Details of dwellings
Semi-detached house; 2 storeys; regional average climate for England & Wales; floor area 88.8m^2; window area 16.9m^2; external doors 3.8m^2; air-tightness 7m³/h.m²
Top floor flat; single storey; regional average climate for England & Wales; floor area 60.9m^2; window area 6.9m^2; external doors 1.9m^2; air-tightness 7m³/h.m² *(A top floor flat normally has an energy demand less than a ground floor flat and greater than a mid-floor flat)*

The analysis has been carried out using SAP 2005, which is the government's Standard Assessment Procedure for the energy performance of dwellings. SAP estimates the annual energy demand and carbon emissions for a particular dwelling of specified dimensions and thermal characteristics, taking into account heating and hot water system types, fuels, and heating controls. It assumes typical occupancy for the size of building, and standard heating demand hours. SAP can deal with a wide range of heating system options, and allows for a varied choice of technical characteristics and configurations. While other models and annual calculation methods are available for particular types of system, it is important for this study to adopt consistent treatment over the whole range of system types so far as is possible.

The fuel emissions and costs for this analysis are shown in Table 2. As the purpose of the study is to examine environmental impact, the carbon emission factors are estimates for year 2006 based on small adjustments to those for 2005 (the latest year for which actual figures are available). They are not the same factors as would be used in SAP to demonstrate compliance with building regulations (see Addendum).

When defining specific heating systems for the examples to be analysed, a number of design and dimensioning choices have to be made. In this study the general approach has been to specify each case in a way that is likely to produce the most favourable performance, consistent with realistic limitations imposed by the size and type of property. The examples chosen are not necessarily economic, in the sense of providing good value for money, and neither would they necessarily comply with the Building Regulations.

A conventional central heating installation with gas condensing boiler and radiators has been chosen as the reference case for both dwellings. The carbon emissions from heating and lighting, in units of kgCO2/m2/yr, are calculated by SAP. Emissions from alternative heating options are then calculated and compared with this reference level. For ease of comparison, emissions are also expressed as percentages, where 100% is the reference level.

Where independent equipment for electrical generation (photovoltaic panels or wind turbines) is installed, the whole of their electrical output has been used to offset the space and water heating demand, whatever heating fuel is used. This implies they are installed in such a way that generated electricity is never wasted, and will be exported to grid when not required within the building. However, independent local generation should not be regarded as part of the heating system, nor is it associated with any particular type of heating: the emissions benefits would be equal in all cases.

Results are presented in Table 3, where they have been ranked in order of increasing carbon emissions, firstly for the semi-detached house and secondly for the flat.

.

Table 2 : Fuel emissions (2006) and costs

	Emissions $kgCO_2/kWh$	Unit price p/kWh	Additional standing charge £
Natural gas	0.191	1.63	34
LPG	0.234	3.71	62
Oil	0.264	2.17	
Bio-kerosene	0.212	4.35	
Wood (pellets, bulk supply)	0.025	3.00	
Electricity - standard tariff	0.539	7.12	
Electricity - 7-hour tariff (on-peak)	0.539	7.65	
Electricity - 7-hour tariff (off-peak)	0.539	2.94	20
Electricity - sold to grid	0.539	3.00	
Community heating (from biomass boilers)	0.025	1.99	

Abbreviations used in Table 3	
ASHP	Air source heat pump
CHP	Combined heat and power (also known as co-generation)
GSHP	Ground source heat pump
ISDA	Integrated storage / direct acting [electric heating]
kWp	KiloWatt peak output
LPG	Liquefied petroleum gas
MVHR	Mechanical ventilation with heat recovery system
MVHR-Q	Mechanical ventilation with heat recovery system that is recognised in Appendix Q of SAP 2005
PV	Photovoltaic (panel)
SWH	Solar water heating (thermal panels)

Table 3 : Environmental impact (CO_2 emissions) and fuel costs						
Building	Case no.	Space heating system	Water heating system	CO_2 emissions Per unit area (kgCO_2/m²/yr)	Relative	Annual fuel costs
SEMI-DETACHED	45	Biomass community heating with biomass CHP	Same	4.15	17%	£ 245
	28	Biomass community heating	Same	7.11	29%	£ 265
	11	Wood boiler	Same	10.02	41%	£ 325
	12	Wood boiler	Same + SWH	10.09	42%	£ 290
	3	Gas boiler with PV (2.5kWp)	Same	12.33	51%	£ 230
	4	Gas boiler with wind turbine (1kWp)	Same	18.96	78%	£ 230
	50	GSHP with heating underfloor (timber)	Same + SWH	20.83	86%	£ 230
	2	Gas boiler	Same + SWH	21.98	91%	£ 210
	29	Gas community heating with gas CHP	Same	22.71	94%	£ 245
	43	Gas boiler with MVHR-Q	Same	22.92	94%	£ 255
	47	GSHP with underfloor (timber) heating	Same	23.07	95%	£ 250
	14	GSHP	Same + SWH	23.54	97%	£ 260
	10	Bio-kerosene boiler	Same	24.16	100%	£ 395
	1	**Gas boiler [reference case]**	**Same**	**24.28**	**100%**	**£ 230**
	48	Gas boiler with underfloor (timber) heating	Same	24.28	100%	£ 230
	13	GSHP	Same	26.22	108%	£ 285
	54	Gas boiler with MVHR	Same	26.31	108%	£ 260
	8	Oil boiler	Same + SWH	26.45	109%	£ 210
	27	Gas community heating	Same	26.79	110%	£ 265
	51	ASHP with heating underfloor (timber)	Same	27.42	113%	£ 305
	6	LPG boiler	Same	27.55	113%	£ 420
	17	ASHP	Same + SWH	27.89	115%	£ 315
	7	Oil boiler	Same	29.61	122%	£ 230
	49	Oil boiler with underfloor (timber) heating	Same	29.61	122%	£ 230
	16	ASHP	Same	31.45	130%	£ 355
	15	GSHP with underfloor (timber) heating	Electric	31.50	130%	£ 270
	5	Gas boiler with heating underfloor (timber)	Electric	33.42	138%	£ 315
	18	ASHP with heating underfloor (timber)	Electric	33.60	138%	£ 375
	9	Oil boiler with heating underfloor (timber)	Electric	36.62	151%	£ 305
	21	Electric panels with PV (2.5kWp)	Electric	36.65	151%	£ 520
	20	Electric panels	Electric + SWH	42.32	174%	£ 475
	22	Electric panels with wind turbine (1kWp)	Electric	43.28	178%	£ 520
	24	Electric ISDA	Electric + SWH	45.08	186%	£ 405
	44	Electric ISDA with MVHR-Q	Electric	46.02	190%	£ 440
	19	Electric panels with appliance thermostats	Electric	46.03	190%	£ 490
	23	Electric ISDA with CELECT	Electric	47.37	195%	£ 360
	26	Electric underfloor (concrete),	Electric + SWH	49.44	204%	£ 335
	52	Electric ISDA with underfloor heating	Electric	54.51	225%	£ 410
	25	Electric underfloor (concrete)	Electric	56.00	231%	£ 370
FLAT	46	Biomass community heating with biomass CHP	Same	4.61	18%	£ 185
	41	Biomass community heating	Same	7.60	30%	£ 195
	42	Gas community heating with gas CHP	Same	23.42	93%	£ 185
	30	**Gas boiler [reference case]**	**Same**	**25.21**	**100%**	**£ 175**
	32	Gas boiler with heating underfloor (timber)	Same	25.21	100%	£ 175
	40	Gas community heating	Same	27.56	109%	£ 195
	35	ASHP with heating underfloor (timber)	Same	28.88	115%	£ 220
	33	ASHP	Same	32.39	128%	£ 255
	31	Gas boiler with heating underfloor (timber)	Electric	35.81	142%	£ 250
	34	ASHP with heating underfloor (timber)	Electric	35.81	142%	£ 275
	37	Electric panels	Electric + SWH	39.22	156%	£ 315
	36	Electric panels with appliance thermostats	Electric	46.61	185%	£ 375
	38	Electric ISDA with CELECT	Electric	47.78	190%	£ 255
	53	Electric ISDA with underfloor heating	Electric	53.70	213%	£ 285
	39	Electric underfloor (concrete)	Electric	54.96	218%	£ 260

3. Commentary on the results

Performance is considered in terms of annual carbon dioxide emissions from plant installed for space and water heating services, with the lowest figures indicating best performance. The ranking in Table 3 provides a reasonable indication of relative performance in the two dwellings analysed. However, many factors are at work in producing results, the most obvious being the set of underlying assumptions made by the SAP program, the design and configuration details of each heating system considered, the carbon factors for the fuels, and the ratio of space heating to water heating demands. For each heating system, different choices affect the annual carbon emissions and there is a range of possible results for every case, so the relative positions in Table 3 should not be considered as definitive in all circumstances.

3.1 Results from the semi-detached house

The range of results runs from 4.15 (best) to 56.00 (worst) in units of $kgCO_2/m^2/yr$. In comparison with the reference case (defined as 100%), the range is 17% (best) to 231% (worst). The results are considered in ascending order (best to worst).

Case 45: Biomass CHP in conjunction with biomass community heating represents what is probably the best performance attainable, though is unlikely to be installed at present for economic and practical reasons. It is more common for biomass CHP to be installed in conjunction with gas or oil community heating, for rapid response to changing load conditions.

Case 11: Wood is assumed to be almost carbon neutral, with very low net CO_2 emissions. A wood-burning boiler gives the best result of the heating systems for individual homes, if it is used for both space and water heating throughout the year. In this case the fuel is wood pellets, which are amenable to automatic firing control but relatively expensive. Lower running costs could be obtained if wood chips or logs were used instead. Many solid fuel appliances are designed for dual fuel (wood or coal), but if coal is burned the emissions will be far higher.

Case 12: A wood-burning boiler in conjunction with thermal solar water heating gives a worse result than one without because of the additional auxiliary electrical power needed. This is because in both cases it is assumed that the boiler is used throughout the year.

Case 3: The photovoltaic panels chosen have peak power output of 2.5kW. That would require an area of about $25m^2$, covering all the south-facing part of the roof. While feasible, this is a larger area than would usually be chosen for a house of this size.

Case 4: The electrical energy generated by a wind turbine is strongly affected by its position and the effects of sheltering or turbulence. Estimation is subject to considerable uncertainty, and relies on methods outside SAP. The assumption in this case is a turbine with 1kW peak output installed in an urban location, with a capacity factor of 10%, generating 877 kWh/yr. This is considered optimistic, as an average wind speed of about 5m/s would be needed (unusual at building level in an urban location).

Case 2: The solar water heating system comprised a $4m^2$ flat collector plate with typical efficiency characteristics ($n0 = 0.8$, $a1 = 4.0$), facing South East at 30° pitch, and 100 litres dedicated solar storage.

Case 43: The MVHR system is one that is recognised under SAP Appendix Q, with better performance than would be assumed otherwise. The SFP and heat exchanger characteristics for SAP Appendix Q were 90% and 1W/litre/s. Air-tightness is reduced from 7 to 5.38 $m^3/h.m^2$.

Case 10: The bio-kerosene blend is assumed to have a carbon intensity similar to that of natural gas. At present it is not known what blend will be placed on the market.

Case 1: This is the reference case, against which the other heating systems are compared. Of the total heating demand, 59% is for space heating and 41% is for water heating. In less well-insulated properties the proportion of space heating may be far higher.

Case 48: Under floor heating has a performance advantage when the temperature of the water circulation through the boiler can be kept low. However, if the same boiler has to provide water heating service (as in this case), or radiator service, the circulation temperature must be higher and overall performance is the same as for the reference case.

Case 54: The MVHR system is not one that is recognised under SAP Appendix Q (compare with case 43).

Case 49: Overall performance is the same as for case 7 – see case 48 for explanation.

Cases 15 to 25: These cases have electric water heating, unlike the earlier ones in which the same heat generator was used for both space and water heating. Although better space heating performance can be obtained from some systems (notably under floor heating and heat pumps) when the heat generator does not also have to provide water heating service, the overall heating performance is found to be worse because the water is heated by electricity instead.

Case 21: See remarks about size of photovoltaic panels in case 3.

Case 22: See remarks about wind turbines in case 4.

3.2 Results from the flat

Results for the flat are broadly similar to those for the semi-detached house, although space heating as a proportion of total heating demand is lower. Fewer cases have been studied because the options requiring roof area or ground space are unlikely to be feasible in most flats. Consequently ground source heat pumps, photovoltaic panels, wind turbines, and oil boilers have been excluded. The range of results runs from 4.61 (best) to 54.96 (worst) in units of kgCO2/m2/yr. In comparison with the reference case (defined as 100%), the range is 18% (best) to 218% (worst). The results are considered in ascending order (best to worst).

Case 46: See remarks about biomass CHP in case 45.

Case 30: This is the reference case, against which the other heating systems are compared. Of the total heating demand, 51% is for space heating and 49% is for water heating. In less well-insulated properties the proportion of space heating may be far higher.

Case 32: See remarks about under floor heating in case 48.

4 Fuel costs and generation gains

Annual fuel costs for heating, hot water, and lighting are also shown in Table 3. Lighting costs do not vary between different examples in the same building. Costs include standing charges, other than for electricity on the standard tariff, and are rounded to the nearest £5 to avoid giving a false sense of precision. Gains from electricity generated by photovoltaic panels or a wind turbine are excluded, but, depending on the proportions of electricity used internally or exported, are estimated at about £80 and £38 respectively. With one exception, fuel prices (shown in Table 2) are obtained from Table 12 of SAP 2005, which gives figures for each fuel type averaged over a period. The exception is bio-kerosene, for which no SAP figure exists, and a provisional estimate has been given by OFTEC.

Fuel prices, and the relativities between them, change frequently and a systematic method of averaging gives a more reasonable guide than the latest spot prices. Nevertheless current prices, and longer term trends, are relevant factors to take into consideration when selecting types of heating systems.

5 Purchase and installation costs

It is not possible to quote purchase and installation costs with precision because much depends on the number of installations (for example, the number of houses on an estate, or flats in a block) and current market factors. For less commonly installed technologies, indicative costs are shown in Table 4. They should be regarded as approximate only, and have been estimated for new buildings of average size in developments of at least 10 dwellings. Costs for installation in existing buildings, especially if taken singly, are likely to be substantially higher – this applies in particular where roof access or groundworks are required, as is the case for thermal solar, photovoltaics, and ground source heat pumps. The installation costs of community heating, especially if combined with CHP, can only be estimated reliably as part of a professional scheme design.

Table 4 : Technology costs and benefits

	System cost	Typical annual output	Typical size or capacity	Payback time	Operating cost	Carbon reduction per £ spent	Carbon cost benefit £/kgC
Wood boiler (pellets)	£1,000/kW	Variable to demand	6kW	Medium	High	High	5
PV	£5,000/kWp	850 kWh/kWp	2kWp	Very long	Low	Low	66
Small wind turbine	£3,000/kWp	50-900 kWh	400Wp	Short	Low	Medium	21
SWH - flat plate	£700/m^2	450 kWh/m^2	2.5m^2	Medium	Low	Medium	28
SWH - evacuated tube	£1,000/m^2	550 kWh/m^2	2.0m^2	Medium	Low	Medium	28
Heat pump	£2,000/kW	Variable to demand	4kW	Medium	Medium	Medium	13

6 Conclusions

Some 50 examples of different heating systems in two properties have been examined and ranked with reference to their overall annual carbon emissions. A wide range of results was obtained, with the highest carbon emissions about 12 times greater than the lowest. As would be expected, the set of results generally follows the carbon intensities of the main heating fuel involved, progressing in order from wood (very low) through gas, LPG, and oil to electricity (high). But different technologies and system types can perturb the expected pattern. For example, heat pumps, although electrically powered, extract a high proportion of the energy required for heating from renewable sources, and can produce results better than the reference case.

The choice of fuel for domestic hot water has a large influence on the results, as hot water is a high proportion of the total demand in the dwellings studied. Better overall results were obtained when hot water was provided from the same heat generator as the space heating. This applies even to systems where a performance advantage can be obtained by providing space heating service only; for example heat pumps perform better with low temperature emitters (e.g. under floor heating), and less well when higher temperatures are required for radiators or domestic hot water service. The study shows, however, that the improved performance obtainable by dedicating a heat pump to space heating produces a worse overall result, because domestic hot water service is then provided by a separate electrical heater. Similar reasoning applies to under floor heating, where better boiler performance is obtainable if the boiler does not also provide hot water service. The penalty of a separate water heating system powered by electricity overturns the expected advantage. The same outcome would not necessarily be obtained in older housing, where poorer insulation may make space heating a much higher proportion of the total heat demand.

Not all of the systems examined would be economic when subjected to life cycle analysis, and in these examples many would not comply with Part L1A of the Building Regulations (England & Wales). For a realistic study of differences due to heating systems alone, the building fabric was unchanged in each case. That would mean many of those with carbon emissions higher than the reference case would not comply, notwithstanding relief given by the fuel factor applied to the target emissions rating.

The inclusion of independent equipment for electrical generation (photovoltaics, wind turbines) shows the potential for reaching building regulations compliance in cases where the choice of heating system would otherwise have made the building non-compliant. But the justification for installing independent local generation stands alone, and does not form part of the argument in favour of (or against) any particular type of heating system or fuel.

The purpose of this study was to assess the relative environmental impact of a variety of domestic heating and hot water systems, and to draw attention to some of the less familiar alternatives that are worthy of further consideration and promotion. Those with the greatest potential have been shown to be:

- Community heating and CHP, fuelled wholly or mainly by biomass
- Wood burning boilers
- Ground source heat pumps with low temperature emitters (e.g. under floor heating)
- Thermal solar panels in conjunction with boiler systems.

Finally it should be remembered that the design and configuration of every type of heating system affects performance and there is a range of possible results for every case.

Many other options could be added to those presented here, and the relative positions in Table 3 (and Table 5) should not be considered as definitive in all circumstances.

References

"Alternatives to conventional central heating systems" - A report prepared for the Energy Efficiency Best Practice Programme in Housing and discussion by the Heating Strategy Group of the Energy Efficiency Partnership for Homes, March 2006

"The Government's Standard Assessment Procedure for Energy Rating of Dwellings - 2005 Edition" - see website www.bre.co.uk/sap2005

Addendum

To comply with building regulations, new dwellings must meet a carbon (CO2) emissions target, and SAP calculates the emissions to see if the target has been met. The carbon factors to be used for the regulatory compliance calculation are specified in the regulations, and may be changed from time to time when the regulations are reviewed.

The carbon factors for regulatory compliance are different from the carbon factors used to evaluate environmental impact in the main part of this study. The latter were based on those published in the Market Transformation Programme Briefing Note BNXS01 Carbon Emission Factors for UK Energy Use, which used the latest available data for electricity generation (year 2005) obtained from BERR. For gas and oil the difference between the two sets of factors is very small (<2%), but for electricity it is substantial (28%).

Table 5 shows the results from SAP calculations for the same heating systems and dwellings in Table 3, but using the carbon factors for regulatory compliance instead of environmental impact. This makes little difference to the ranking for those near the top and bottom of the table, but a more noticeable alteration in the middle where the proportion of electricity to total energy varies more widely between closely-ranked technologies. A lower carbon factor for electricity favours some heating technologies (e.g. heat pumps) and penalises others (e.g. micro-CHP).

It should be noted that carbon factors for regulatory compliance may change when the regulations are updated, in the light of new data on energy production. Also, although Table 5 refers to regulatory compliance CO2 emissions, that does not mean that the examples shown comply with the current regulations, and some do not. Compliance is established by comparison with target emission rates, which are modified by fuel-specific factors in the regulations that are also subject to potential change.

Table 5 : CO_2 emissions using regulatory compliance factors, and fuel costs

Building	Case no.	Space heating system	Water heating system	CO_2 emissions: Per unit area ($kgCO_2/m^2/yr$)	CO_2 emissions: Relative	Annual fuel costs
SEMI-DETACHED	45	Biomass community heating with biomass CHP	Same	3.26	14%	£ 245
	28	Biomass community heating	Same	6.21	27%	£ 265
	12	Wood boiler	Same + SWH	8.33	37%	£ 290
	11	Wood boiler	Same	8.35	37%	£ 325
	3	Gas boiler with PV (2.5kWp)	Same	10.63	47%	£ 230
	50	GSHP with heating underfloor (timber)	Same + SWH	16.31	72%	£ 230
	47	GSHP with underfloor (timber) heating	Same	18.06	80%	£ 250
	4	Gas boiler with wind turbine (1kWp)	Same	18.42	82%	£ 230
	14	GSHP	Same + SWH	18.43	82%	£ 260
	2	Gas boiler	Same + SWH	20.18	89%	£ 210
	13	GSHP	Same	20.53	91%	£ 285
	43	Gas boiler with MVHR-Q	Same	21.19	94%	£ 255
	29	Gas community heating with gas CHP	Same	21.36	95%	£ 245
	51	ASHP with heating underfloor (timber)	Same	21.47	95%	£ 305
	17	ASHP	Same + SWH	21.84	97%	£ 315
	10	Bio-kerosene boiler	Same	22.40	99%	£ 395
	1	**Gas boiler [reference case]**	**Same**	**22.59**	**100%**	**£ 230**
	48	Gas boiler with underfloor (timber) heating	Same	22.59	100%	£ 230
	54	Gas boiler with MVHR	Same	23.96	106%	£ 260
	8	Oil boiler	Same + SWH	24.59	109%	£ 210
	16	ASHP	Same	24.62	109%	£ 355
	15	GSHP with underfloor (timber) heating	Electric	24.66	109%	£ 270
	6	LPG boiler	Same	25.86	114%	£ 420
	27	Gas community heating	Same	25.89	115%	£ 265
	21	Electric panels with PV (2.5kWp)	Electric	26.10	116%	£ 520
	18	ASHP with heating underfloor (timber)	Electric	26.30	116%	£ 375
	7	Oil boiler	Same	27.85	123%	£ 230
	49	Oil boiler with underfloor (timber) heating	Same	27.85	123%	£ 230
	5	Gas boiler with heating underfloor (timber)	Electric	28.14	125%	£ 315
	9	Oil boiler with heating underfloor (timber)	Electric	31.27	138%	£ 305
	20	Electric panels	Electric + SWH	33.13	147%	£ 475
	22	Electric panels with wind turbine (1kWp)	Electric	33.89	150%	£ 520
	24	Electric ISDA	Electric + SWH	35.30	156%	£ 405
	19	Electric panels with appliance thermostats	Electric	36.03	159%	£ 490
	44	Electric ISDA with MVHR-Q	Electric	36.03	159%	£ 440
	23	Electric ISDA with CELECT	Electric	37.09	164%	£ 360
	26	Electric underfloor (concrete),	Electric + SWH	38.71	171%	£ 335
	52	Electric ISDA with underfloor heating	Electric	42.68	189%	£ 410
	25	Electric underfloor (concrete)	Electric	43.85	194%	£ 370
FLAT	46	Biomass community heating with biomass CHP	Same	3.62	15%	£ 185
	41	Biomass community heating	Same	6.61	28%	£ 195
	42	Gas community heating with gas CHP	Same	21.97	94%	£ 185
	35	ASHP with heating underfloor (timber)	Same	22.61	97%	£ 220
	30	**Gas boiler [reference case]**	**Same**	**23.38**	**100%**	**£ 175**
	32	Gas boiler with heating underfloor (timber)	Same	23.38	100%	£ 175
	33	ASHP	Same	25.36	108%	£ 255
	40	Gas community heating	Same	26.56	114%	£ 195
	34	ASHP with heating underfloor (timber)	Electric	28.04	120%	£ 275
	31	Gas boiler with heating underfloor (timber)	Electric	29.79	127%	£ 250
	37	Electric panels	Electric + SWH	30.70	131%	£ 315
	36	Electric panels with appliance thermostats	Electric	36.49	156%	£ 375
	38	Electric ISDA with CELECT	Electric	37.41	160%	£ 255
	53	Electric ISDA with underfloor heating	Electric	42.04	180%	£ 285
	39	Electric underfloor (concrete)	Electric	43.03	184%	£ 260

For abbreviations used please see the list preceding Table 3.